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

Exam CIE4143 Shell Analysis
Tuesday 11 August 2020, 13:30 – 16:30 hours

Choose A, B, C or D.

1. Consider the cathedral Notre-Dame in Paris. In the roof vaults are two large holes caused by timber parts that fell down in the fire. What would happen if the damaged vaults collapse completely?

   A The cathedral would collapse too.
   B Construction workers may be injured by falling vault parts.
   C The re-opening date would be pushed back.
   D A budget overrun because all damage to the vaults will need to be repaired.

2. The optimal arch has a sagitta equal to 40% of the span. What is a constraint of this rule?

   A The load is uniformly distributed per horizontal width.
   B The thickness is uniform over the length of the arch (not tapered).
   C Actually, the optimal sagitta is a bit less than 40%.
   D It is only valid for thin arches.

3. What do we do with a large stress in a supported edge of a steel shell?

   A Accept yielding
   B Increase the local thickness
   C Specify steel with a small Young's modulus everywhere
   D Recalibrate the influence length

4. If an optimal dome is overloaded it fails by …

   A … bending.
   B … crushing.
   C … buckling.
   D … fatigue.

5. Consider a torus (handout 3, page 30). As drawn $b > 2a$.
   Is the Gaussian curvature somewhere zero?
   Is the mean curvature somewhere zero?

   A Yes, Yes
   B Yes, No
   C No, Yes
   D No, No

6. Consider il Duomo di Firenze (handout 3, p. 38).
   Span 44 m. Masonry thickness t = 1.7 m (inner dome). Masonry mass ρ = 2000 kg/m^3.
   What is the hoop stress in the bottom of the dome?

   A 40 N/mm^2
   B 4 N/mm^2
   C 0.4 N/mm^2
   D 0.04 N/mm^2

7. The shell membrane equations cannot describe ...

   A … in-extensional deformation.
   B … edge disturbance.
   C … middle third rule.
   D … dome deflection.

8. The shear stiffness of a tube is $\frac{1}{2}GA$, where G is the material shear modulus and A is the cross-section area. Is this formula valid for I-sections too?

   A probably not; the formula for I-sections can be derived too.
   B yes; provided the I-section parts are thin.
   C yes; provided the I-section is simply supported.
   D yes; provided the I-section parts are thin and the I-section is simply supported.

9. In the reader, Bernoulli's hypothesis is proved for circular cross-sections (handout 4, p. 48).
   Why is not it proved for other cross-sections too?

   A It is not true for other cross-sections.
   B This is outside the scope. It has been proved for other cross-sections in other books.
   C This probably takes too much space.
   D Extension to other cross-sections is trivial.

10. How do we know that the Sanders-Koiter equations are correct?

    A They were derived independently by Sanders and by Koiter.
      So, one is a check of the other.
    B They have the property of no strains for rigid translations.
    C They were derived from experimentally confirmed laws.
    D We don't. We only know that many tried to show that they are not correct, without success.

11. In a shell edge m_{xx} = 30 kNm/m, m_{yy} = - 6 kNm/m, m_{xy} = 10 kNm/m
    What is the concentrated shear force?

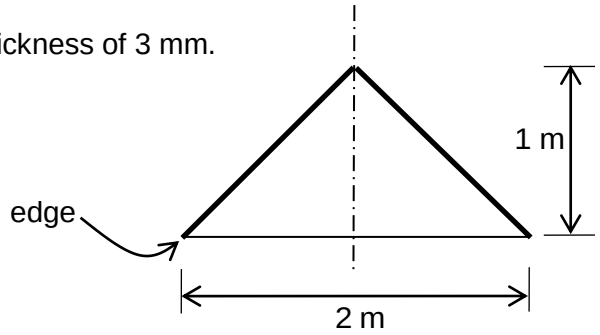
    A 33 kN
    B - 10 kN
    C ± 17 kN
    D 12 kN

12. A shell model has shape, supports and loading. We compute the deformation and the stresses. In general, models have independent variables (input) and dependent variables (output). What are good examples?

    A Independent α_x, dependent α_y.
    B Independent u_x, dependent p_x.
    C Independent ρ_{xy}, dependent n_{xy}.
    D Independent k_{xy}, dependent m_{xy}.

13. A cone has a diameter of 2 m, a height of 1 m and a thickness of 3 mm. What is the influence length of the edge?

    A 3.0 mm
    B 14.2 mm
    C 131 mm
    D 156 mm



14. Which shell element type is most used?

    A Flat elements
    B Elements derived from the Sanders-Koiter equations
    C Semiloof elements
    D Elements derived from a solid

15. Three finite element analyses were performed of a shell structure. The first used 200 mm elements (22.2 mm deflection), the second 100 mm elements (25.2 mm deflection) and the third 50 mm elements (25.9 mm deflection). What is the error of the deflection?

    A O(1)
    B O(h)
    C $O(h^2)$
    D $O(h^3)$

16. What does not help to remove an hourglass mode?

    A Switch off reduced integration.
    B Replace one square element by two triangle elements.
    C Fix more edge dofs.
    D Reduce the load.

17. What is the difference between edge disturbances and singularities?

    A Not much, essentially they are the same.
    B Edge disturbances are realistic, singularities are unrealistic.
    C Edge disturbances occur often, singularities occur rarely.
    D Edge disturbances are dangerous, singularities are harmless.

18. The software SCIA Engineer checks equilibrium of load and support reactions. Why?

A Somebody could have made a mistake in specifying the load.
B There is no need for this check. The programmers just want to make a good impression.
C If there is equilibrium, the stiffness matrix is solved sufficiently accurately.
D Doing it by hand would take much time.

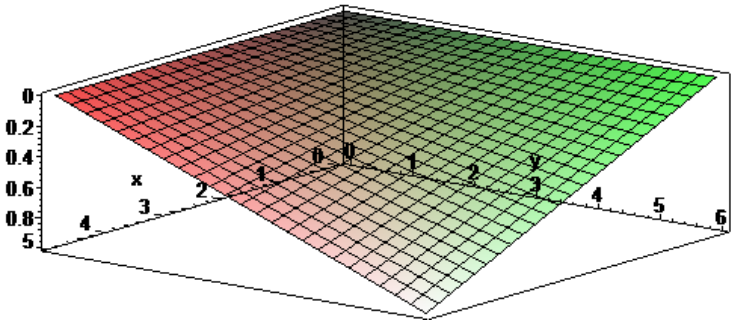
19. In a shell at some location
t = 3 mm,
m_{xx} = 256 N, m_{yy} = 132 N, m_{xy} = -97 N,
n_{xx} = 354 N/mm, n_{yy} = -354 N/mm, n_{xy} = 146 N/mm, n_{yx} = 146 N/mm.
q_x = 97 N/mm, q_y = -31 N/mm
What is σ_{xy} in the middle surface?

A 4.74 N/mm^2
B 43.5 N/mm^2
C 48.7 N/mm^2
D 118 N/mm^2

20. Which quantity does not depend on the choice of local x y z coordinate system?

A Mean curvature k_m
B Von Misses stress σ_{VM}
C In plane shear force n_{xy}
D Largest principal moment m_1

21. A hypar shell is 5 m wide, 6 m long and 1 m high. What is its mean curvature k_m ?



A 0
B 1/(15 m)
C 1/(28 m)
D 1/(30 m)

22. What is in-extensional deformation?

    A Deformation without strains
    B Deformation for which the strains of the middle surface are zero
    C Deformation with very small strains or stresses due to shell bending
    D Exceptionally large shell deflection

23. A point load perpendicular to a shell produces membrane forces and moments.
    Is there a singularity in the membrane forces?
    Is there a singularity in the moments?

    A Yes, Yes
    B Yes, No
    C No, Yes
    D No, No

24. There is no orthogonal parameterisation of a monkey saddle.
    Apparently, this is very difficult to derive. Why should we try to derive it?

    A The figure in the reader is unclear and a computer generated figure would be an important improvement.
    B The star umbilic is a dangerous feature of many finite element solutions, which must be understood.
    C There is an urgent need for analysing and building monkey saddle shells.
    D It is fun and you never know what it will be good for.

25. The program SCIA Engineer always performs a linear elastic analysis before computing natural frequencies. Why?

    A In the linear analysis the finite element *mesh* is generated.
      The same mesh is used for computing the natural frequencies.
    B In the linear analysis the *deformation* is computed.
      Natural frequencies depend on the deformation.
    C In the linear analysis *membrane forces* are computed.
      Natural frequencies depend on the membrane forces.
    D In the linear analysis *support reactions* are computed.
      Natural frequencies depend sometimes on the support reactions.

26. Consider a thin shell with a negative Gaussian curvature.
    Tension must dominate compression for all load combinations. Why?

    A Otherwise it will buckle as a plate.
    B Otherwise its natural frequencies will be too small (< 1 Hz).
    C Otherwise its deflection will be too large.
    D Otherwise it will deform in-extensionally.

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

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

28. A tube can vibrate in a beam mode and in a shell mode.
We are interested in the mode that gives the smallest frequency.
Which parameter determines this?

A Boundary conditions
B Tube length l
C Mass density ρ
D Young's modulus E

29. When developing design formulas, we do most derivations analytically and determine the missing numbers by finite element analysis. In the future another method may be possible; we will not do any analytical derivations, only finite element analyses and curve fit the computation results. Why is this future method often not possible at present?

A Successful curve fitting methods need to be developed.
B Performing hundreds of finite element analyses takes too much time.
C Advanced finite element analyses cannot be accepted without manual checking.
D The number of possible curve fit functions is too large.

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 74% of the answers were correct …. B, C and D severely underestimate the
2. A 83% destruction that will happen when there is no
3. A 74% middle third for the pressure line to go through.
4. C 78%
5. B 65%
6. C 65% ……. > $d := 44 \cdot m$: $t := 1.7 \cdot m$: $\text{rho} := 2000 \cdot \frac{kg}{m^3}$: $g := 10 \cdot \frac{N}{kg}$: $m := 1000 \cdot mm$:

> $a := \frac{d}{2}$: $p := \text{rho} \cdot g \cdot t$: $n := p \cdot a$: $\text{sigma} := \frac{n}{t}$;

$$\sigma := \frac{0.4400000000\ N}{mm^2}$$

7. B 48% ……. A 39% is wrong because zero extensions can be described,
8. A 87% C 13% is wrong because the pressure line is always in the middle third,
9. A 87% D 0%
10. D 4% …… A 39% is wrong because many scientists derived different equations,
    B 13% is wrong because this property is just one of several,
    C 43% is wrong. Starting the derivation from laws is a good idea but along the way additional choices were made.

> This is how it works. We need equations to describe something. The equations need to have properties, for example be in equilibrium, be the same in different coordinate systems, the results need to be invariant to rigid translations. Not all properties are formulated in advance. Also, we may need to drop some properties if they appear too difficult to fulfil. We puzzle until we find equations that have the properties. Any puzzle method is fine. This puzzle method is often called derivation but it is not a straight forward process. Often the puzzle method is not suitable for publication. We just publish the equations, demonstrate the properties and give other scientists time to show that we are wrong. If they cannot, we are right … until somebody does find a problem.
>
> Isn't it called Popper's falsification principle?

11. C 61% …….. > $mxx := 30 \cdot \frac{kN \cdot m}{m}$: $myy := -6 \cdot \frac{kN \cdot m}{m}$: $mxy := 10. \cdot \frac{kN \cdot m}{m}$:

> $V := \text{sqrt}\left(mxy^2 - mxx \cdot myy\right)$;

$$V := 16.73320053\ kN\sim$$

12. D 57%
13. D 17% …….. > $d := 2 \cdot m$: $h := 1 \cdot m$: $t := 3 \cdot mm$: $m := 1000 \cdot mm$:

> $a := \text{sqrt}(2.) \cdot m$: $li := 2.4 \cdot \text{sqrt}(a \cdot t)$;

$$li := 156.3253350\ mm\sim$$

The radius of curvature is the *perpendicular* distance to the centre line.

14. D 91%
15. C 83% …….. > $u1 := 22.2 \cdot mm$: $u2 := 25.2 \cdot mm$: $u3 := 25.9 \cdot mm$:
16. D 78%
17. B 91% > $b := \log[2.]\left(\frac{u2 - u1}{u3 - u2}\right)$;
18. C 100%

$$b := 2.099535674$$

19. C 96%
20. B 48% …….. A 43% is wrong because mean curvature changes sign when
21. A 78% the *z* direction is changed (inwards instead of outwards).
22. B 91%
23. C 43% …….. A 43% is wrong because the membrane forces just have a value.

24. D 13% …….. A 9% is too much work for a small result,
B 43% is wrong because umbilics are not dangerous at all,
C 35%, Do you know somebody who wants to pay for a monkey saddle?
Solving this is just a mathematical challenge.
25. C 70%
26. A 91%
27. A 100%
28. B 78%
29. D 0% …… A 17% … Many curve fitting methods have been developed.
30. 83% B 65% … Most finite element computations take just a few minutes.
C 17% … Outliers can be filtered out of the data set.

Suppose a problem has 6 input variables and 1 output variable. There are many equations that could provide a suitable design formula. For example, we can add and subtract the input variables. We can multiply and divide them, we can take the root, use cos, log, exp, tan, sin, arcsin. We can also use advanced functions such as Bessel functions, gamma function and the normal distribution. The number of possible design formulas is very, very large and we need to try many to find the one that fits well.

That is why we still use analytical methods. The analysis gives us suggestions for the fit function. With much hard work and a bit of luck we need to fit only one constant, which can be done with just one finite element analysis.

Instead of deriving a design formula, we could also train an artificial neural network. Unfortunately, this is still very difficult. Moreover, how do we give this neural network to designers, do they know how to use it and will they trust it?

The grade is $\frac{40s - 290}{91}$ rounded to the closest half, where s is the number of correct answers.

The grade formula above is derived as follows. A student with grade g knows 30/10 g answers. This student guesses 29 - 29/10 g answers. The expected number of correct answers is s = 30/10 g + (29 - 29/10 g)/4, from which g was solved.

