Online Grading in Structural Engineering

Terence A. Weigel

Abstract

The author has developed software that assists with grading in CEE 422, Fundamentals of Steel Design, taught at the University of Louisville. The software is able to grade three of the four components used to assess proficiency in CEE 422: in-class problems solved by teams of students; out-of-class problems (homework) solved individually; and in-class quizzes taken individually. The fourth grading component, project design and presentation, are graded manually. This paper focuses on grading of the homework component.

To have his / her homework graded, a student accesses the software system from any Internet-connected computer; however, grading for in-class problems and quizzes is restricted to access through computers located in the room in which the class is taught. Some of the features of the current version of the system are:

- Individualized data for homework / in-class problems;
- Immediate feedback on correct / incorrect answers;
- Levels of difficulty for homework problems;
- Partial credit for homework / in-class problems;
- Help system;
- Penalty for multiple attempts;
- Beginning and ending time for each problem / quiz;
- Automated bookkeeping.

Introduction

By its nature, structural analysis / design are tasks that involve solving problems that require many numerical calculations. For example, designing a wide-flange column typically involves overall analysis of the structure, evaluation of applicable load combinations to obtain critical column loads, evaluation of slenderness ratios, determination of design capacities of various wide-flange sections, and selecting the “best” section to resist the critical loads. It follows naturally then that courses in structural engineering curricula require aspiring engineers to achieve proficiency with these tasks. Most courses in structural engineering curricula incorporate problem solving as a significant component of the assessment process that determines a student’s final grade. In many cases these problems are out-of-class “homework” assignments, but other forms are also used.

For most students aspiring to the structural engineering profession, mastery of curricular technical material increases directly with the number of problems he or she solves. Exposure to problem solving can be controlled to an extent, through the number of such assignments given. However, there is a limit to what can be required – for a given class size, an instructor can do only so much grading, even with help from a student assistant. A grading scheme that permits an instructor to assign more problems, not significantly increase (or even reduce) the grading load and still check assignments in detail, would significantly enhance the efficacy of the educational process.

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This paper describes a software system (hereafter simply referred to as “the grader”) under development by the author, which has the potential to achieve most of these goals. The system is offered online, using the Internet as the interface between students and the grader. It is worth noting that even though the grading system is presented in the context of a single structural design course, it has application in any technical curriculum, or, for that matter, in any instructional setting in which numerical results are important. It is even possible that the schema could be extended to courses and/or problems in a non-numerical domain.

Although the grader is capable of grading quizzes, the focus of this paper is its capabilities for assessing homework, as it is currently being used in CEE 422, Fundamentals of Steel Design, taught at the University of Louisville. Mechanics of the actual grading is accomplished using C++ based software and the Internet implementation uses a dedicated server with PHP and JavaScript for the scripting languages and MYSQL as the database management system.

The current configuration of the homework grader has these characteristics:

- Individualized problems - each student is given a unique set of data for his / her problem;
- Immediate feedback on correct / incorrect answers;
- The ability of the instructor to specify levels of difficulty for a problem - the same problem can be given with varying levels of difficulty. For example, at the lowest level of difficulty, the student may be “guided” to the final answer by requiring all intermediate answers (thereby outlining the required calculation sequence) and given generous help for incorrect values, while the highest level of difficulty might offer little help and grade only the final answer;
- Partial credit - this is achieved (where possible) by reworking subsequent parts of the problem using incorrect intermediate answers submitted by the student;
- A Help system available for those parts of the problem where answers are incorrect. Varying levels or help may be specified;
- The capability to “penalize” students for multiple tries and even to reissue new data after a certain number of tries. It is also possible to configure the system to impose no such penalties;
- The ability for the instructor to set a beginning and ending time during which students can work on a given problem;
- Full bookkeeping automation, including assigning of grades and partial credit, recording of grades in a database, notification (via email) to the student of his / her grade and notification (via email) to the instructor of a summary of all grades on a given homework. The only actions required by the instructor are selection of problems to be assigned, setting times when the problems are available, assignment of difficulty levels and Help levels, point value to be given for partial credit, and assignment of penalties for multiple attempts.

Existing Automated Grading Systems

Research with on-line assessment has been undertaken at several universities [Crepeau, 3; Jung, 4; Murden, 5; Weigel, 6], and there are several available commercial systems for on-line / distance learning that provide an assessment component. These include: Blackboard (www.blackboard.com), InternetQuiz (www.familyeducation.com), Quizzer (www.pmachine.com/quizzer), WebAssign (www.webassign.com) and WebCT (www.webct.com). Apropos to this paper, AISC [AISC, 1] offers a system of web-based quizzes comprised of multiple choice and essay questions. Grading of the multiple choice questions is automated, but the essay question must be graded manually.

Of the existing on-line assessment systems, the most widely used testing form appears to be multiple choice. Other forms such as true/false, matching, ordering, and fill-in-the-blank are also offered however. WebAssign supports problems with randomly generated data, and problems having answers in symbolic form. WebCT reportedly offers the capability to grade essay questions.
CEE 422 – Fundamentals of Steel Design

CEE 422, Fundamentals of Steel Design, is taught once a year to fourth-year students in the Department of Civil and Environmental Engineering at the University of Louisville. Load and Resistance Factor Design (LRFD) [AISC, 2] methodology is taught. In most cases, it is the student’s first exposure to structural design, and in this sense is a critical course because it establishes a basis for the student’s successful performance in other design courses. More information on all aspects of CEE 422 can be found on the following web site:

www.louisville.edu/speed/civil/courses/taweig01/cee422-SteelDesign/cee422.html

The on-line grading methodology has been used in CEE 422 for about eight years and early experiences with the methodology are described in a paper by Weigel [2001,1]. The system has matured significantly since that paper was written.

Grader Operation

A typical problem (CD-0001) given in CEE 422 is shown in Figure 1. The student accesses the problem by going to the course website and entering his or her student number and password. The grader then displays the problem, exactly as it appears in Figure 1.

Problem CD-0001 requires that a wide-flange column be designed. The student is also required to provide some additional information about the selected column, in this case, the governing axial load (\( P_u \) - based on the controlling ASCE-7 load combination), the slenderness parameter (\( \lambda_c \)), the critical axial stress for the column (\( F_{cr} \)), and the column capacity (\( \phi_c P_n \)).

An individual solves his or her respective problem as he or she sees fit (calculator, pencil and paper, spreadsheet or other software), enters the answers in the fields provided, and submits the answers for grading.

The answers submitted by the student are collected by a PHP / JavaScript script (which uses an HTML FORM object) and submitted to a C++ program for grading. By using a C++ program to check answers, the grader is able to give partial credit and display customized help. When the grader detects an incorrect answer, it reworks the remainder of the problem based on that incorrect result. Student answers subsequent to the incorrect value are compared to the recomputed values. The system is capable of managing multiple incorrect answers.

The partial credit system results in three classifications of answers:

- Apparently unconditionally correct (✓ - green check)
- Apparently conditionally correct (✔ - amber check) - these answers appear to be correct, when evaluated based on previous incorrect answer(s)
- Apparently unconditionally incorrect (✗ - red X) - these answers appear to be incorrect, even when evaluated based on previous incorrect answer(s)

Results from a student submission are shown in Figure 2. In this case the student has computed \( P_u \) correctly, but has not selected the lightest available section (W14X90). An incorrect choice for the lightest section makes all other answers (which depend on the properties of the selected section) incorrect. However, the student has apparently computed these values correctly, when the properties of the selected section (W12X96) are used. For these answers the student is given 80% of the possible credit.
CD-0001 Design of a Wide-Flange Column

Use the LRFD specification to select the lightest W section that can adequately support the indicated compressive loads. Make your selection only from the sections listed in Table 4-2 of Part 4 of the Manual of Steel Construction. Combine the loads to determine the critical value from the ASCE-7 load combinations.

At its base the column is fixed about both axes, and at its top it is pinned about both axes. In addition, it has a weak axis brace located as indicated above the base of the column. The strong axis is unbraced full length. Use the appropriate recommended design values for $k$ found in Table C-C2.1 of the Commentary to the LRFD Specification.

Do your calculations and report your answers with at least three decimal digits accuracy. Report your answers in the specified units, but do not actually include units with the values you enter (that is, enter numerical values only). Submit your answers in units of kips and inches.

<table>
<thead>
<tr>
<th>Problem Data Assignment Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>A992</td>
</tr>
</tbody>
</table>
Figure 1 - Column Design Problem

Wide flange you selected

<table>
<thead>
<tr>
<th>Wide Flange Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>W14X808</td>
</tr>
<tr>
<td>W14X730</td>
</tr>
<tr>
<td>W14X665</td>
</tr>
<tr>
<td>W14X605</td>
</tr>
<tr>
<td>W14X550</td>
</tr>
</tbody>
</table>

Controlling axial load ($P_a$)

<table>
<thead>
<tr>
<th>$P_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

Section area

<table>
<thead>
<tr>
<th>Section Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

Controlling slenderness ratio

<table>
<thead>
<tr>
<th>$\lambda_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

$F_{cr}$

<table>
<thead>
<tr>
<th>$F_{cr}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

$\phi P_n$

<table>
<thead>
<tr>
<th>$\phi P_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

Submit answers for grading
.points given for getting the lightest section.

<table>
<thead>
<tr>
<th>Item</th>
<th>Your Answer</th>
<th>Grade</th>
<th>Help / Hints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selected Wide-flange</td>
<td>W12X96</td>
<td>✗ (0.8)</td>
<td>Your section is acceptable but there is one section lighter acceptable section.</td>
</tr>
<tr>
<td>$P_u$</td>
<td>1092</td>
<td>✓ (1.0)</td>
<td></td>
</tr>
<tr>
<td>Section Area</td>
<td>28.2</td>
<td>✓ (0.8)</td>
<td>This is area of the wide-flange section you selected.</td>
</tr>
<tr>
<td>Controlling Slenderness Ratio</td>
<td>23.3</td>
<td>✓ (0.8)</td>
<td>This value will be the larger slenderness ratio about the x and y axes, respectively. For the y axis, you must determine whether the upper or lower part of the column has the larger slenderness ratio.</td>
</tr>
<tr>
<td>$\lambda_c$</td>
<td>0.380</td>
<td>✓ (0.8)</td>
<td>The equation for finding $\lambda_c$ is found in Section E2 of the LRFD Specification.</td>
</tr>
<tr>
<td>$F_{cr}$</td>
<td>48.05</td>
<td>✓ (0.8)</td>
<td>The equation for finding $F_{cr}$ is found in Section E2 of the LRFD Specification. If you have been assigned a steel with a yield stress of 36 or 50 ksi you may also use the design aids in the LRFD Appendices to get this value.</td>
</tr>
<tr>
<td>$\phi_cP_n$</td>
<td>1151.9</td>
<td>✓ (0.8)</td>
<td>The equation for finding the column capacity is found in Section E2 of the LRFD Specification.</td>
</tr>
</tbody>
</table>

Grade = 82.9
If you choose to try again your grade will be multiplied by 0.95.

**Figure 2 - Grader Response to Student Input**

**Grader Options**

The grader has several options that can be set by the instructor. These include:

- A penalty for multiple attempts on a problem
- Assignment of a new set of data after a specified number of attempts
- The time at which the problem becomes available for solution
- The time at which the problem is no longer available for solution
- Credit to be given for conditionally correct answers

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The author sets these options as follows. Assignments become available immediately after class concludes. It expires at 8 am on the day of the next class. CEE 422 normally meets from 8 to 8:50 MWF, so an assignment given starting at 9 am on Monday will expire at 8 am on the following Wednesday. The student is permitted three attempts with his or her initial set of data. The first attempt is worth 100%, the second attempt is worth 95% and the third attempt is worth 90% (in other words, there is a 5% penalty for each attempt after the first). After three attempts, the student is given a new set of data. The first attempt with this set of data is worth 95%, the second is worth 90%, and the third is worth 85%. Another attempt will result in the student being given a new set of data. The student may stop at any point he or she is satisfied with the grade achieved.

**Automation Features**

The grader has several features which automate tasks normally done manually by the instructor. Each time the student submits answers for grading, his or her score is entered into a database, the number of attempts on the problem is updated and the re-trial penalty is updated. In addition, the student is sent an email with his or her grade on that attempt. When an assignment expires, the system sends the instructor an email with summary of scores for all students on that assignment.

**Developing Problems**

When creating new problems for use by the grader, care must be used in several areas. First, it must be decided exactly what the problem is intended to illustrate, how to best accomplish this, how the new problem will fit with other problems assigned, and how the problem should be posed to make it practical and representative of similar problems found in the practice of structural engineering.

Next, procedures for generating data must be considered. Data cannot be truly random, because problems based on completely random data will frequently have absurd solutions or no solution. Data must be “randomly” drawn from carefully constrained ranges, selected to produce problems having reasonable and pedagogically effective results. Further, data generation must be such that each student is working a unique problem.

The author has automated the process of generating assignments in CEE 422. He has developed C++ software that does the following:

a) Generate a PHP script that displays individual problems. The PHP script checks the MYSQL database to determine if the student has attempted this problem before, or if the student should be given a new set of data. If it is the first attempt on a problem, the script enters the necessary information in the database, generates HTML statements to display the problem (including a figure if necessary) and then calls a C++ that generates the data table in the problem statement. If it is not the first attempt on this problem and if new data is not to be assigned, the PHP script updates the number of attempts for this student and this problem in the database and displays the problem;

b) Generate a second PHP script that is responsible for having the answers graded. This script calls a second C++ program that checks answers, assigns credit, prints help / hints, and assigns a score for this attempt. The output of this PHP script / C++ program is shown in Figure 2. The PHP script records the grade determined by the C++ program and displays the information shown in Figure 2.
Assessment of the Current Version of the Grader

Advantages

From the instructor’s point of view, the CEE 422 grading system offers these advantages over traditional grading schemes:

a) Assignments completed on time – when an assignment is posted, it is done so with an opening time and a closing time. Work on the assignment cannot begin before the opening time; and if a student attempts to submit an assignment after the closing time, the grader will refuse to accept it. Moreover, there is apparently something psychologically compelling about a computer-imposed deadline that is honored. Since implementing this system, the author has had very few “excuses” as to why assignments could not be completed to meet the assigned deadline;

b) More assignments can be given and graded. Since the computer does most of the grading, significant time commitment is shifted from the instructor;

c) Improved likelihood that each student does his / her own work. This is evidenced by the fact that the author gets many more questions related to homework and reading material than he did before on-line grader was implemented;

d) While no formal study has been done, the author believes that students develop better problem-solving skills with the grader. Whether this leads to better understanding of the material is a different question that also requires a formal study to answer.

From the student’s point of view, the positive features of the system are:

a) Substantial, justifiable partial credit;

b) The ability to rework a problem as many times as desired to achieve a satisfactory grade;

c) Immediate feedback on which parts of the problem they have worked correctly and which parts they have not done correctly;

d) Help available for those parts of the problem where their answers are incorrect;

e) A belief that they have a better understanding of the course material.

Improvements

In its current state of development the grader is effective and has potential to significantly improve the learning process in a course such as CEE 422. However, areas exist where improvement can be made. Some of the more important issues requiring attention are:

a) Guided Solutions – One criticism that has been leveled at this type of grading system is that it artificially guides students toward a solution. Asking the student for all the intermediate results necessary to obtain the final answer is not how problems are posed in the practice of structural engineering. Furthermore, there is a risk that the student may look at the problem as a series of unrelated numbers and fail to make the connection between the process and the result. If this were to occur it would be counterproductive. However, the flexibility of on-line grader readily offers an answer to this criticism - by giving a mix of problems requiring all intermediate results, only a few intermediate results, and some problems requesting only the final answer, the effects of “guided solutions” can be minimized;

b) Inability to Detect Alternate, Acceptable Solutions – Design is a process wherein there are many acceptable solutions. In its current form the grader is not good at evaluating alternatives.
However, the author is working on schemes that would allow the grader to assess alternate solutions;

c) Inadequate Library of Problems – The author currently has a total library of 35 problems, split roughly over approximately 16 topic areas covered in CEE 422. This library of problems is much too small. Related to this issue is the fact that each student receives the same problem, albeit with different data. A scheme that would permit each student to be assigned a different problem but in the same topic area (that is, each student would have a column design problem, but not the same column design problem) would further assure that individuals do their own work;

d) Emasculation through Programmed Solutions - Any system of this type is vulnerable to defeat through software specifically developed to solve the assigned problems. While it is probably not possible to eliminate this threat, the author is working on schemes to reduce risks posed by such programs.

**Summary and Conclusions**

Initial results with the on-line grading system implemented in CEE 422 show promise. The author continues to work to improve the system where needed. He considers this to be only the first step toward improving comprehension of the material being taught. Improved comprehension will allow prospective structural engineers to make well informed and well thought out decisions, which, after all, is the real goal of instruction. Plans include development and testing in courses other than CEE 422, testing in courses other than those taught by the author, and formalized studies to determine the efficacy of the grader.

**References**


**Terence A. Weigel**

Terry Weigel has been a member of the civil engineering faculty of the University of Louisville since 1977. He is a registered civil and structural engineer with an interest in masonry, seismic analysis and design, structural applications involving computers and, in particular, on-line grading. Terry currently has NSF-funded research underway to evaluate the impact on infrastructure of the 2003 power outage. He is a member of ASEE, The Masonry Society (TMS), NEHRP sub-committee TS5 (Masonry Structures) and TS-10 (Low-Rise Structures), and several committees of the Masonry Standards Joint Committee (MSJC).