Parameter ID Project (20% of total grade)

Hysteresis is commonly seen in nonlinear dynamics, where the restoring force of a system not only depends on the instantaneous, current displacement, but also on its response history. Accurate modelling and prediction of hysteretic behaviour would enable optimal decision-making for the health state and risk of future damage/fault/failure for engineering systems. An important characteristic of hysteretic behaviour is the time-varying stiffness ***k*** in the following dynamic equation of motion is not a constant:

$$m\ddot{v} + c\dot{v} + kv = -m\ddot{v}_g \tag{1}$$

where *m* is the mass and *c* is the damping. v, $\dot{v}$, $\ddot{v}$ are system displacement, velocity and acceleration, respectively. $\ddot{v}_g$ is the input acceleration. *k* is the stiffness changing over time.

Therefore, a differential model (the Bouc-Wen model) considering nonlinear stiffness has been widely used to predict hysteretic behaviours in engineering, as shown in Figure 1, it can lead to an equation of motion defined:

$$m\ddot{v} + c\dot{v} + \alpha k_0 v + (1-\alpha)k_0 z = -m\ddot{v}_g \tag{2}$$

where *z* is the hysteretic element to account for energy dissipation. *α* is the post-yielding ratio between the elastic and plastic stiffness.

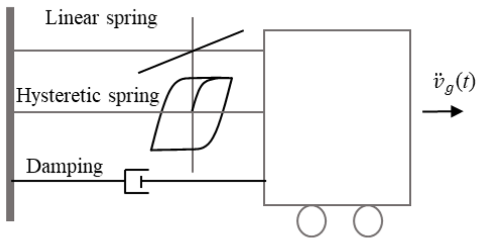

Figure 1. A Single DOF Bouc-Wen model

The Bouc-Wen model assumes the hysteretic restoring force *f*(*t*) comprises a linear spring element of stiffnes, k_0, and a hysteretic component in parallel:

$$f(t) = \alpha k_0 v + (1-\alpha)k_0 z \tag{3}$$

A differential form of Equation (3) can be expressed:

$$df = \alpha k_0 dv + (1-\alpha)k_0 dz \tag{4}$$

Dividing *dv* on both sides of Equation (4), the instant tangent stiffness *k*(*t*) can be obtained:

$$k(t) = \frac{df}{dv} = \alpha k_0 + (1-\alpha)k_0\frac{dz}{dv} \tag{5a}$$

Substituting Equation (5a) the relation $\frac{\dot{z}}{\dot{v}} = \frac{dz/dt}{dv/dt} = \frac{dz}{dv}$, means Equation (5a) can be rewritten:

$$k(t) = \frac{df}{dv} = \alpha k_0 + (1-\alpha)k_0\frac{\dot{z}}{\dot{v}} \tag{5b}$$

Thus, the change of stiffness $k(t)$ is determined by the initial stiffness k_0, the post-yielding ratio α and the differential function $\frac{\dot{z}}{\dot{v}}$. A simple definition of $\frac{\dot{z}}{\dot{v}}$ for a non-degrading yielding systems is defined:

$$\frac{\dot{z}}{\dot{v}} = 1 - 0.5 * (sign(\dot{v}z) + 1)\left|\frac{z}{dy}\right|^2 \tag{6}$$

where dy > 0 is the yielding deformation, and sign is a signum function defined:

$$sign(x) = \begin{cases} 1 & x > 0 \\ 0 & x = 0 \\ -1 & x < 0 \end{cases} \tag{7}$$

Therefore, the simplified Bouc-Wen model can be determined by the identifying parameters k_0, α and dy.

Hence, your task in this project is to identify the unknown parameters $\boldsymbol{k_0}$, $\boldsymbol{\alpha}$ and ***dy*** given observations of $\boldsymbol{z}$, $\boldsymbol{v}$, $\dot{\boldsymbol{v}}$, $\ddot{\boldsymbol{v}}$ and $\ddot{\boldsymbol{v}}_{\boldsymbol{g}}$. The Mass is assumed to be a normalized constant value with ***m*=1**. The value of ***c*** is also given for different combinations of k_0, α and dy. In particular:

Task 1: Find ***only*** the initial stiffness k_0 and post-yielding ratio α using Equations (2) and (3)

a) Can the Least Squares method be used to identify k_0 and α? Why?
b) Can the Gradient method be used to identify k_0 and α? Why?
c) Choose method (a) or (b) to identify k_0 and α. Show the flowchart or step-by-step procedure for your algorithm. Plot the error surface or counter map to check your identification results.

Note: You do not need the value of dy to identify k_0 and α in Task 1.

Task 2: Identify the yielding deformation dy using Equations (6)

a) Use the Integral-based method to identify dy. Show the flowchart or step-by-step procedure for the algorithm.
b) Is there any other method eligible for identifying dy? If yes, state how you would implement the method.

Equally, you do not need k_0 and α to identify dy in Task 2.

Project Data

(1) Each student will use different data generated from different combinations of unknown parameters. All the project data are available in the folder **"ENME403 Para ID Data"** via the following dropbox link:

https://www.dropbox.com/sh/k1iai3rqdbe7g0w/AAAcyjavWVY7FlNNRj_FHMS0a?dl=0

You will find your own data file named after your Student ID number, as shown below:

StudentID_number11334805.mat

StudentID_number11365861.mat

StudentID_number11785636.mat

StudentID_number12015205.mat

StudentID_number12832870.mat

(2) You can then download your data and use the following Matlab function to load your data in Matlab workspace:

load('StudentID_numberxxxxxxxx.mat','Project_Data','Mass','Damping')

For example, use load('StudentID_number12345678.mat','Project_Data','Mass','Damping') if your student number is 12345678.

(3) Finally, you will find "Project_Data" is a 2001x5 matrix, where 2001 is the total number of observations. Each of the 5 (five) columns in the "Project_Data" matrix represents one type of observations $\ddot{v}_g$, v, $\dot{v}$, $\ddot{v}$ and z. Therefore, **Project_Data = [$\ddot{v}_g$, v, $\dot{v}$, $\ddot{v}$, z].**

The variables "Mass" and "Damping" provides the values for m and c, respectively, in Equation (2).

The time interval or step size for the integral based method is **Δt=0.005**.

Note: *All the data sets have been tested to ensure a good identification outcome.*

REPORT: The report requirements include:

- Total maximum of **6 pages**, not including cover sheet or references. **No appendices!**
- Focus on your plots and flowcharts to tell the story.
- **12 point** Times New Roman font, or similar and leave margins **at default normal sizes.**
- Use a short report structure (see attached). Use sections for Introduction, Methods, Results, Discussion. If your project report is poorly structured you will lose marks.
- Use plots/figures to support your discussion. The biggest rule of plots is clarity. A plot that is too full/too fuzzy/unreadable is useless. Include all axes labels and legends. Separate plots in the same figure should be labelled a), b), c) etc, and referred to in the caption.

Report Submission:

- Report will be submitted via an online portal on learn page under the Section of "**Report Submission for Parameter ID**".
- Save your report using a filename that has your **student number** and your **family name**, such as: "<student number>-<family name>" e.g. "12345678-Zhou"
- Accepted file types include **word** document (.doc&.docx) and **pdf** document (.pdf)
- Submission will be due **11:59pm on 28th May**, 2020.

How to write a short report

Abstract: An abstract is not always necessary, depending on the context of the report. It serves to give a very brief overview of the reason the analysis was carried out, the key details of the methods, main results (with numbers), and main conclusions (interpretation of results).

Introduction: A well written report will convey information as clearly as possible so that the reader should not have to work hard to find the main outcomes and conclusions. An introduction will include background information pertinent to the subject being discussed. This could be previous research (carried out by you or others), or background concepts important to understanding your results as a whole. Be careful not to include details that should be in the methods. An introduction should include a short statement of what the report is about and why.

Methods: The purpose of the methods section is to describe what you did in enough detail that it can be repeated by someone else. This will typically include any models being used (and sometimes a derivation if required – depends on the intended audience), laboratory set up, a description of any data being used (if applicable - e.g. in parameter ID situations you are using existing data), what analyses or processes were carried out to generate your results (include key details/settings/numbers etc). Keep in mind your intended audience and their level of familiarity with your work when giving details as to lab set up. Equations should be numbered, and all parameters/terms briefly described and values given as appropriate. Don't reference an equation before it appears in your report.

Results: The results section presents the key aspects of what your analysis/experiment showed, with little interpretation or implications (save that for your discussion). Your results will drive your report. Figures and tables are key in presenting your results, and your results section and discussion will be structured around them. Table captions are placed above the table, and figure captions below the figure. Refer to figures/tables in text by their number, not by their placement on the page (e.g. above/below/right/left). Figures/tables and their captions should be able to be understood at a basic level independent of the text around them (i.e. the reader shouldn't have to go digging to work out what you are plotting against what and with what method). Use capitals when referring to Figure X or Table Y.

Figures should be clear and easy to read (not fuzzy, no miniscule text). Include all axes labels and units. If possible, plot several things on the same plot to show comparisons. If printing in black and white make sure the line styles are sufficiently different to differentiate data. Include legends. Separate plots in the same figure should be labelled a), b), c) etc, and referred to in the caption.

If presenting data in tables, think carefully about how many significant figures and/or decimal places should be used. If presenting data distributions include the mean and standard deviation, or median and inter quartile range, as appropriate. Use lines and shading to make your table easy to read.

Discussion: The discussion tells your reader what your results mean, why they are important, and how much they can be trusted. Your discussion will interpret your results, and may also include a discussion of the limitations of your methods or data or a comparison to other data in literature. You may also justify why you used a certain method here, or compare results from different methods. Depending on the context of your report, your discussion may be merged with the results section.

Conclusions: This section is important for briefly communicating the key results and main interpretation/implications/significance. Often your reader will look at the figures/tables and conclusions first to discern the main outcomes of your report and why they are important, before reading the details of methods and discussion. Don't include any new information (methods/results/discussion) in your conclusion.