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

Exam CIEM5301 Shell Structures
Thursday 6 November 2025, 9:00 – 12:00 hours

Choose A, B, C or D.

1 The Shine dome in Canberra has a diameter of 45.75 m, a sagitta of 12.00 m and a thickness of 100 mm at the top and 600 mm at the bottom. Is it thin?

A Yes, but not very thin.
B Yes, except for the edge.
C Yes, it is too thin.
D No, 27.8 < 30

2 Each arch below carries a line load that is horizontally distributed. Which arch needs the least material?



A B C D

3 An edge disturbance is primarily associated with … [1]

A … a uniformly distributed load.
B … fixed or pinned edges.
C … roller supports.
D … elastic deformation.

4 Large stresses can occur in the edges of thin shells. How do we deal with this?

A Design thick edges.
B Include solid edge beams.
C Let it yield.
D Support the shell by rollers.

5 An optimal dome is also fully stressed. What causes this?

A The material is used optimally because it is compressed to its limit everywhere.
B Materials get stronger when compressed in two directions simultaneously.
C It has no bending moments.
D It is not.

6 We want to know the curvature after loading. We add the curvature deformation tensor to the curvature tensor. Is this correct?

A Yes
B No, we need to subtract.
C No, we need to add the radii of curvature.
D No, we need to add the principal values.

7 The deflection of a dome due to self-weight is $(1+(1+\nu)\ln 2)\frac{pa^2}{Et}$. How do we know?

A It is in shell literature.
B It was derived with the shell membrane equations.
C It was derived with a finite element analysis.
D There is no such equation. Domes are too complicated.

8 A steel tube has a diameter of 734 mm, a thickness of 32 mm and a length of 12 m. The shear force in the tube is V = 6213 kN. What is the Von Mises stress?

A 200 N/mm^2
B 300
C 400
D 500

9 What is the best thin shell theory?

A Love's theory
B Reissner-Mindlin theory
C Sanders-Koiter equations
D Finite element method

10 The diaphragm boundary condition of a shell is similar to a ...

A ... roller support of a beam
B ... fixed support of a beam
C ... free end of a beam
D ... hinged support of a beam

11 We design a cylindrical silo. It is made of steel. The circular edge is supported by rollers. The load causes an edge displacement of 1.43 mm. We change the design and fix the edge. What is the bending stress?

a = 950 mm, t = 2 mm, w_0 = 1.43 mm

A 75 N/mm^2
B 150
C 300
D 600

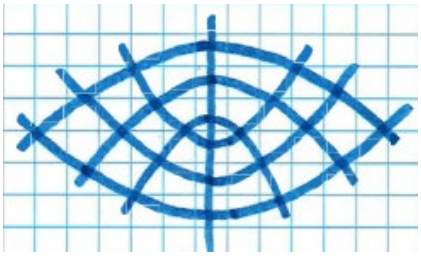
12 What is the governing collapse mode of most large thin shell structures?

A crushing
B yielding
C cracking
D buckling

13 A shell has a curvature, which is a tensor. Does this also work the other way around? For example, can the membrane force tensor, be displayed as a shell?

A No, membrane forces follow from Airy's stress function but *x* and *y* are exchanged.
B No, membrane forces need to comply with the equation of Gauß.
C No, the derivations of curvature and the membrane forces are different.
D No, if this were useful, somebody would have done it.

14 What kind of umbilic is this?



A Star
B Lemon
C Monstar
D Flame

15 You calculated the strength of your shell object. Which input parameters were difficult to determine and important for the result? (For this question you can choose more than one answer.)

A Radius of curvature
B Shell thickness
C Knockdown factor
D Material strength
E Poisson's ratio
F Young's modulus
G Shape imperfections
H Edge imperfections
I Fracture energy
J Buckling mode
K Influence length
L Edge disturbance
M Singularities

16 A thin concrete cylinder is loaded axially. What is the buckling load?

a = 405 mm, t = 5 mm

A -400 kN
B -90
C -40
D -20

17 In 1881, Rayleigh derived a formula for the smallest natural frequency of a half sphere. However, the value of a constant was missing. How can we determine this constant quickly and accurately?

A Ask another physicist.
B Ask AI.
C Do a finite element analysis.
D Perform experiments.

18 Which of the following statements is **not** correct? [2]

A Gaussian curvature is the product of the principal curvatures.
B A surface with zero Gaussian curvature is a plane, cylinder or cone.
C A shell with positive Gaussian curvature has compressive stress in all directions.
D Gaussian curvature does not depend on the coordinate system.

19 What is going on in a re-entrant corner of a linear elastic model?

A Edge disturbance
B Stress concentration
C Singularity
D Umbilic

20 Consider Ramos' shell formula. What do we use it for?

A Singularities of re-entrant corners
B Point loads on negatively curved shells
C Local moments due to an edge disturbance
D Inextensional deformation of thin shells

21 Consider the hyperboloid on page 155. Are the curvature trajectories displayed?

A Yes
B No, these are parameter lines.
C No, $k_{xy} = 0$
D No, umbilics are absent ($k_1 = k_2$)

22 The large bell of the Dom tower is modelled with a finite element program. Its smallest natural frequency is 185 Hz. Did something go wrong?

Mass ..... 2981 kg
Diameter ..... 1.25 m
Thickness ..... 100 mm
Brass Young's modulus ..... 10^5 N/mm^2

A Yes, people cannot hear this frequency.
B Yes, large bells go back and forth in about one second.
C No, finite element programs are extensively tested.
D No, a hand calculation gives 215 Hz.

23 Consider Enneper's surface with diaphragm boundary conditions. The natural frequencies do not depend on the curvature. Under which condition is this true?

A The shell is square and shallow.
B The shell edges are completely free.
C There are no singularities in the shell.
D The shell is on Earth.

24 The shell roof and floors of a museum vibrate with a frequency of 1 Hz and an amplitude of 1 mm. Do visitors feel dizzy?

A Yes, it is unpleasant.
B Yes, it is strongly noticeable.
C No, it is hardly noticeable.
D No, it is not noticeable.

25 Where does the name "Monte Carlo method" come from?

A Computing probabilities is like playing solitaire in the famous Monte Carlo casino.
B The method was proposed in 1947 at the University of Monaco at Monte Carlo.
C The first successful application of the method was in 1948 by Sir. Adrian Monte Carlo.
D The method was developed in a top secret defence project with the name Monte Carlo.

26 A limit state function can be approximated with load combinations. Under what condition?

A The load and resistance factors have been calibrated.
B The shell is not overdesigned.
C The limit state function is linear.
D The stochastic variables are normally distributed.

27 We want to determine the yearly collapse probability with 5% accuracy. We use (crude) Monte Carlo. How many iterations are required?

A 2 000 000 000
B 1 000 000
C 100 000
D 2 000

28 We use Eurocode load combinations and partial factors for designing the shell roof of a hospital in the Netherlands. Of course, the hospital will be occupied by people, day and night. The computed 1 year failure probability is 3/1000 000. The design live is 70 year. The 70 year failure probability is 209/1000 000. Are the partial factors okay?

A Yes, 3/1000 000 is sufficient personal safety and the economic target is on the safe side. (CC2, new, wind, 2600/1000 000)

B Yes, almost everybody will be less than 1/3 of a year in the hospital. 1/3 x 3/1000 000 is acceptable. The economic target is not governing.

C No, the 1 year failure probability is too high for personal safety and the economic target is too far off. (CC3, new, wind, 480/1000 000)

D No, the Eurocode is not for shell roofs.

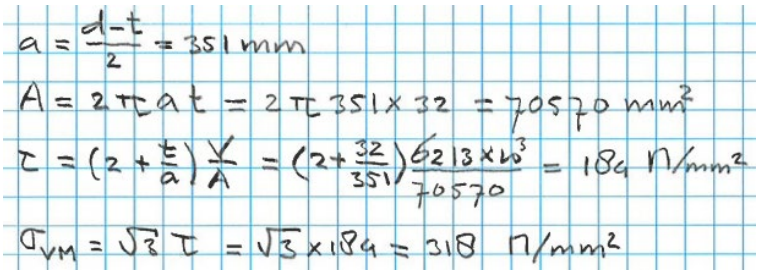
29 A chain of 970 links has a strength of 11 kN. The standard deviation is 1 kN. One link has a strength of ...

A ... 0.011 kN
B ... 11 kN
C ... 13 kN
D ... 18 kN

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 90% of the answers are correct.
2 B 93%
3 B 100%
4 C 77% … B 17% is wrong because an edge beam **creates** an edge disturbance.
5 D 83%
6 B 33% … See appendix “Increase of the Gaussian curvature”.
7 B 67%
8 B 57% …
9 C 87%



10 A 20% … D 73% is wrong because displacement perpendicular to the diaphragm is not resisted.

11 D 40% …
12 D 100%

```
> restart:
> a := 950·mm: t := 2·mm: w0 := 1.43·mm:
> E := 2.1e5·N/mm^2: nu := 0.35: assume(mm > 0): assume(N > 0):
> k := E·t/a^2: EI := E·t^3/(12(1 - nu^2)): M := w0·sqrt(k·EI): m := M:
> sigma := m/((1/6)·t^2);
```

$$\sigma := \frac{584.4788383\ N\sim}{mm\sim^2}$$

13 A 33% … B 17% is wrong because **curvature** needs to comply with the equation of Gauß, C 50% is a true statement but not the point and D 0% has wisdom but a curious scientist will try it anyway.
14 B 90%
15 not A, E, F, I, J, K, L or M 40%

16 A 83% …

```
> a := 405·mm: t := 5 mm: E := 20000·N/mm^2: N := kN/1000:
> ncr := -0.6·E·t^2/a: mult := (1/6)·ncr: Fult := 2·3.1415·a·mult;
```

$$Fult := -314.1499999\ kN$$

17 C 90% … D 10% is wrong because making specimens would take much time and the measured results would not be accurate.
18 C 93%
19 C 93%
20 B 97%
21 A 53% … B 43% is wrong; The parameter lines are also trajectories since $k_{xy} = 0$ consequently $k_{xx} = k_2$ and $k_{yy} = k_1$
22 D 77% ... C 17% is wrong because here we check ourselves not the program.

```
> restart :
> M := 2981·kg : d := 1.25·m : t := 100·mm : E := 10^5·N/mm^2 :
> rho := 8700·kg/m^3 : nu := 0.32 :
> N := kg·m/s^2 : m := 1000·mm : assume(m > 0) : assume(s > 0) :
> a := (d − t)/2 :
> fn := 0.2407·t/a^2·sqrt(E/(rho·(1 + nu)));
                                  fn := 214.8294462/s~
```

23 A 90%

24 C

25 D 67% … A 33% is a mix of two anecdotes. The name was intended to **not** explain the method.

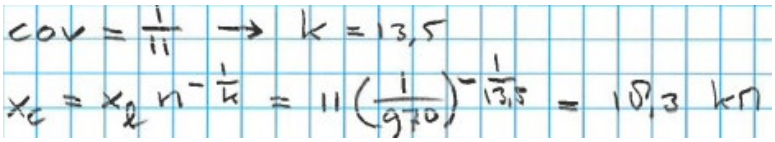
26 B 20% … A 20% is wrong because the way in which the load and resistance factors are derived does not matter. C 50% is wrong because the limit state function can have any shape. D 10% is wrong because the limit state function is independent of the distributions.

27 A 70% … B 17% is wrong: We compute probabilities of 1/1000 000 so if we do 1000 000 iterations we have about 1 failure and we need 2000 failures.

28 B 40% … A 23% is wrong because 3/1000 000 is insufficient personal safety and there exists no “safe side” for economic safety. C 37% is wrong because we cannot make it safer and unsafer simultaneously. D 0% is not the point. By the way: the Eurocode is also for shell roofs.

29 D 70% …

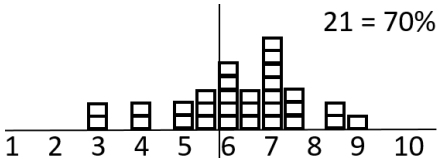
30 84%



Question 24 is removed from the exam because the reader was updated too late. The grade is (5*s* – 35) / 11 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* 29

a = -35/11
b = 5/11



[1] Question by Yu-Cih Lin, January 2025
[2] Question by Jos te Hennepe, January 2025