Design and Building of a Load Frame for Buckling Test

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Abstract

Members, such as columns, which are by their nature subjected to compressive load, might experience deflection perpendicular to axial deflection of the member and therefore failure. This structural failure is known as buckling and might happen even if the compressive strength of the material is larger than applied compressive force. Euler in 1757 developed a mathematical model for maximum buckling capacity of a member. He presented the maximum load that a member can carry before failure due to buckling as a function of the length, moment of inertia of the cross section, modulus of elasticity of material and the fixity conditions of the member. Mostly, civil engineering students learn about the theory of buckling in the spring of their sophomore year in a Statics II course. Static II is combined with a two-hour weekly laboratory session. In this laboratory course different modes of failure of members such as failure due to tension, compression, shear and torsion load is demonstrated. As failure due to buckling is a very common type of failure in columns, there is an essential need to include a buckling test in the syllabus for Statics II laboratory. This paper explains the step-by-step design and building of a load frame which will specifically be used for conducting buckling tests. Force and displacement data will be measured simultaneously during the buckling test, and three different fixing conditions (fixed, pinned and free) at each end of the specimen can be applied to demonstrate the effect of member connection in buckling capacity of the member. This load frame can be used in the lab and can play a big role in explaining the concept of buckling to civil engineering students.

Introduction

One of the most critical modes of failure in columns is buckling. When a long column is subjected to compressive force, the member might deflect perpendicular to the direction of the force. Excessive deflection due to axial force might result to failure of the column. This mode of failure is known as buckling. When a member fails due to buckling, although the member is under compressive force, but the failure is not due to lack of compressive strength of the material. Mainly, columns are designed for the buckling capacity. Figure 1 presents a concrete column experiencing buckling under compressive force.

Figure 1: Buckling failure of a member under compression force [1]

Leonhard Euler derived a mathematical formula to compute the maximum load a column can tolerate before failure due to buckling. This critical force, known as Euler's Critical Load is function of material, cross section and fixity of the end connections of column. Euler's critical load is defined as:

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2} \quad [2] \ (1)$$

In which:

P_{cr} : Euler's critical load

E: Modulus of elasticity of the member

I: Moment of inertia of the member

L: Length of the member

K: Column effective length factor

Understanding the concept of this mode of failure is essential for civil engineering students. The concept of buckling of columns is taught to students mainly in sophomore year and in a Statics II course. Demonstration of buckling is an essential tool to teach this concept and make the subject more understandable. It would be very useful to establish the concept, and demonstrate the effect of Modulus of elasticity, moment of inertia, length and fixity of the member to first year students without detailing Euler's Critical Load formula. In addition, construction and design of this load frame is a very good project for mechanical and electrical engineering students. Two undergraduate students worked under supervision of a laboratory technician and a professor to design and construct a load frame for buckling tests. This paper describes the design and construction of a load frame for educational purposes.

Design and Built

The first step to designing the load frame is to understand the application and therefore needs for the frame. As mentioned, the load frame is mainly needed to demonstrate the fundamentals of buckling. Hence, there is a need to design a frame that can apply force to specimens of various lengths, materials, cross sections and different fixity at the end connections. In addition, there is a need to collect data including, load and change in specimen's length during the test.

Loading system:

Two columns connected to a steel base plate forms the body of the load frame. The two columns are connected to a smaller steel plate on top. The loading system contains a long-threaded rod which is connected to a motor. The motor and loading arm are attached to the top plate. The specimen can be connected to the threaded rod. By running the motor, the treaded rod move downward and therefore load the specimen. The rate of applying load to the specimen is equal to the Revolutions Per Minute (RPM) of the motor. To avoid a sudden loading a motor with small RPM is picked for loading purpose. The body of the load frame and loading system is shown in Figure 2.

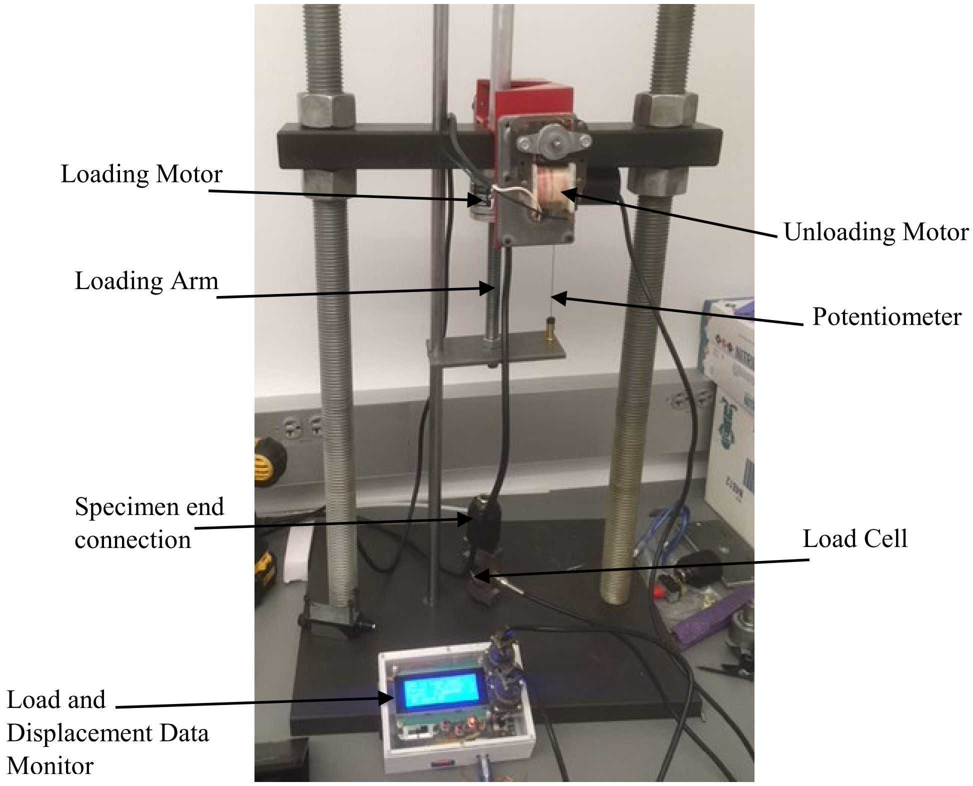


Figure 2: Load frame and loading system

Load Cell and Potentiometer:

A load cell is connected to the bottom plate of the frame to measure the applied load during the test. The specimen can be connected to the load cell at its bottom end. Since the load frame is designed for educational purposes, the need for extensive loading and therefore high capacity load cell is not necessary. The load cell has the capacity of maximum 300 kg. The load cell and its connection to load frame is shown in Figure 3.

Figure 3: Load cell

Change in the height of the specimen is measured using a potentiometer attached to a base plate. Potentiometer is shown in Figure 4.

Figure 4: Potentiometer to measure the displacement

Specimen Connections:

A very important parameter in teaching the concept of buckling is to demonstrate the effect of fixity of the two ends of the member in Euler's critical load and also the deformed shape of the member under buckling (K in equation 1). The behavior of a column which is fixed at the end connection is different than a column which is pinned at both ends. Figure 5 shows the difference in buckling of different members under buckling.

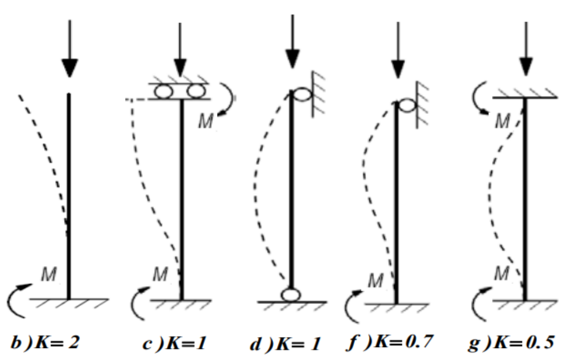
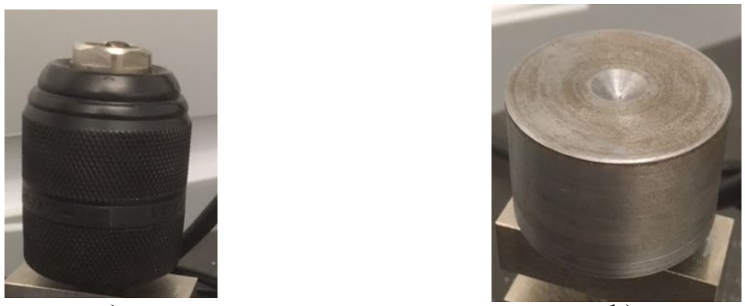


Figure 5: Effect of fixity on buckling of a member

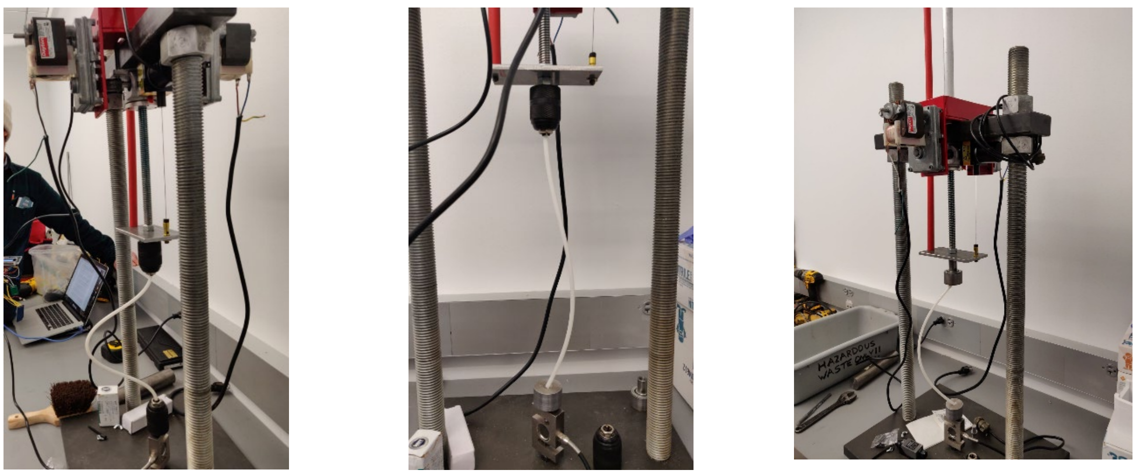
Figure 6 shows the adjustable connection which can be attached to the load frame to demonstrate the 3 different conditions of fixed-fixed, pined-pined, fixed-pined.



a) b)

Figure 6: a) Fixed connection and b) pinned connections

A nylon member was tested under the load frame to demonstrate the effect of fixity on buckling for first-year students. Figure 7 demonstrate the specimen tested under 3 different fixity at end connections.



a) b) c)

Figure 7: Nylon specimen tested for demonstration of the effect of fixity on buckling a) fixed-fixed b) fixed-pinned c) pinned-pinned

Unloading system:

A second motor is attached to the threaded rod. This motor rotates in the reverse direction as loading motor, and therefore it can be used for unloading and specimen length adjustments purposes.

Data Collection and monitoring systems:

Load and displacement data, is collected in a SD card, using an Arduino microcontroller. In addition to a SD card, data can be seen during the test using LCD screen. Figure 8 which is created by Fritzing, presents the wiring diagram for data collection and monitoring systems.

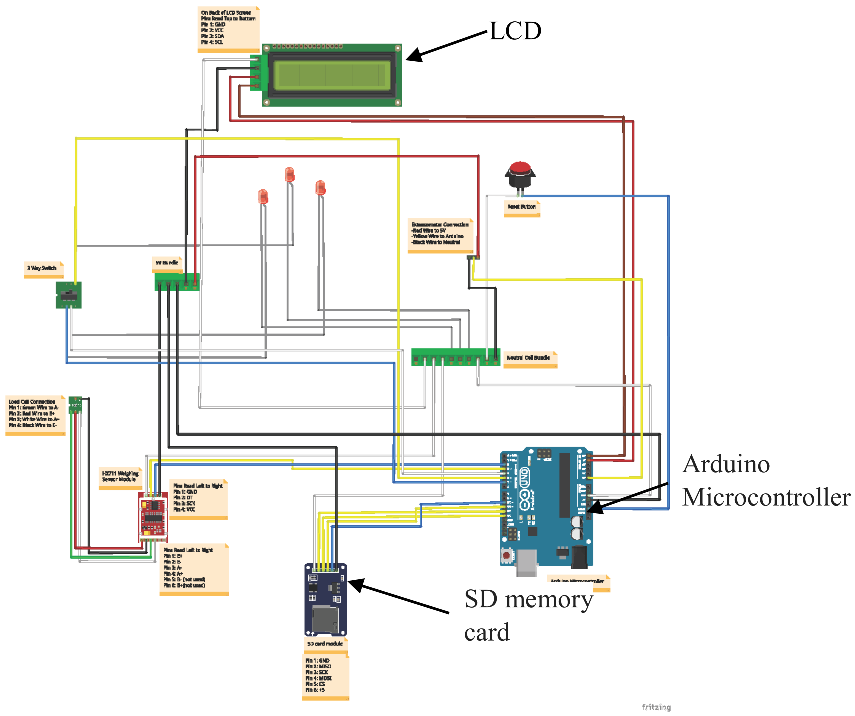


Figure 8: Wiring diagram of data collection and monitoring systems

Application:

The load frame is constructed to demonstrate the concept of buckling in columns. This set-up has applications in

1. Statics II / Mechanics of Materials class demonstration (Sophomore students)
2. Introduction to Engineering class (First year students)
3. Outreach for high school students (especially during open house, accepted students' days etc.)

This setup will have a major impact on the engineering understanding for 70 sophomore level students in the Civil Engineering. It will have an impact on approximately 350 first year students as a part of Introduction to Engineering course. In addition, this set up will impact several high school students to generate interest in Engineering.

Since, this is a new set-up, it was presented as a pilot study at the beginning of the semester to demonstrate the concept of buckling and effect of fixity on shape of buckling to first-year students. Students understood the behavior of columns in structures, and the type of displacement they might experience. This was very encouraging because this is a particularly difficult topic to visualize. Although these students will learn about the theoretical concept of buckling in the sophomore year, they demonstrated through the oral questions that the visualization of the concept helped them to understand the concept.

In addition to first year students a test was demonstrated to five senior students who were familiar with the concept of buckling. The students learnt the theory of buckling in their sophomore year while the concept was not demonstrated to them. All five students agreed that demonstration of the buckling helps in understanding the concept and agreed that the designed load frame is an appropriate tool for statics II class. The students mentioned that they understood the effect of end-fixity on buckling capacity of a member better after seeing the demonstration and wished that they had the opportunity to use this set-up in the sophomore year.

Authors are planning to use the frame in a Statics II course to demonstrate the concept of buckling at the end of Spring 2019 semester and have plans to possibly use it in the Introduction to Engineering course in Fall 2019.

Figure 9 shows the application of load frame for first year students in Spring 2019.

Figure 9: Demonstration of the concept of buckling for first year class

Conclusion and Future Work:

The design and construction of this frame was a successful project, which was mainly built by students. In addition to the fact that the department will benefit from having a load frame for buckling test, having such a hands-on project is useful for students who were involved in design and construction of the frame.

One of the places that the load frame needs to be improved for further usage, is by adding a free end fixity connection. This type of connection can help the instructor to demonstrate a fixed-free connection in addition to available connections.

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