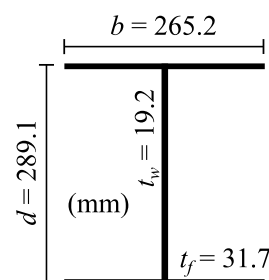# CIVE50003 Computational Methods II

Coursework – Influence lines and bridge structures

This project is to be carried out individually using the Matlab programming environment. Please make an electronic submission on Blackboard of a report (no more than 12 pages in *pdf* format) and your complete Matlab code (all *m* files). Your report should include a detailed critique of your findings in the context of finite element and structural theory, including computational considerations where appropriate. Please write carefully and professionally and use appropriate formatting in your document. You may collaborate and use any code released to you, but you may *not* share *any* files or results. The deadline is 5 pm on Wednesday 5th April 2023.

You have been asked to investigate the statics of a truss bridge under the action of a moving train locomotive with the aid of *influence lines*. An influence line tracks the change of a force or moment at a single location depending on how a load pattern moves across the structure. It is an important concept in the study of bridges.

A symmetric truss bridge is illustrated in Fig. 1. It consists of a simply-supported 'central span' resting on the tips of two opposing 'cantilever arms', which in turn are supported by 'anchor arms'. Assume that all members, or 'chords', are pin-ended bars carrying only an axial force. Such bridges were commonly built as part of railway networks in the 19th century all over the world (the Forth Railway Bridge in Edinburgh is a famous example), and were often statically determinate to enable a simple analysis of the statics. The action of the locomotive may be represented as a 2 MN point load moving along the bottom line of horizontal chords from A to F.

Assume that each chord is a built-up I-section with dimensions as shown to the right. Assume a modulus of elasticity of 200 GPa and, where applicable, a yield stress of 355 MPa.
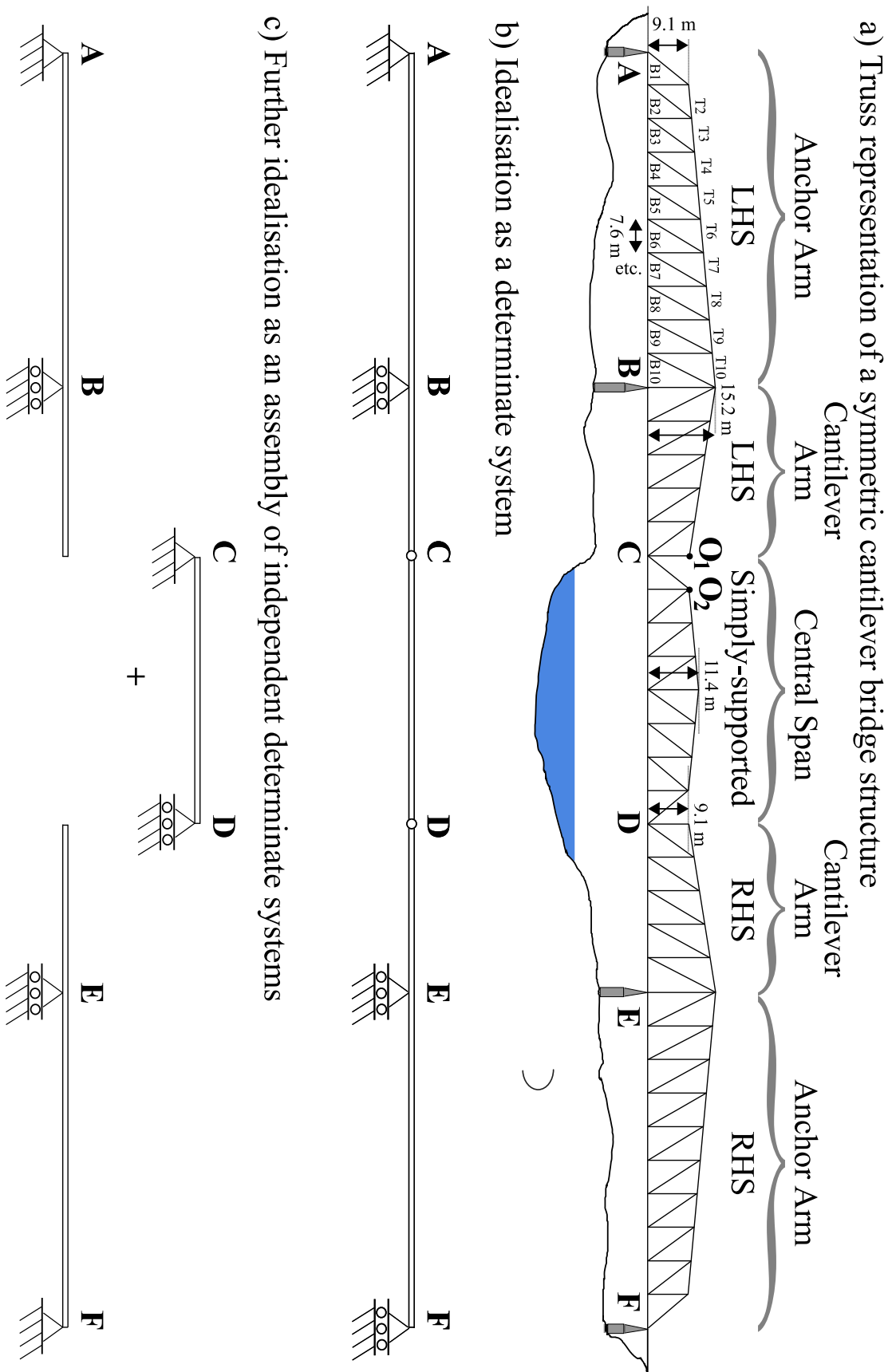
$b = 265.2$

$d = 289.1$

$t_w = 19.2$

(mm)

$t_f = 31.7$

a) Truss representation of a symmetric cantilever bridge structure

Anchor Arm · Cantilever Arm · Central Span · Cantilever Arm · Anchor Arm

LHS · LHS · Simply-supported · RHS · RHS

9.1 m 7.6 m etc. 15.2 m 11.4 m 9.1 m

B1 B2 B3 B4 B5 B6 B7 B8 B9 B10
T2 T3 T4 T5 T6 T7 T8 T9 T10

O_1 O_2

A B C D E F

b) Idealisation as a determinate system

A B C D E F

c) Further idealisation as an assembly of independent determinate systems

A B

C D

+

C D E F

Fig. 1 – Determinate truss steel railway bridge and its various idealisations. The geometry is also given, with each 'bay' having a 7.6 m span.

NOTE: In what follows you may find it beneficial and intuitive to 'animate' the bridge as the locomotive passes over it. The following code snippet can be usefully adapted for this:

```
figure('unit', normalized','outerposition',[0 0 1 1]);
% insert intermediate code here
for (each locomotive position)
    % insert intermediate code here
    clf;
    % execute FE plotting code here and a 'hold on'
    drawnow; pause(0.5);
end
```

Q1. Considering only global static equilibrium and without using finite element analysis yet, <u>draw</u> the influence lines for the vertical reactions at A and B as the locomotive moves from A to F. <u>Draw</u> the influence line for the vertical force that must be resisted by the DEF portion of the bridge when the locomotive is on the ABCD portion of the bridge. Treat this henceforth as a vertical 'reaction' at D.

Q2. With reference to your hand calculations in Q1 and also Fig. 1, <u>explain</u> why a finite element model of the entire structure ABCDEF is not necessary.

Q3. <u>Write</u> a general Matlab Class BRIDGE to represent a finite element model of only the ABCD portion of the bridge, treating the effect of the DEF portion as a horizontal roller support at D (<u>why?</u>). <u>Research</u> Cholesky decomposition (the *chol* command) and <u>use</u> it in the most efficient way possible in your FE solver, <u>justifying</u> why it can be very beneficial to performance. <u>Show</u> that you are able to obtain the same influence lines for the vertical reactions at A, B and D as in Q1. <u>Comment</u> on how you could, in fact, reduce the size of the finite element model even further.

NOTE: the very general Matlab Class BRIDGE should abstractly represent any possible bridge model you will encounter here. The generic modules for matrix assembly, FE solution, plotting (perhaps with force calculation) should be coded as separate methods of such a Class, in addition to the 'create instance' method. Since every truss model will have the same nodes, dofs and element connectivity and will differ only through the locations of the point load representing the moving locomotive, you should have this 'base arrangement' come as standard each time you create an instance of the Class and this information should not be present in your

main calling program. Neat and elegant code is required, with proper commentary, annotation and indentation (consider using CTR+I to automate this).

Q4. Using both structural and computational arguments, <u>demonstrate</u> why the loss of *any* diagonal chord is a Bad Thing.

Q5. <u>Add</u> a single horizontal chord at the location identified by O_1O_2 in Fig. 1. <u>Compare</u> the influence lines for the vertical reactions at A, B and D that you now obtain with those from Q1 and Q3. <u>Comment</u> on the possible reasons for any differences.
NOTE: whether or not to include this chord should be a method of your Class.

Q6. <u>Remove</u> the additional horizontal chord that you added in Q5. <u>Compute</u> the influence lines for the bottom chords marked B1 to B10 in Fig. 1 and plot these all on the *same* properly-annotated figure. <u>Which</u> of these chords exhibits the maximum possible axial force and <u>where</u> is the locomotive located when it does so? <u>Do</u> the same anew for the top chords marked T2 to T10 (on their own common figure).
NOTE: use the dofs that you compute by FE for each model to calculate the axial force in each chord of interest via the transformation matrix for a 2D bar element. For the bottom chords, your influence lines should resemble something like this:

Bottom chords in AB
member forces
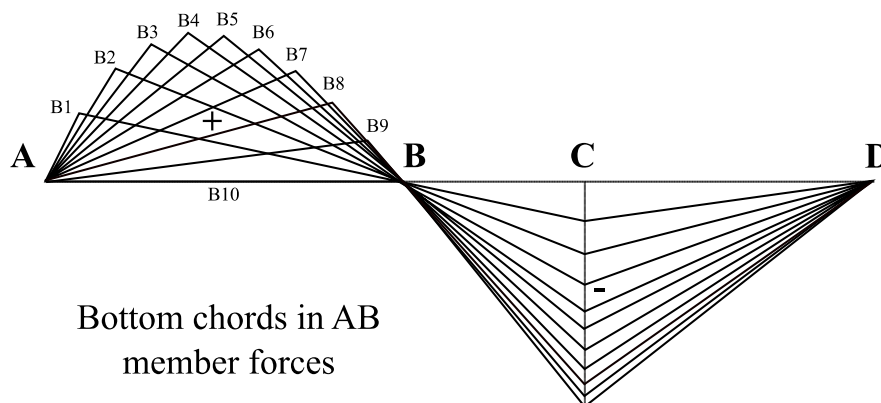
Q7. <u>What</u> is the factor of safety of the bridge against a) Euler column buckling and b) plastic collapse and <u>what</u> is the critical chord in AB for both conditions? <u>Comment</u> on whether the top and bottom chords of the anchor arm can safely resist the passing locomotive. Structurally, <u>where</u> is the *worst* place to put the locomotive?

NOTE: The critical Euler column buckling load for pin-ended member of length L is $P_{cr} = EI(\pi/L)^2$, where I is the 2nd moment of area in minor-axis bending, while the squash load is $P_s = A\sigma_y$. The truss chord members are so slender that buckling will probably always control under compression.

Q8 <u>Repeat</u> Q6 and Q7 with the additional horizontal chord at O_1O_2. How do the influence lines and factor of safety change?

Q9* (OPTIONAL BONUS). <u>Consider</u> Fig. 2 below, and then <u>watch</u> Buster Keaton over the Easter holidays.

Fig. 2 – A scene from Buster Keaton's 1926 film *The General*. Yes, they actually destroyed a train and a bridge in order to film this. It was the most expensive film scene shot during the silent film era.

References

Snyder L.K. (1932) "A study of influence line analysis of stresses in a cantilever style highway bridge" *MSc Thesis*, School of Mines and Metallurgy, The University of Missouri, USA.

END

AJS Feb' 23

This figure should help you in creating your global dof and element numbering.

9.1 m

A

B1
B2
B3
B4
B5
B6
B7
B8
B9
B10

T2
T3
T4
T5
T6
T7
T8
T9
T10

7.6 m

15.2 m

B

$O_1 O_2$

C

9.1 m

11.4 m

D

9.1 m

6