Széchenyi István University

Department of Applied Mechanics

Homework

(CAE Methods – FEM assignment)

The purpose of this assignment is to make students familiar with using a simple 2D finite element code (written in Julia/LowLevelFEM) as well a professional finite element software and learn how to write Technical Report.

Objectives: A plane stress problem (with loads and supports) is given (See Appendix). The dimensions of the component to be tested are also given in the Appendix. Determine the stress state of the component, show the distribution of the typical stresses. Find the critical points of the structure and determine the appropriate stresses in them. Compare your results with other finite element softwares (e.g., ANSYS, ABAQUS, etc.) Discuss the results. Make a Technical Report.

Specific tasks:

- Determine the appropriate mechanical model.
- Divide the geometry into finite elements
- Give the boundary conditions.
- Solve the stress state of the body and show it (some typical stress distributions) in a figure. Indicate which stress can be seen.
- Repeat the computation with different meshes. (Compare the solutions for meshes with different element sizes, different approximation order.)
- Make graphs of stresses of some interesting points (e.g. stress singularities) as a function of DOF (Degrees Of Freedom) — use logarithmic scale.
- Recommend an element size and approximation order which gives reliable solution (within reasonable time).
- Compare the solutions solved by Julia/LowLevelFEM and ANSYS or ABAQUS.
- Discuss the results.

Technical Report: The deliverable is a Technical Report written according to the international engineering and scientific standards. The structure and format of Technical Reports is rather rigid and therefore easy to learn (once learned, it can be reused for the rest of the students career). *In general, a Technical Report should have sufficient information so that the reader can repeat the work we have done. It is important to describe the reasons of the choices we have made, i.e., not just WHAT have we done, but also WHY? (For example, why did we choose the concrete boundary conditions we applied, etc.)*

Technical Report *should contain enough details so that their results can be reproduced by someone else* not able to talk to you in person. This means that you must show all details on how did you obtain the results. For example, for FEM calculations, tell what element types were used, how large were the elements and why, what boundary conditions (supports and loads) were applied, what software were used to solve the problem, how does it work, how many iterations were used, what was the convergence criteria and why, what type of computer and processor was used, what were the runtimes, etc. so that the reader can reproduce the mesh and to repeat the simulations. Follow the "WHY" and not the "WHAT" philosophy, e.g. explain that WHY did you do something, instead of just telling WHAT did you do or choose.

Reports should be written in 3$^{\text{rd}}$ person, i.e., avoid using "I have decided", etc. Instead one should say "It has been decided".

The length of the home assignment must be between eight and ten pages (A4 size) with 2-2.5 cm margins. Use 12pt sized "Roman" characters (like this document).

A Technical Report on FEM (Finite Element Method) has the following sections:

- Title, Author, Institution and Date (on the top of the page — *no title page*).
- Abstract (max. 10-15 lines long summary of key contents of paper): it is essentially equivalent to a "summary" of what is in the report. It should describe briefly (no more than half page) that
  - why was this report written?
  - what methodologies were used (literature review, conceptual design, calculations, simulations, experimental testing, etc.)
  - key results
  - key conclusions
- Introduction
  - Should describe the big picture of
    - why have we done the work described in the technical report,
    - how does it fit into the overall project – for large projects like ours.
  - It should zoom in on the objectives of the work in 3-4 "concentric circles", in which the smallest circle is the paragraph explaining that what was the objective of this technical report.
  - Normally it has four paragraphs:
    - Intro into the problem (eg. why are simulations important?,. . .)
    - Review of the State-of-the-art.
    - Why do we do this work?
    - What are the objectives of this paper?
  - Example: if we need to write a report on how to clean the kitchen floor, we should have 3-4 paragraphs on the following topics:
    - Health is important – nobody wants to get sick.

    – A key element to prevent any sickness is hygiene.
    – Hygiene is especially important in the area(s) where we work with food.
    – *The objective of this report is* (this is how all your report's Intro should end)... to describe how to mop the kitchen floor.

- Problem description:
    - Sketch the geometry of the given problem (do not scan it from here, use vector graphic programs like e.g. inkscape). Choice of the proper mechanical model (with detailed explanation) (e.g., linearly elastic material, neglecting dynamic effects, plane stress problem, etc.)
- Boundary and/or Initial Conditions
    - Describe the Boundary and Initial conditions (if any) chosen. Show them on the above sketch or a new one.
- Mesh generation
    - What type of mesh is used? (structured, unstructured?) How was the mesh generated (manually or automatically)? Is the mesh 2D or 3D? What other features does the mesh have (shape and size of the finite elements, order of approximation, etc.)? Show the mesh in a figure.
- Numerical Method
    - Which code (software) is used? What type of equations does it solve? What type of discretization does it use (Finite Element, Finite Volume, Finite Difference, Spectral Method?). What is the order of spatial and time discretization (1^{st} , 2^{nd} or higher?). What numerical method does it use to solve the equations (explicit or implicit, direct or iterative)? What convergence criteria were used? Did we run steady or unsteady simulations? Did we use linear or non-linear solver? (Why?)
- Verification of results:
    - The goal is to verify that the numerical simulations are independent of the numerical parameter we have chosen, i.e., they are credible.
    - Perform a grid dependence and/or time step dependence test (the latter one only if time step was a parameter chosen by us).
    - What was the coarse, medium and fine mesh density? How many elements end nodes does the mesh contain? What is the degrees of freedom (DOF) of the problem? What was the time step size under investigation?
    - Show graph of a suitable parameter (e.g., normal stress or equivalent stress – you decide) with three mesh densities or time step sizes.
    - Make a conclusion that which mesh is suitable for further simulations.
- Validation of results:
    - Comparison of FEM results with analytical or experimental results (here Julia/LowLevelFEM vs. ANSYS or ABAQUS).

- ◦ Say that which mesh or time step size results (from above) are you going to compare.
  - Describe briefly that what do you compare to (theory or experiment or both or something else).
  - Show experiment or analytical results and FEM results (here the two FEM results) *in the same graph* (you might need to manually measure the experimental data from the graphs provided and to type them into a proper software).

- Results and Discussions:
  - Now that we are confident in the correctness and accuracy of the FEM simulations, we can start to analyze the results. (e.g., equivalent stresses in control points).
  - Show the results asked in the specific tasks of the Assignment text.
  - Comment on the key physical features on the figures.
  - Discuss the reliability of the results.

- Conclusions:
  - Note: this is not a summary! (the Abstract is there for a summary), but...
  - This should be a list of key conclusions, with recommendations for future work

- Acknowledgements (may omit this section):
  - Thank here to anyone you wish (usually to sponsoring agencies) or to a person who is not listed among the authors but helped a lot in completing this paper.
  - Do not thank the Instructor of this course, he is just doing his job by teaching you...

- References:
  - List here all the literature sources (books, journal papers, conference papers,...) you refer to (took information from it).
  - You must refer to these sources with their reference numbers put into brackets.
  - You can only list references here, which you actually refer to in the text.
  - You can refer only to books, journal papers, conference papers or abstracts, BSc, MSc or PhD thesis, technical reports which can be found in Google Scholar (Google's scientific search engine, `https://scholar.google.com`) or in libraries. These are usually peer-reviewed works.
  - *Do not refer to sources from the internet!* (e.g. http://www.something.com/products).
  - Examples for references can be seen in [1, 2].

You can abbreviate expressions which are often occurs. At the first occurrence in text, mention full name, followed by abbreviation in parentheses, i.e., "Finite Element Method (FEM)". After this, you may use the abbreviation only throughout the text.

All equations must be numbered (except for inline equations). Numbers of equations are placed on the right side of the page in parentheses. Numbered equations can be referenced by the number of the equation in parentheses, as you can see in equation (1).

$$\underline{\underline{K}}\,\underline{\underline{q}} = \underline{\underline{f}} \tag{1}$$

All figures and tables must be numbered and captioned. Numbers and captions are above the tables and below the figures. All the figures and tables must be cited at least ones in the text. (e.g., . . . The dimensions of the plate (see Figure 1) can be found in Table 1. . .)

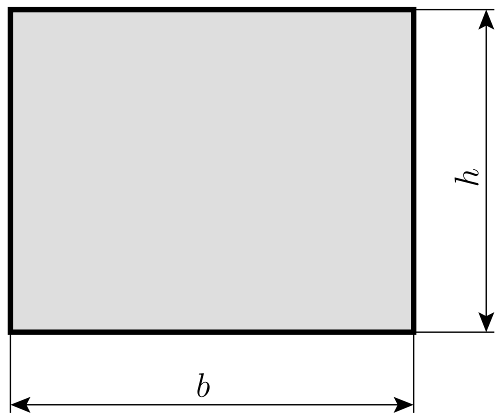

Figure 1: Dimensions of the plate

Table 1: Dimensions of the plate

dimension	name
b	base
h	height

Do not use colors in graphs. Instead of them use different line styles, e.g. solid line, dashed lines, dotted lines, etc.

Equations:

- For writing physical quantities always use *equation editor* (the characters will be written in different style than the normal text).
- In the physical quantities there must be space between the size and unit.
- Always use *italic* characters for physical quantities an Roman characters for units (e.g. $m = 3\,\mathrm{kg}, \quad l = 2\,\mathrm{m}$ – watch the difference between m and m).
- Do not use units inside the equations (use it only for the results).
- Use dot in the multiplication only if the lack of it causes misunderstand. E.g. $2 \cdot 3 = 6$, but $(a + b)^2 = a^2 + 2ab + b^2$
- In cross product do not use "x". Instead of this use "$\times$" from the equations editor.
- *Never* use "*" to denote multiplication.

To make the Technical Report it is strongly recommended to use the $\LaTeX\,2_\varepsilon$ environment (`https://www.latex-project.org/`) or the $\LaTeX\,2_\varepsilon$ based LyX text editor software `https://lyx.org`, which satisfy the prescribed formal requirements. These software are open source and freely downloadable from the internet. LaTeX is widely used in the scientific world. The assignments written in LaTeX worth additional ten points.

The Technical Report must be uploaded to Moodle in **pdf** format. *Incomplete work will be evaluated as invalid.*

Deadline for submission: **5 May 2024, 23:59.**

6 March 2024

Balázs Pere
Associate Professor

References

[1] Bathe, K.-J.: *Finite Element Procedures*, Prentice Hall, New Jersey, 1996

[2] Hertz, H.: *Über die Berührung fester elastischer Körper*, Journal für die reine und angewandte Mathematik, **92**, 156-171, (1881)

Appendix

Problems to solve are given in Figure 2. The sizes of the problem, supports, displacements and loads can be found in Table 2.

Figure 2: Problems

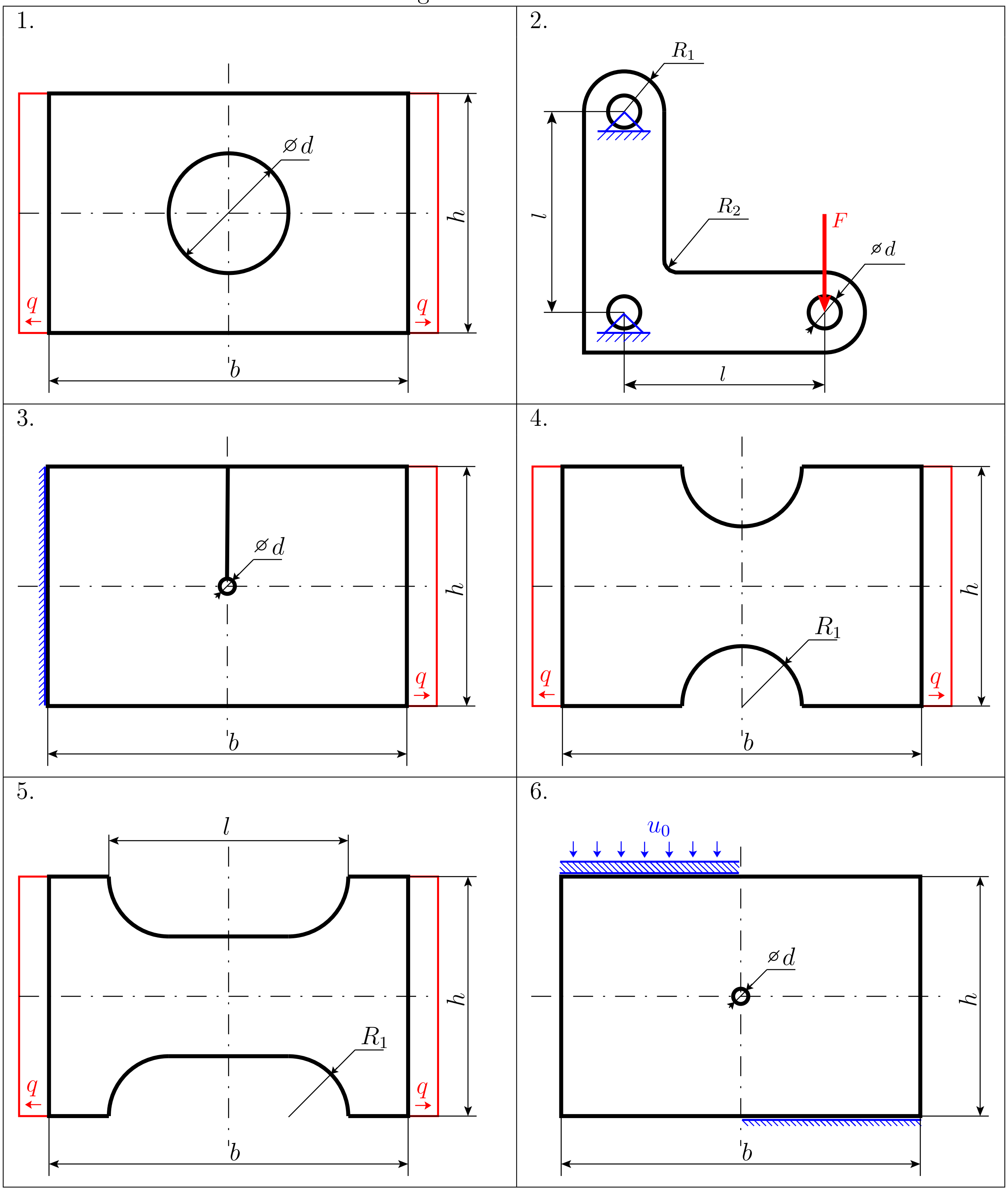

Table 2: Sizes and boundary conditions. Thickness is 1 mm.

Neptun code	problem	b	h	d	l	R_1	R_2	q	F	u_0
		[mm]						[N/mm^2]	[N]	[mm]
Q39HXA	1	200	100	50	-	-	-	1	-	-
IKFVZ5	2	-	-	10	80	10	2	-	100	-
NZR4BM	3	200	100	4	-	-	-	1	-	-
BLXUAR	4	200	50	-	-	12	-	1	-	-
VL8XH3	5	200	50	-	160	12	-	1	-	-
TL6RQG	6	200	100	5	-	-	-	-	-	0.01