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The Critical Pick: A Crane Rigging Demonstration

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Abstract

This demonstration, an application of static equilibrium and geometry knowledge, depicts the importance of rigging angles during crane lift operations on a construction site. Reducing rigging angles results in a significant amplification of forces in the rigging, potentially leading to failure. By varying the connection points and sling length, students will be able to calculate the predicted forces and analyze the best combination of connection points and sling lengths to successfully complete the critical lift. The forces in rigging (sling, chain, wire rope, webbing, shackles, etc.) increase substantially as the angle formed by the sling leg and the horizontal datum becomes smaller. The key engineering principle with this demonstration is related to an understanding of statics. Students must comprehend that decreasing the angle creates a horizontal force component that increases the tension in the rigging. The demonstration takes 15-20 minutes to complete in class.

Introduction

"Seeing is believing!" and "A picture is worth a thousand words!" stand out among the excess of possible phrases one could apply to why models and demonstrations (demos) are an essential facet of engineering education. But the effective application of models and demos is hardly as simple as an overused cliché. Vander Schaaf and Klosky[1] note that for many students, physical reality becomes lost in seemingly endless equations and an apparent jumble of theory and practical application. Wankat and Oreovicz[2] are one of many that state "classroom demonstrations during lecture can provide a concrete learning experience and the chance for discovery."

Vander Schaaf and Klosky[1] identified four primary reasons to integrate models and demos into classroom instruction, which are as follows:

> "1. Push students toward an active mode of learning;
> 2. Excite interest in the topic;
> 3. Link theory to the student's natural knowledge; and
> 4. Engage global learners fully."

Using this crane rigging demonstration is one more way to positively engage with your students in the classroom.

Background

The crane rigging demo study included 60 students from two separate semesters of MC300 (Fundamentals of Engineering Mechanics and Design, which combines statics and introductory mechanics topics). As the largest course within the Department of Civil and Mechanical Engineering, the student population consists of every civil and mechanical engineering major, as well as non-engineering majors as the first course of a three-course engineering sequence. The course is the entryway into the department, as it is the first course all civil and mechanical engineering majors take during the first semester of sophomore year. However, approximately two-thirds of the students that take MC300 in an academic year are not civil or mechanical engineering majors. Most of the non-majors are sophomores and juniors, while a small population of the course are seniors. The 60 students assessed in this study were an accurate representation of the diversity within the entire course. The three-credit hour course is taught over thirty 75-minute lessons. Most lessons are lecture style with board work and an extensive use of physical models and demos. Some of the lessons include time in the lab (since there is no dedicated lab period) and others focus on learning through flipping the class using Inquiry Based Learning Activities (IBLA).

The demo was shown to the first group of students on the 30th lesson (of 30) of the course giving them adequate depth of knowledge to confidently answer the questions in class. The demo was shown to the second group of students on the 2nd lesson (of 30) of the course after completing a lesson on basic forces and moments as related to 2D equilibrium. The intent behind showing the demo at different points in the course was to analyze its effectiveness as a learning tool for teaching statics and equilibrium and if students valued the demo in a comparable manner.

Engineering Principles

This demonstration depicts the importance of rigging angles during crane lift operations on a construction site. By varying the connection points and/or sling length, students are able to calculate the predicted sling tension and analyze the best combination of connection points and sling lengths to successfully complete the critical lift. The demonstration takes 15-20 minutes to complete in class.

A sling's working load limit (WLL) is based on a crane lift performed at a straight (90°) angle. The forces in rigging (sling, chain, wire rope, webbing, shackles, etc.) increase substantially as the angle formed by the sling leg and the horizontal datum becomes smaller. Table 1 shows the increased force applied to the rigging (F_{sling}) when the rigging angle is reduced even though beam weight is constant (W_{beam}). Figure 1 shows a visual representation of Table 1 and highlights the significant increase of the force carried by the sling as the sling angle becomes smaller (note the reversal of the horizontal axis scale). The weight of the beam is assumed to be evenly distributed to each sling. Figure 2 shows a complete system with the main components being the spring scales, metal chains, links, screw eyes, 2x6 wooden "critical pick", and 10-pound weight to amplify the load. The key engineering principle with this demonstration is related to an understanding of statics. Students must comprehend that decreasing the angle creates a horizontal force component (x component) that in turn increases the tension in the rigging as shown in Figure 3.

Table 1. Sling Force as a Percentage of Half the Beam Weight

½ W_{beam} (lb)	**Angle (θ)**	**F_{sling} (lb)**	**% of ½ W_{beam}**
1.00	90 deg	1.00	100%
1.00	60 deg	1.15	115%
1.00	45 deg	1.41	141%
1.00	30 deg	2.00	200%
1.00	20 deg	2.92	292%
1.00	10 deg	5.76	576%

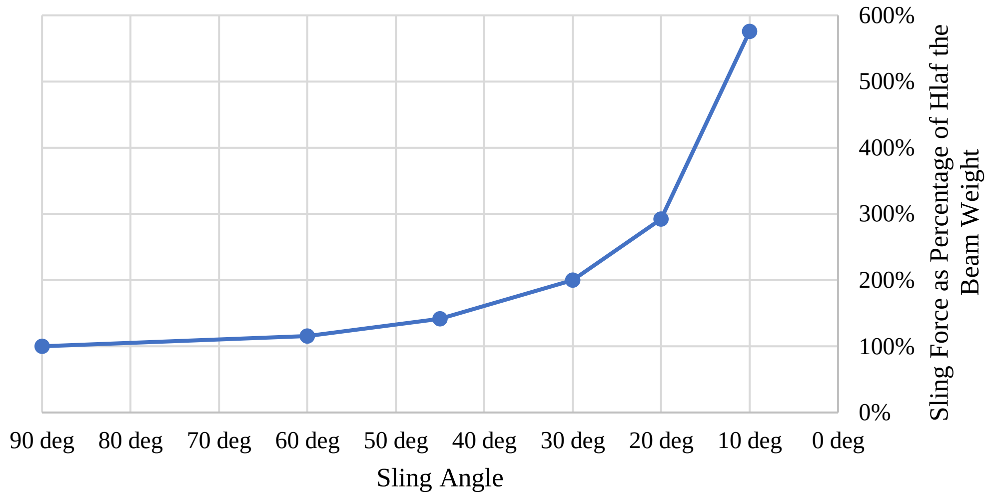

Figure 1. Sling Force – Sling Angle Relationship as a Percentage of Half the Beam Weight

Figure 2. Critical Pick Demo

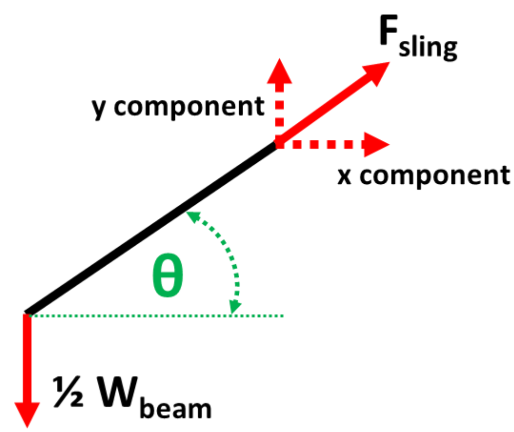

Figure 3. Forces Acting on Critical Pick

Building the Demonstration

Build and verify your model using the material list in Table 2 and the dimensions in Figure 4. After cutting the 2x6 to 3-foot length, install the screw eyes along the centerline at the distances shown in Figure 4. The imperfect connections at the screw eyes and the variation in the spring scale as a load is applied make predicting the exact angle difficult. The placement of the screw eyes and the length of the chain are intended to replicate scenarios with the connections at 30°, 45°, and 60°. To ensure the spring scale hook remains centered during the lift (and creates an equal force in both scales), use wire or duct tape to prevent its movement.

Table 2. Crane Rigging Demo Required Items

Item	Qty	Cost	Description/Details
3/16 in chain	2x 2-ft sections	$8 ($2 per foot)	These represent the sling for the lift.
Twist link chain	1 foot	$1.50	This is smaller than the straight chain and is used to connect the weight plate to the spring link on the lower screw eye.
2x6 x 3 feet	1	$6	Most pieces come in 8-foot sections. Once cut to size, this is the critical pick.
3/4 in x 3 in screw eyes	7	$5 ($1.25 per 2 pack)	These are used for the rigging connection points on top and the load connection point on the bottom. 130-pound capacity.
3/16 in quick link	1	$2.25	This locks and hold the two spring scales along each chain. It also is used for the top spring scale to analyze the total weight of the lift. 450-pound capacity.
3 in spring link	3	$3 ($1 each)	These are used for quick connections of the chains to the screw eyes and the weight to the load screw eye. 150-pound capacity.
20-lb spring scale	3	$34.50 ($11.50 each)	These scales measure the weight of the lift and along each chain.
10-lb weight plate	1	$11	This increases the weight of the critical lift.
Crane Demo	1	Total Cost = $71.25	Based on prices in this table Total estimated build time: 60 minutes

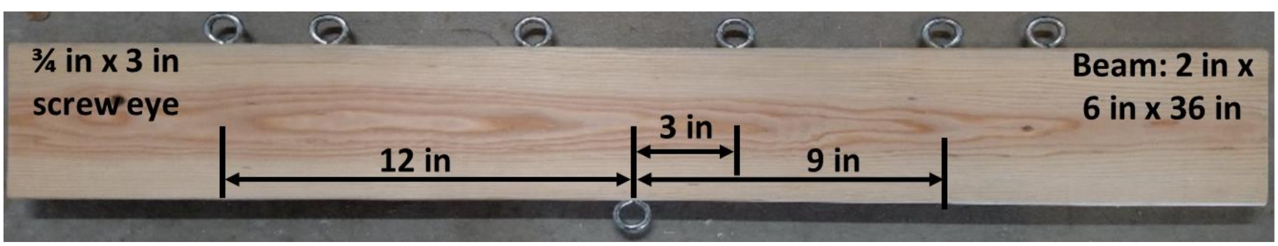

Figure 4. Critical Pick Building Dimensions

Classroom Implementation

Display the 2x6 beam at the front of the class, but do not have anything connected to it. Let the students build their answer as they work to solve the problem. Bruhl et al[3] and Bruhl, Hanus, and Klosky[4] discuss the importance of developing engineering judgement and using self-discovery in the classroom. This demo can function as an IBLA to help develop engineering judgement if presented beyond the traditional instructor guided demo method. The scenario is as follows; the students are new project engineers on a job site. The project manager is out sick and leaves them in charge for the day. The easy day gets complicated when the crane operator insists on executing the project's critical crane lift on short notice due to impending weather. However, due to the unscheduled nature of the request, the project engineer is unsure if the slings on hand are capable of safely executing the lift. The project engineer tells the crew that the crane lift will happen in 15 minutes, which buys some time. The project engineer runs back to the trailer to calculate how to use the two (2) 11-ton slings to lift the 15 to 16-ton object worth $2 million. The object has only three "picking eyes" on each side to maintain its balance. The crane operator recommended the connections farthest from the center to help with stability.

The total weight of the demonstration should be 15-16 pounds. Explain to the students that they could use trigonometry to calculate the required sling lengths given the fixed connection points and desired connection angles. However, the variation in this model makes it difficult to perfectly replicate such detailed specifics. As the spring scales extend to register the weight, they alter the length of the cable and therefore the angle at the connection and the resulting tension within the cable. Calculations that include spring deflection yield the following cable length *approximations* to get the desired connection angles: 30° (no chain, but chain must hang from connection for consistent weight) as shown in Figure 5, 45° (3 links) as shown in Figure 6, and 60° (9 links). Table 3 highlights the actual vs. expected angles. These values only apply when analyzing the pick eye that is 12 inches from center.

Figure 5. 30 Degree Connection Angle

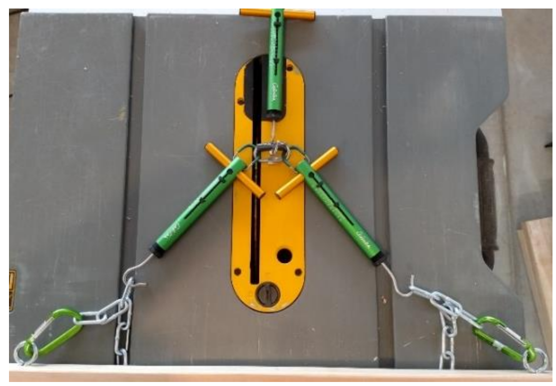

Figure 6. 45 Degree Connection Angle

Table 3. Actual vs. Expected Angles at Pick Eye 12 Inches from Center

L_{sling}	Expected Angle (θ)	F_{sling} (lb)	½ W_{beam} (lb)	Test Angle (θ)
No chains	30.0 deg	15.0	7.5	30.0 deg
3 links	45.0 deg	11.8	7.5	39.5 deg
9 links	60.0 deg	9.0	7.5	56.4 deg

As shown above, the angles are not always perfect matches, but are close enough to effectively highlight the amplification of forces in the sling based on rigging angles. Notice the applied force on the sling exceeds its 11lb capacity at 45 degrees!

Student Assessments

The demo was shown to the first group of students (n=32) on the on the 30th lesson (of 30) of the course of term 19-1 (Fall 2018). The demo was shown to the second group of students (n=28) on the 2nd lesson (of 30) of the course of term 19-2 (Spring 2019) after completing a lesson on forces and moments as related to 2D equilibrium. While the numbers are not enough to necessarily prove statistical significance, the online, anonymous survey's results coincide with expected results based on the point in the course when the demonstration was shown. The students in term 19-1 had participated in the entire course and seen the importance and continued application of 2D equilibrium throughout the entirety of the course. The students in term 19-2 were only on their second lesson and had not seen the continued application of these principles applied through a semester's worth of learning.

Table 4. Crane Rigging Demo Survey Results

QUESTION	19-1 (n=32)	19-2 (n=28)
Q1. The demonstration and hands-on activity helped me understand the engineering concepts.	4.69	4.39
Q2. The demonstration and hands-on-activity stimulated my thinking.	4.38	4.36
Q3. I understand the engineering concepts (statics and equilibrium) better having seen this demonstration.	4.38	4.07
Q4. The hands-on activity was effective for learning these engineering concepts (statics and equilibrium).	4.38	4.04
Q5. Seeing this demonstration early in the course (would have)* helped me understand the concepts better. *Only for 19-1	4.28	4.21
Q6. Demonstrations, like this, help me feel more confident with the material.	4.44	4.29
5 = Strongly Agree, 4 = Agree, 3 = Neutral, 2 = Disagree, 1 = Strongly Disagree		

This data highlights similarities in that the demonstration and hands on activity stimulated the students' thinking to almost the same degree whether on lesson two or lesson thirty. Both semesters also agreed that seeing the demonstration helped them understand the concepts of statics and equilibrium better. For questions one and two, every student in both 19-1 and 19-2, agreed or strongly agreed with each question.

The data also highlights areas of conflict, which arguably correlate to the time in the course with which the demonstration was presented. The largest variation in score (0.34) between the two groups was with question four. Again, the students in 19-1 with a complete semester tended to agree more strongly with the effectiveness of the demo, compared to the students in 19-2. The author believes the students in 19-2 did not have enough exposure to statics and equilibrium, given that lesson two was their first class discussing the topic, to fully understand whether or not the demonstration was a good example of statics and equilibrium. They may not perceive the value in the activity due to their lack of experience with the topic, but they may actually learn it better because of this experience that challenged them early in the learning process. Further assessment of this demo to the students in 19-2 at the end of the semester could help support this hypothesis.

Additional Application

This demonstration makes for a good discussion on Factors of Safety. Ask the students about their tolerance for safety and how close to the sling's capacity would they execute the lift. Did they inspect the slings? A sling's rating is accurate when it leaves the manufacturer, but how have they been maintained? Are they rusty, worn, or frayed? This is a great opportunity to have different examples (both type and quality) of slings to pass around the class and have students assess a sling's current state relative to its specified WLL. These questions lead into real world examples and ways they would handle the situation if they believe the pick should not happen. Showing PowerPoint slides with pictures of failed crane lifts during this conversation helps them gain a better visual understanding of the consequences of failure in regards to crane operations.

Conclusion

While it is easy to get lost in technological advances that make relaying information to students more efficient, it cannot be assumed that being easier to relay the information equates to being easier to retain, comprehend, and synthesize the information for future application. Straightforward IBLAs/demonstrations like this crane rigging demo help stimulate student learning, get them more involved in the classroom, and aid in their perception of material comprehension. This demo is part of a "How-to Guide" with 70 engineering demos (created primarily by many individuals through the Hands On Mechanics effort[1 5 6]) as a consolidated effort created by the author. The entirety of this work is available for free at ASEE's website: www.handsonmechanics.org.

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