RIBBITT – Teaching Elements of Engineering Design Using a Child's Toy

Indranil Goswami, Morgan State University

Abstract

Civil engineering freshmen at ___________ University are taught a second semester orientation course which gives them an overview of the major sub-disciplines within their chosen field, in addition to working on an open ended team structured design project. The course is taught by a team of faculty from the department, who also guide the projects. One of the components taught in this course was an interactive exercise in mechanics, using a simple toy called "Frog Hoppers".

During this exercise, students were exposed to engineering concepts such as strength of materials, kinematics of projectile motion, aerodynamics, elasticity and work and energy principles. Given the limitations of their technical background, these concepts were presented in 'bite-size' modules, without overemphasizing theory. They were also taught to recognize the sources of error in experimental endeavors and the importance of understanding and quantifying these errors.

Students were given two hours to complete the exercise. In the first hour, they were introduced to the topic and some of the underlying theory. They were also directed to work within their team structures and develop strategies about some of the open-ended aspects of the exercise. The second hour was used by the students to perform the various parts of the experiment and record their observations. Students were required to submit a written report outlining and explaining their findings. Students in this orientation course are required to complete a detailed evaluation of the various components of the course. The fairly recent introduction of this element into the course means that, to date, there is little feedback about how freshmen respond to the relevance of this exercise for their chosen curriculum.

Background

Following a non-discipline-specific course *Orientation to Engineering (ORIE 104)* in their first semester, civil engineering freshmen at ___________ University take a course titled *Introduction to Civil Engineering (CEGR 105)* in their second semester. The course is designed to give them an overview of the major sub-disciplines within civil engineering – structural, geotechnical, environmental, water resources and transportation engineering. In addition to this overview, students are assigned an open ended team-structured design project, which is varied from semester to semester. The course is taught by a team of faculty from the department, who also guide the teams on the design project.

As part of the structural engineering component of the course, one of the modules that has been taught for the past two years (spring 2008 and spring 2009 semesters) is a hands-on exercise in mechanics, using a simple toy called "*Frog Hoppers*". During this exercise, students are exposed to engineering concepts such as strength of materials, kinematics of projectile motion, aerodynamics, elasticity and work and energy principles. The typical freshman in this course is either taking College Physics I concurrently with this course or is yet to take it. The activity, therefore, does not overemphasize theory but rather encourages students to appreciate and quantify the engineering complexity hidden behind the design of this rather 'simple' toy. They are also taught to recognize the sources of error in experimental endeavors and the importance of understanding and quantifying these errors.

Students are given two hours to complete the exercise. In the first hour, they are introduced to the topic and some of the underlying theory. They are also directed to work within their team structures and develop strategies about some of the open-ended aspects of the exercise. The second hour is used by the students to perform the various parts of the experiment and record their observations. Students are required to submit a written report outlining and explaining their findings.

Frog Hoppers

The objective of the game *Frog Hoppers* is to use an elastic spring-like element (the frog's tail) to make the plastic frog jump into a plastic bucket, which also serves as the container. The exercise, in which students received instructions and then proceeded to conduct their experiments, is organized into the following modules – (1) measurements, (2) kinematics (projectile motion), (3) structural mechanics (bending), (4) dynamic coupling, (5) fatigue strength and (6) aerodynamics.

In the first hour of the exercise, students are encouraged to 'think aloud' with the instructor. The objective of the discussion is to make students recognize and appreciate the place of structural mechanics in the field of structural engineering. The class discusses structural systems, structural analysis and structural design.

During the second hour, students are formed into teams of approximately 4-5 students per team. Each team is then directed to proceed through a set of learning modules that require them to make specific measurements and perform related calculations. These modules are described below.

Learning Modules

In learning module 1 (measurements), students are asked to make and record precise measurements of various physical elements of the toy.

In learning module 2 (kinematics), projectile motion of a particle is reviewed. The discussion in this module also focuses on the fact that the actual object being studied is not a particle, but has distributed mass. This must be appreciated in order to understand various sources of error in the experiment.

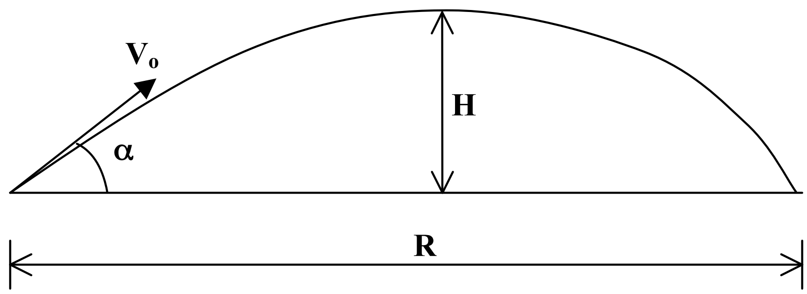

Figure 1: Projectile Motion of a Particle in a Gravitational Field

Students are asked to measure horizontal range (R) and maximum height (H) for various launch conditions. Launch conditions are varied by compressing the tail-spring of the frog to specific levels.

The theoretical range (R) of the projectile is given by

$$R = \frac{V_o^2 \sin 2\alpha}{g}$$

The theoretical maximum height (H) of the projectile is given by

$$H = \frac{V_o^2 \sin^2 \alpha}{2g}$$

The launch velocity and angle are estimated theoretically using the kinematics equations.

$$\alpha = \tan^{-1}\left(\frac{4H}{R}\right)$$

$$V_o = \sqrt{gR \sin 2\alpha}$$

Students are encouraged to record their findings in a systematic manner. A typical table is shown below.

Launch No.	**H (mm)**	**R (mm)**	**Δ (mm)**	$\alpha = \tan^{-1}\left(\frac{4H}{R}\right)$	$V_o = \sqrt{gR \sin 2\alpha}$	$E = \left(\frac{4mL^3}{bt^3}\right)\left(\frac{V_o^2}{\Delta^2}\right)$
1						
2						
3						
4						
5						

Table: Summary Data for Launches 1-5

In learning module 3 (structural mechanics), the students are exposed to the concept of flexural stiffness of beams. The theory of a cantilever beam subjected to a transverse tip load (see figure 2) is reviewed. This theory is the used to model the elastic strain energy stored in the frog's tail.

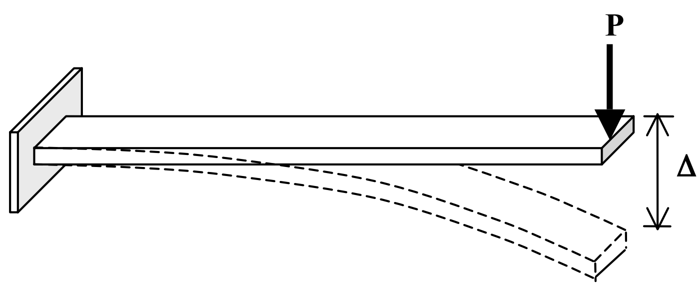

Figure 2: Bending of a Cantilever Beam under Tip Load

Based on elastic bending theory, the (maximum) tip deflection of a cantilever beam is given by

$$\Delta = \frac{PL^3}{3EI} = \frac{4PL^3}{Ebt^3}$$

where E = modulus of elasticity of the beam material
b = width of the beam
t = thickness (depth) of the beam

The frog is launched into motion by pushing down on its tail, thereby storing elastic energy. Upon release, this energy is converted into kinetic energy, resulting in the frog attaining a launch velocity V_o. If it is assumed that the potential energy of the frog at the instant of launch is zero (neglecting the slight depression below the datum), then equating the spring elastic energy to the frog's kinetic energy, we have

$$\frac{1}{2}k\Delta^2 = \frac{1}{2}mV_o^2 \Rightarrow k = \frac{mV_o^2}{\Delta^2}$$

The spring stiffness k is the elastic stiffness of a cantilever beam given by

$$k = \frac{3EI}{L^3} = \frac{3E}{L^3}\frac{bt^3}{12} = \frac{Ebt^3}{4L^3}$$

Equating the two expressions for the tail stiffness (k), the following result is obtained

$$k = \frac{Ebt^3}{4L^3} = \frac{mV_o^2}{\Delta^2} \Rightarrow E = \frac{4mV_o^2L^3}{bt^3\Delta^2} = \left(\frac{4mL^3}{bt^3}\right)\left(\frac{V_o^2}{\Delta^2}\right)$$

The terms m, L, b and t are measured with a high degree of precision, using a digital balance and a Vernier caliper. The launch velocity V_o is an estimation using particle kinematics. The depression of the elastic tail (Δ) is varied for each launch and measured.

In learning module 4, the group discusses dynamic coupling between support and structure. The lid of the plastic bucket doubles as a launching surface. The added elasticity of the lid serves to increase the range (R) of the frog. By using two separate launch positions for the frog, students make multiple measurements of the range.

In learning module 5, the class discusses the concept of fatigue strength. How a material responds to the repeated cycles of loading and unloading as opposed to supporting a sustained load for a long time is key in determining the durability of the material and the long-term quality of the toy. In this module, students are encouraged to research online using the keywords 'fatigue strength' and write a definition for it.

In learning module 6, the class discusses the effect of air drag on the results obtained from the experiment. The equations used in this exercise are based on *particle kinematics*, i.e. for an object that can be modeled as a particle (occupying no space). However, the plastic frog does have significant drag potential and therefore, particle kinematics is not strictly valid.

In designing experiments, it is always important to understand the various sources of *systematic error* that are embedded in the methodology (in addition to *random human error* that can always occur, even in perfectly designed experiments. The presence of such errors, produced as a result of simplifying assumptions, does not completely invalidate the experiment, as long as the results are significant and these errors are within some acceptable bounds.

Student Feedback

Students in this orientation course are required to complete a detailed evaluation of the various components of the course. The fairly recent introduction of this element into the course means that, to date, there is limited feedback about how freshmen respond to the relevance of this exercise for their chosen curriculum. However, it seems that both times that this exercise has been conducted, students seemed to respond positively to it.