CIVE:96008: Dynamics of Structures **Spring 2020/2021**

Coursework

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1 Introduction

The ability of sloshing liquids to enhance the dynamic response of structures has been well established. The use of this form of dynamic control represents an easy way to reduce the motion of a variety of structures from towers to space rockets. In the field of civil and structural engineering, many examples can be found where sloshing dampers have been implemented. Figure 1, for example, presents a view of the One Rincon Hill South Tower in San Francisco (US) that uses a tuned liquid damper to control the building response under strong winds. Other structures, such as elevated water tanks or even buildings with top level pools can benefit from such behaviour. In this coursework:

> You will use your knowledge of Dynamics to specify the maximum possible height of still water that leads to the smallest deformation possible in a small scale structure carrying a water container subjected to harmonic base motion.

Figure 1: One Rincon Hill South Tower and its liquid damper.

2 Available data

You will approach this task as a structural engineer with limited access to the site and limited information. Therefore, to characterise the dynamic properties of the structure, you will be relying on a video recording of a free vibration test (to be uploaded to the BB site) conducted on the structure in its empty state (without water in the tank).

Other relevant data that may be of help are:
(i) the free vibration test has been recorded at a frame rate of 240 fps, *is this good enough?*
(ii) the support structure is made of PLA (Polylactic acid plastic),
(iii) the total height of the structure, without the water tank, is 14 cm (other geometric dimensions are given in Figure 2), and
(iv) a water tank is attached to the top of the structure. This container is made of acrylic (1.5 mm thick) and has internal dimensions of roughly 5cm by 5cm in plan and a total height of 5cm of which only 3 cm can be filled with water.

Parameter	Value
b_column	42 mm
b_upper_slab	42 mm
b_lower_slab	42 mm
d_column	2 mm
d_upper_slab	80 mm
d_lower_slab	72 mm
t_top	5 mm
t_bottom	6 mm
height	140 mm

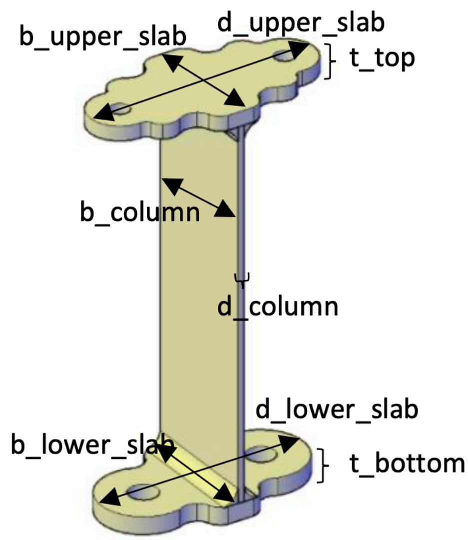


Figure 2: Available geometric characteristics of the SDOF supporting structure.

Among the things that you do not know are: the actual weight of the structure, the weight of the water tank or container, the PLA material density. etc. Although you know that infill densities in the order of 60 - 30% have been used for the manufacture (3D printing) of similar structures.

3 Operational (design) conditions - test

Although the video of the free vibration test provided was carried out on an empty structure (i.e. without water). The clients are interested in the largest amount of water that can be stored in the tank (placed on top of the structure) yet they are also interested in the smallest possible lateral deformation under harmonic base motion simulating operational (design) conditions.

To simulate the operational conditions a second test will be carried out: Once the structure is filled with water (to your specified height), it will be subjected to a simulated motion at its base. This test will be carried out in an Arduino-controlled servo-mechanically actuated uni-directional shaking table (Figure 3) under the following conditions:

- Nearly harmonic base motion of 10 mm displacement amplitude with a dominant frequency of 3.5 Hz.

- There will inevitably be some period of transient motion but the focus of your task is only on the steady-state part of the response.

- Structural failure under this conditions is akin to failure of the commissioned task.

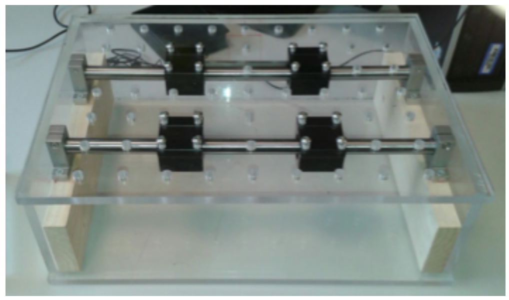


Figure 3: Shaking table.

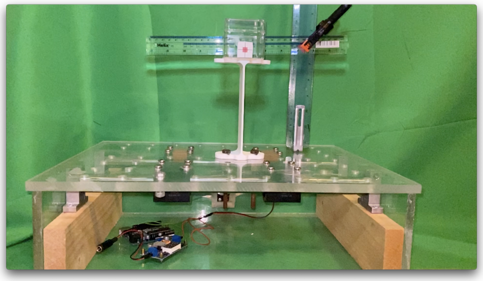
4 Steps to the calculation

- **Step 1:** In this exciting experiment you will first need to characterise the dynamic properties of a small scale single-degree-of-freedom (SDOF) structure based on what you know about free vibrations and using the video provided. For post-processing the video you can use Tracker (https://physlets.org/tracker/).

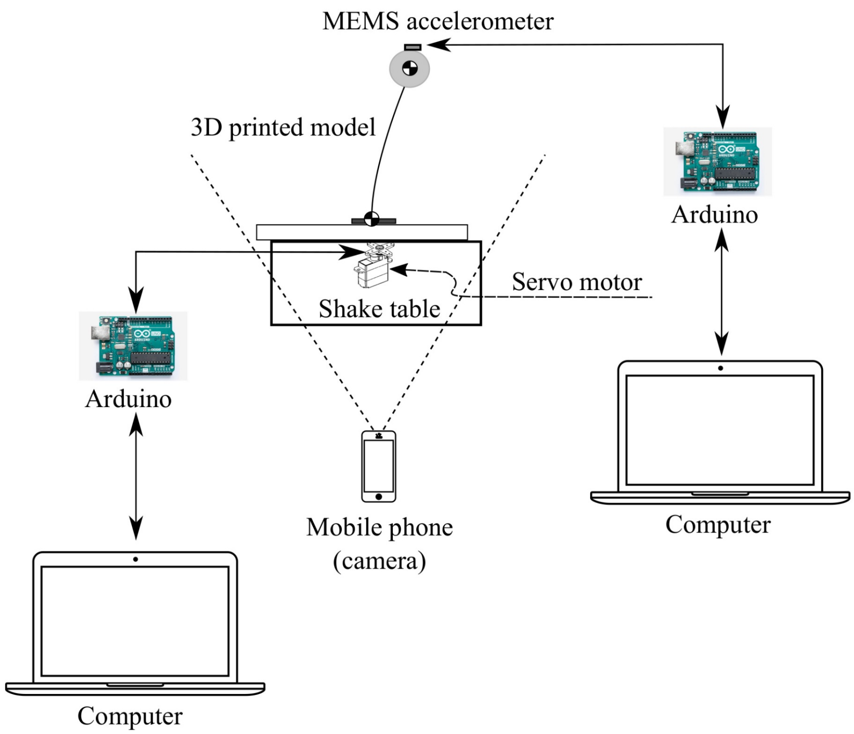
- **Step 2:** Use your knowledge of Dynamics and the tuned mass damper (with sloshing) equations to explore the response of the structure with water and determine the optimal height of still water that can be carried safely. *Remember that the client is interested in the largest amount of water and the smallest displacement under base-motion.* Some questions you will need to grapple with are for example: What is the best way to treat the unknowns of this problem? How do I analyse the range of potential solutions in a systematic and scientific way? How can I reduce the problem to first principles and what are those physical principles? What is the consequence of my assumptions?

- **Step 3:** Once you have specified a given water height, an experiment will be conducted with the structure filled to that level and you will receive a video recording of it. You will post-process the video recording and compare your estimations with the experimental results.

- **Step 4:** Prepare your submission. Describe all relevant assumptions, include a clear outline of the process you followed for the structural assessment and evaluation of potential scenarios. Ask yourself questions like: Can I Identify any differences between the assumed models, my calculations and what happened during the experiment? How these differences or alternative assumptions led to different accuracies in the physical experiment? How can different errors be explained? Can I identify how the predictions could be improved? Is there anything my group did not account for? You can also revise your calculations and show that your new calculated prediction comes closer (if you had high errors) or moves away from your experimental results (if your initial predicted values were very accurate). Take this as an opportunity for reflective learning, not a blame game. Avoid inconsequential comments like: If we had had access to the testing we would have measured this, or that; instead focus on any physical insight you may have gained from the aspects of the experience under your control.



(a) General view.



(b) Schematic view.

Figure 4: Experiemental set-up. Note that only the video recording will be available.

5 Submission of your estimation of water height and peak displacement

Each group should submit by email to c.malaga@imperial.ac.uk by the **1st of March before 3pm**:
1) a single height in mm (rounded to the +- 2 mm) from 0 to 30 mm.
2) an estimate of the maximum top steady-state displacement of the structure under operational (design conditions) in mm.

6 Experiment

The structure will be filled to the height specified by your group and tested under the loading conditions described above. The video recording will be uploaded to the BlackBoard course site or emailed to each group towards the end of the week commencing the 1st of March.

7 Final Submission

By the 25th of March before 5 pm through the BB coursework boxes AND electronically to c.malaga@imperial.ac.uk you should hand in:
(i) a three-pager pdf summarizing your assessment and decisions process and the technical justification of the height of water specified (together with the necessary formulate and graphs as considered necessary) including a short discussion of the comparisons between your estimations and the measurements ,
(ii) a single .fig file (Matlab) with all your figures, and
(iii) a video submission no more than 6 minutes long reporting on the activity as discussed below.

A submission folder will be created in Blackboard for the final submission. However, please send a second copy of your files to c.malaga@imperial.ac.uk using https://fileexchange.ic.ac.uk

Minimum contents of the submission

The submission includes 3 components:

(i) 3 pages + cover sheet. Minimum font size 10 and A4 pages. This should include:

Page 1 (≈1 mark)- a clear and succinct description of the steps followed to determine the height of water indicated in your first submission.

Page 2 (≈1 mark) - selected figures, at least one of which should compare the estimated and recorded response of the structure. Remember to focus on the steady-sate response only.

Page 3 (≈2 marks) - half a page of conclusions of the experience and half a page on reflections (what did you learn, what will you improve on your submission if you had the chance). *Include one line where you specify one or several aspects of your submission/work on which you would like to receive feedback[1].

(ii) **A single** "GroupNumber.fig" file (Matlab) with all the figures of the report (≈1 mark).

(iii) A multimedia submission in the form of a video (MP4 format) of **no more than 6 minutes**. The video submission can be prepared in any device of your choice and should include high quality audiovisual material (e.g. graphs, renderings, photos). As a minimum it should include:

1. An explanation of your initial assessment process and how you arrived to the water height specified, (≈ 2 marks)

2. A broad description of the testing, (≈ 1 mark)

[1]There seems to be some confusion as to what feedback is. Feedback is not a justification of the marks awarded (marks will be allocated against the rubric explained herein and you will receive a form with general comments on this). Feedback, instead, is something different, it is information to be used as a basis for your personal improvement. In the context of this coursework, in order for feedback to be helpful it should be a technical comment that can be actionable by you in your future studies or professional development so please be specific with your request.

3. A detailed description of the steps you took to post-process the results, ($\approx$ 2 marks)

4. A summary of your experimental results and a **critical and insightful** discussion of their comparison with your initial calculations, ($\approx$ 3 marks)

5. A few take-aways from the experience, ($\approx$ 1 mark)

6. A reflection on your learning process, ($\approx$ 1 mark)

7. A list of references employed (if any)

8 Marking criteria

Marking will be generally aligned to the mark allocations outlined in the previous section. But emphasis will be placed on the demonstration of technical critical thinking and physical insight. The effectiveness of the design (water height specification) will be asses in direct proportion to the amount of water that the client can hold on the structure and inversely proportional to the peak steady-state displacement experienced by the filled structure under base motion. The Department's approved criteria for coursework marking will be used (e.g. *"some elements correct but incomplete understanding of the relevant principles"* corresponds to a D while an A is awarded to *"excellent work and presentation with substantial level of independent enquiry."*)

Please feel free to drop me an email (c.malaga@imperial.ac.uk) or text me via MS Teams to arrange a meeting if you require further discussion.