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

Write your name and study number at the top of your work.

Exam CIE4150 Plastic Analysis of Structures
Thursday 29 June 2023, 13:30 – 16:30 hours

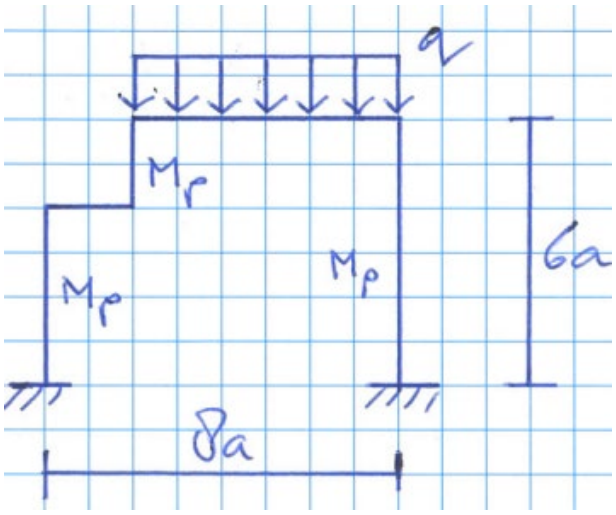


Figure 1. Frame structure

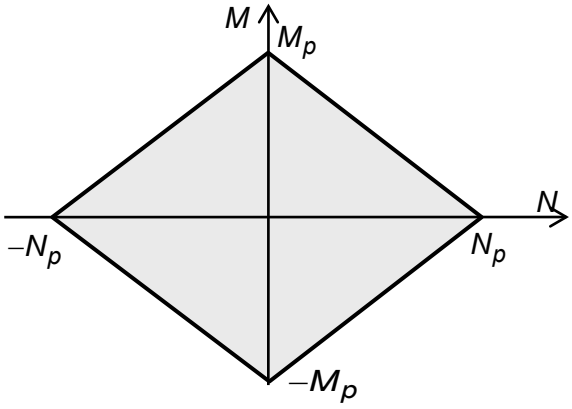


Figure 2. Yield contours

Problem 1

A frame consists of five members (Fig.1). All members have a strength M_p. The members are rigidly connected. The supports are fixed. The structure is loaded by an evenly distributed line load q. The relation of Figure 2 exists between the plastic moments and the plastic normal forces.

$$N_p = \beta \frac{M_p}{a}$$

The influence of shear on the yield contour is neglected. Buckling and second order effects are not considered.

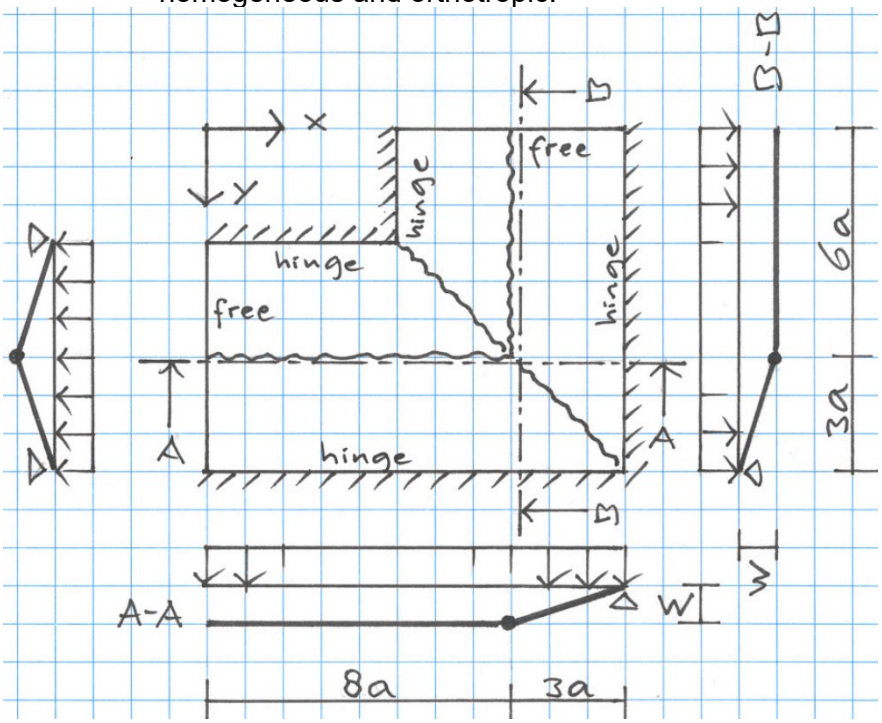
a Assume $\beta \to \infty$. Determine the collapse load q for all possible mechanisms. Write the collapse loads as functions of M_p and a. What is the decisive collapse load? (1.5 point)

b Assume $\beta \to \infty$. Draw the bending moment diagram and normal force diagram for the structure at the moment of collapse. (1.5 points)

c Assume $\beta = 5$. Choose one of the following problems (You need not do both).
– Determine the largest lower-bound for q.
– Determine the smallest upper-bound for q.
You only need to write down the equations and not solve the equations (1.5 points).

Problem 2

A reinforced concrete plate has simply supported edges and free edges (Fig. 3). It carries an evenly distributed load p [kN/m^2]. There is no other load on the plate. The plate is homogeneous and orthotropic.



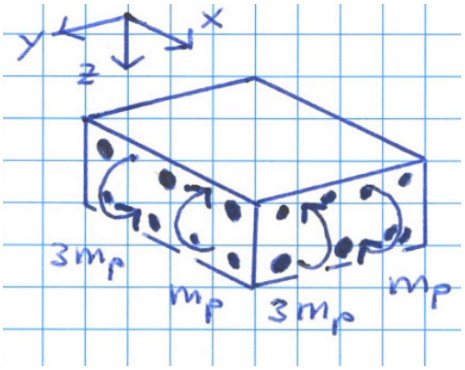


Figure 3. Plate dimensions and reinforcement

a Consider the yield line patterns of Figure 4. Which of these patterns give kinematically possible mechanisms? (1 point)

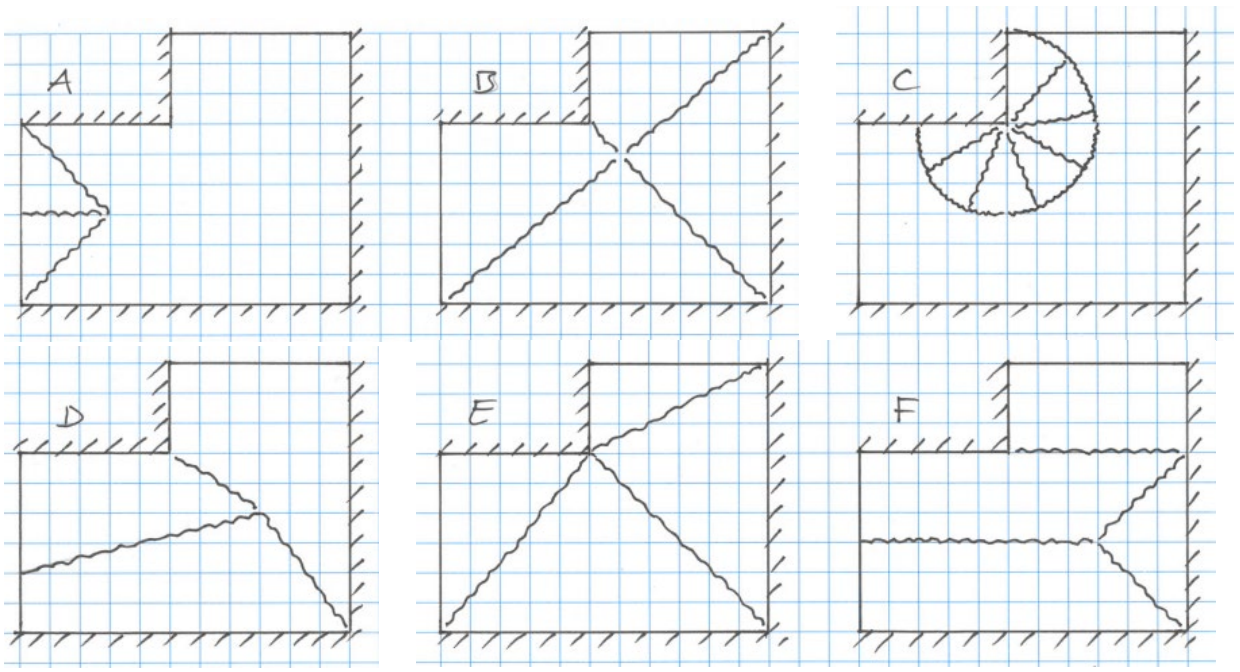


Figure 4. Yield line patterns of problem 2a

b Consider the yield line pattern of Figure 3. Determine an upper-bound for p expressed in m_p and a (1.5 point).

c Determine the largest lower-bound for p using torsion free beams ($m_{xy} = 0$). You need only to write down the equations and not solve the equations. (1.5 point)

Problem 3

a A statically indeterminate ductile structure is partially heated by direct solar radiation. Do we include temperature as a load case for the ultimate limit state?
Choose A, B, C or D. (0.5 point)

A No; expansions joints absorb the temperature strains.
B No; temperature strains do not change the collapse load.
C Yes; a temperature gradient may increase the moments.
D Yes; the increased temperature reduces the compressive strength.

b A frame structure is statically indeterminate to the 5th degree. It has 13 locations of possible plastic hinges. An upperbound analysis is performed. How many mechanisms can occur?
Choose A, B, C or D. (0.5 point)

A 6
B 13
C 17
D 1716

c The lowerbound requirements are … Choose A, B, C or D. (0.5 point)

A ductility, equilibrium, $M < Mp$
B equilibrium, $M < Mp$, normality
C $M < Mp$, normality, ductility
D normality, ductility, equilibrium

Answer to problem 1a

Answer to problem 1b

Answer to problem 1c

Upper-bound

Lower-bound

Answer to problem 2a

A, F

3 or less correct ……. 0.0 point
4 correct …….. 0.3 point
5 correct …….. 0.7 point
6 correct ……... 1.0 point

Answer to problem 2b

Answer to problem 2c

Answer to problem 3

a B
b D
c A