Shell exam, 10 August 2021, 13:30 – 16:30 hours

1a A reinforced concrete dome has a span of 53 m, a sagitta of 10 m and a thickness of 420 mm. Is it thin? Explain your answer.

Yes; a = 1/2 s + 1/8 l^2/s = 1/2*10 + 1/8*53^2/10 = 40 m; 40/0.420 = 96 > 30

1b A cylindrical steam engine kettle has an overpressure of 0.67 N/mm2. Its diameter is 2 m and its thickness is 3 mm. What is the stress in the hull? Explain your answer.

n = p a = 0.67*1000 = 670 N/mm; σ = n/t = 670/3 = 223 N/mm2

2a A reinforced concrete dome has a span of 53 m, a sagitta of 10 m. Is this shell shape optimal? Explain your answer.

No; 10/53 = 0.19 optimal would be 0.3

2b A shell has the following curvature. kxx = -1/(4 m), kyy = 1/(7 m), kxy = -1/(3 m). What is the mean curvature? Explain your answer.

(kxx + kyy)/2 = (-1/4 + 1/7)/2 = -0.054 1/m = -1/(18.7 m)

3a Consider a spherical dome loaded by self-weight. At what location is the hoop force zero?

52°

3b A spherical dome has a curvature of 1/(20 m) and a thickness of 70 mm. Self-weight plus dead load is 2 kN/m2. What is the stress in the top?

n = -1/2 p a = -1/2*2*20 = -20 kN/m; σ = n/t = -20/70 = -0.29 N/mm2

4a Which shell phenomena cannot be described by the shell membrane equations?

Edge disturbance

4b Plane cross-sections of circular cylindrical tubes remain plane under bending, shear and torsion loading. Which part of this statement is proved in the reader? Explain your answer.

Bending and shear ... in simply supported beams loaded by self-weight

5a A free shell edge has a torsion moment mxy = 9.48 kNm/m and a shear force vx = 131 kN/m. The edge is 100 mm thick. (The y axis points out of the edge.) What is the shear stress in the edge?

s = 3/2 vx/t – 3/2 sqrt(10) V/t^2 = 3/2*131/100 – 3/2*sqrt(10)*9480/100^2 = -2.53 N/mm^2

5b Are the Sanders-Koiter equations suitable for thick shells? Explain your answer.

No, because shear deformation is not included

6a A shell has a fixed edge in the x direction. The curvature is kxy = 1/(30 m). The edge length is 12 m. The shell is 10 mm thick. What finite element size is recommended? Explain your answer. Is this size in the direction of the edge, perpendicular to the edge or in both directions?

li = 2.25 (a t l)^(1/3) = 2.25*(30*0.010*12)^(1/3) = 3.45 m; h = li/6 = 3.45/6 = 0.57 m

Perpendicular to the edge.

6b A shell has fixed edge in the x direction. The curvature is kxy = 1/(40 m). The edge length is 8 m. The shell is 18 mm thick. At what distance from the edge are the effects of the edge disturbance negligible? Explain your answer.

li = 2.25 (a t l)^(1/3) = 2.25*(40*0.018*8)^(1/3) = 4.03

7a What is a Gauss point?

Location in a finite element where the material behaviour is computed.

7b The accuracy of a finite element model depends on model accuracy and arithmetic accuracy. Suppose we have a model and reduce the element size. Which accuracy increases and which decreases?

Model accuracy increases; arithmetic accuracy decreases.

8a Suppose that a buckling load factor is 0.9. Is this sufficient? Explain your answer.

No. The structures buckles at 90% of the load combination. It should be 100% or more.

8b Suppose we are designing reinforcement for a concrete shell. In a fixed edge we can choose to let the reinforcement yield and the concrete crack. Defend this choice?

The peak moment is local (edge disturbance) and yielding will reduce the moment. We can make provisions that corrosion will not occur despite large crack widths.

9a An architect designs a timber grid shell made of 30 mm thick laths. Young's modulus is 10000 N/mm2. The tensile and compressive strengths are 10 N/mm2 (safety factor included). What principal curvatures are possible?

k1 = 2 f/(Et) = 2*10 / (10000*30) = 1/(15 m)

9b Which second order tensors occur in the Sanders-Koiter equations?

Moments, curvature, membrane forces, strains of the middle surface, deformation curvature

10a Usually thin shells are very stiff but occasionally they can be surprisingly flexible. How is this called?

In-extensional deformation

10b Consider a perpendicular point load on a shell structure. The shell is properly supported so there is no in-extensional deformation. What is stiffer: positive Gaussian curvature or negative Gaussian curvature? What is the ratio between these stiffnesses?

Positive is stiffer because it gives less deflection; sqrt(3)/4 < 0.92.

Positive is about twice as stiff; 0.92/(sqrt(3)/4) = 2.12.

11a When you write a finite element program, it makes sense to divide the work in three parts. Which parts?

Pre-processing, computation, post-processing

11b Sometimes SCIA replaces a rectangular element by two triangular elements. Why does it do this?

Apparently, SCIA elements cannot be twisted; they must be flat.

12a How do we estimate nult when we know ncr?

Multiply with the knockdown factor 1/6.

12b A steel shell is analysed by a finite element program. The linear elastic analysis produces a membrane force of -48 kN/m. The radius of curvature perpendicular to this membrane force is 5.2 m. The shell is 3 mm thick. The linear buckling analysis produces a buckling load factor of 4.15. Check the buckling load factor with a hand calculation.

ncr = -0.6 E t^2/a = -0.6*2.1*10^5*3^2/5200 = -218 N/mm; λ = ncr/nxx = -218/-48 = 4.5;

This is about the same as the linear buckling analysis.

13a Critical load factors larger than 6 are mostly safe. How?

The knockdown factor of 1/6 is mostly safe.

13b What is the technical reason for adding ribs or stiffeners to a shell?

Buckling

14a Does an in plane shear force nxy in a shell make the natural frequency larger, smaller or does it have no influence? Explain your answer.

Smaller ... because there is a minus in the square panel formula.

14b Consider Enneper's surface with diaphragm boundary conditions. What is the contribution of curvature to the natural frequency? Explain your answer.

None ... because kxx + kyy = 0 and kxy = 0 in the square panel formula.

