# SIMULATION, VISUALIZATION AND SELF-ASSESSMENT ENHANCED ENGINEERING EDUCATION: THE STIFFNESS MATRIX METHOD MODULE FOR STRUCTURAL ANALYSIS COURSE

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### Abstract

Existing macromedia FLASH software, which has extensive and exciting simulation and visualization capabilities, are utilized to develop the “Stiffness Matrix Method” (SMM) module, which is one of the topics covered in a Structural Analysis I course, offered at the junior level at Old Dominion University. The developed software (under FLASH environment), including tutorials to explain all necessary theoretical background, formulas, step-by-step computerized procedures, and numerical examples, is presented in a simple user-friendly, visual, and interactive environment to enhance students’ learning. Due to numerous graphical visualization and simulation examples embedded in the module, it is expected that the developed software package will be a valuable tool for both students and instructors. Furthermore, as a bi-product, the developed software package can also be used as a “research tool,” in addition to its intended application to engineering education.

### Introduction

The Stiffness Method (SMM) module is being developed for the CEE 310 Structural Analysis [1-3], a junior-level course required for the BS in Civil Engineering program. The module will be implemented and assessed during the Spring 2008 semester. The module development and implementation is part of an ongoing transformation of undergraduate education at Old Dominion University, which seeks to integrate technology-based student learning tools in a number of undergraduate engineering courses. Twelve faculty members from three engineering departments are participating in a NSF supported project that uses simulation and visualization to enhance quality of engineering education. The motivation for this transformation comes from the fact that students in general but engineering students in particular have much greater familiarity and inclination to use computers, Internet and videogames as compared to their counterparts a generation ago. As a result, current generation students are more inclined to learn visually. In order to accommodate these computer savvy and visual learners it is important to develop web-tools for undergraduate engineering education that are simulation and visualization based, and that can be used in anytime-anywhere mode.

The SMM module includes brief reading sections on the various components of the SMM process and the theoretical backgrounds behind the developed formulas adopted for calculations. The reading sections are followed by an interactive application unit, which includes the computation of the structural responses (such as nodal displacements, member-end-actions and support reactions), visualization and animation (such as plots of un-deformed and deformed structures) [4], and highlighted observations to enhance student learning. Students are then assigned exercises, which require both hand calculations and the use of the interactive unit. Figure 1 shows an example of interactive (and visual) application unit for the “pre-processing” phase (to create the structural model using the developed SMM module). This pre-processing phase is followed by structural “analysis/computation” (to calculate the structural responses) and the “post-processing” (to display the structural responses in the “graphical” forms) phases (see Figure 1).

The objectives and the outcomes of the module and their mapping are shown in Table 1. The table also includes the level of achievement

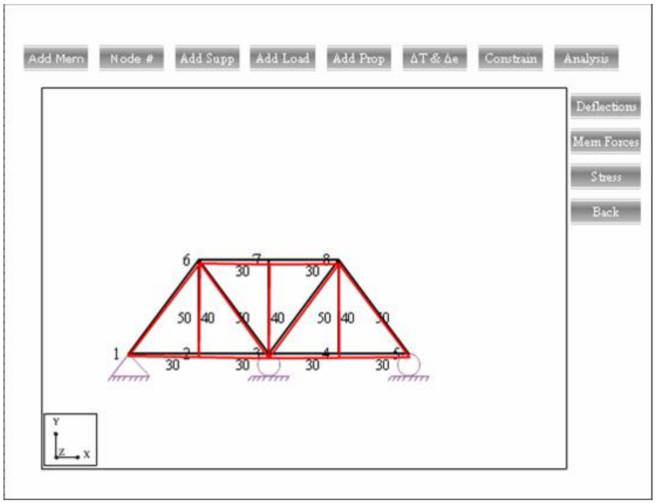



Figure 1: Deflected Shape for Support "Settlements" Example.

for each outcome targets in relation to Bloom's taxonomy [5].

Figure 2 displays the layout of the module's structure. It also shows how the various components of the module contribute to the outcomes as well as the practicality, hierarchical, connectivity and the viscompana characteristics.

A few definitions associated with the above Figure 2 are given below:

Viscompana: Is an abbreviation for <u>vis</u>ualization, <u>comp</u>utation and <u>ana</u>lysis

Hierarchical: Refers to a module characteristics that signifies a hierarchical, from simple to more complex levels of analysis, arrangement of subject matter in the module.

Connectivity: Or interconnectivity refers to a module characteristics that relates or connects a subject matter presented before or after the module with subject matter presented in the module.

Practicality: Refers to practical applications of the module in the real-life context.

Table 1: Objectives and Outcomes of the Developed SMM Module.

| Objectives and Outcomes | Bloom's Level of Achievement | Objective 1: Students are able to compute/verify the structural responses (using either SMM and/or other methods learned from CEE 310 course) | Objective 2: Students can conduct "what if" studies, and are familiar with modern computer software/hardware technology |
|---|---|---|---|
| Outcome 1: Students can create the structural model/problem (in a user-friendly, interactive, visual environment) | Knowledge | × | × |
| Outcome 2: Students can compute "element" stiffness matrices, in both local & global references | Comprehension (level 1) | × | |
| Outcome 3: Students can "assemble" the "global" stiffness matrix, load vector and impose proper "boundary conditions" | Comprehension (level 2) | × | |
| Outcome 4: Students can compute and visualize the structural responses | Application/Analysis | × | × |
| Outcome 5: Students can conduct "what if" studies, interpreting the results and identify/fix potential errors made in earlier phase (such as creating an unstable/improper structural model) | Analysis/Synthesis | × | × |

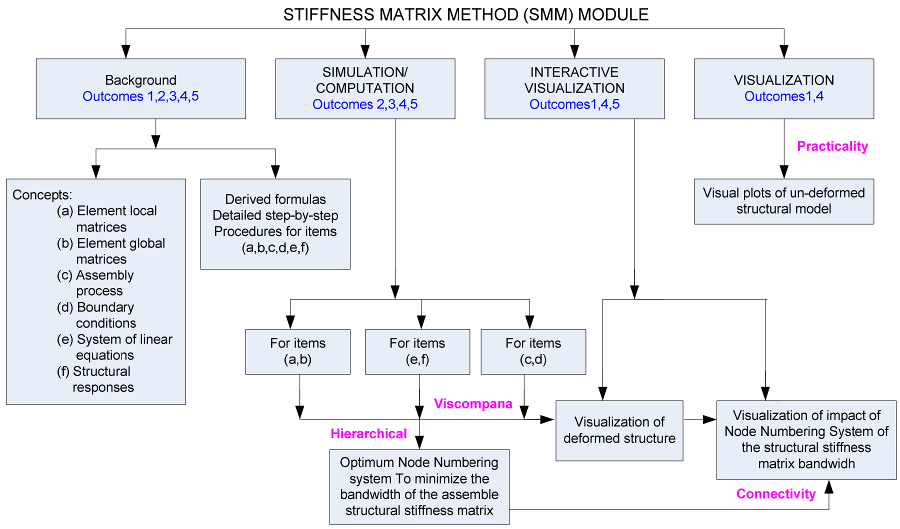



Figure 2: Layout of Stiffness Matrix Method (SMM) Module.

The web-based module will be assessed by comparing two sets of students, one who have access to the module and have used it during the course. This group is designated as the "experimental" group. The other group, known as the "control" group, will not have access to the module, and group's learning will be based only on conventional classroom teaching. Both groups will be tested using a quiz or a test administered during the course. The "control" group was tested during Spring 2007 course offering. The "experimental" group will be tested during Spring 2008 semester. A comparison and a statistical analysis of test results will be used to determine the efficiency of module for student learning enhancement. These results will be reported in a paper at a future date.

The comparison of pre-module and post-module test results will demonstrate how successful the module is. The assessment rubric shown in Table 2 will be used to prepare and grade these tests. In addition, student and instructor surveys will be conducted.

## Theoretical Background for the Stiffness Matrix Method

The entire Stiffness Matrix Method (SMM) will involve with the following major components (also refer to Figure 2):

(a) Element local matrices
(b) Element global matrices
(c) Assembly process
(d) Boundary conditions
(e) Solution of system of linear equations
(f) Structural responses

Details of the above key components has been explained and presented in the ODU website www.lions.odu.edu/~amoha006 (Then click on the theoretical development module). More advanced treatments of the above item (e) can be found in Refs. [6-8].

***Example***

Indeterminate Truss with Support Settlements (see Figure 1)
This example is pulled out from Example 7. (See www.lions.odu.edu/~amoha006, theoretical development module).

Several examples and theoretical developments presented on the above ODU website have been extracted from Refs. [1-3, 9-11].

Table 2: Assessment Rubric for the Stiffness Matrix Method (SMM) Module.

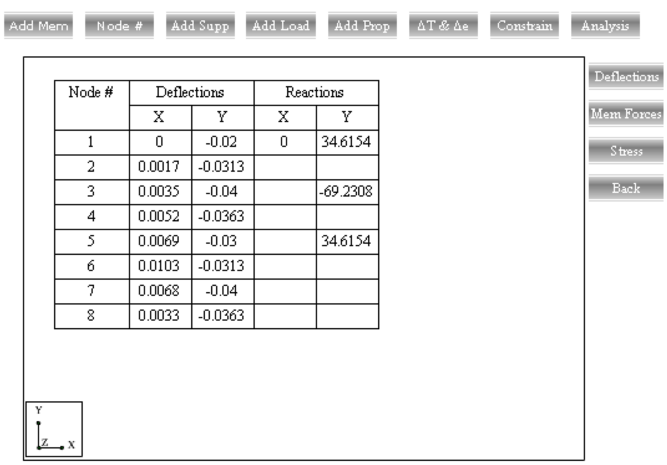
| Out-come | Unacceptable | Marginal | Acceptable | Excellent |
|---|---|---|---|---|
| 1 | Little/no knowledge of what data is required to create a structural model/problem. | Can identify some data required to create a structural model. | Can identify most data required, but have difficulty to follow interactive instructions to (visually) create a structural model. | Can identify all data required and to visually/interactively create a structural model. |
| 2 | Inadequate ability to identify the degree-of-freedom (dof), size and rotational matrices associated with a particular truss/beam/frame element | Know to identify the dof and size of element matrices, but can't compute numerical values of element stiffness matrix in local references | Can compute the element stiffness matrix in local references. | Know to transform element stiffness matrix from local to global references. |
| 3 | Inadequate ability to determine the locations of element stiffness within the "structural" stiffness matrix. Also does NOT know how to impose "boundary conditions" | Know to place the locations of element stiffness matrices in a structural stiffness matrix. However, still confuse to handle "over-lap" terms. | Know how to "assemble" the structural stiffness matrix. Still have some difficulty to impose "boundary conditions". | Completely understand the assembly process, including properly imposed "boundary conditions". |
| 4 | Can't recognize the roles of linear equation solver (to solve for nodal displacements). Have no ideas to compute member-end-actions, support reactions. Have no abilities to interpret the obtained results. | Know to compute the nodal displacements, and member-end-actions. | Know to compute all structural responses. However, still have some difficulty to interpret the computed results. | Know to compute all structural responses, and have abilities to interpret the computed results. |
| 5 | Can't identify important parameters that have impacts on the structural responses. No abilities to apply the SMM software to conduct "what if" studies. Can't identify/fix errors made in preparing the structural model. | Can identify some important parameters for conducting "what if" studies. | Can identify most (or all) important parameters for "what if" studies. | Can conduct all "what if" studies, interpreting the computed results and be able to identify/fix potential errors made in earlier phase (such as preparing the input structural model). |

Compute the bar forces in this truss due to the following support movements.

$E=30x\ 10^3$ kips/in$^2$.
Support at joint 1 vertical displacement = 0.24 in. down.
Support at joint 3 vertical displacement = 0.48 in. down.

Support at joint 5 vertical displacement = 0.36 in. down.

All members have the same cross-sectional area (= 10in$^2$). The output results (nodal joint deflections and support reaction forces) are shown in Figure 3.




| Node # | Deflections | | Reactions | |
|---|---|---|---|---|
| | X | Y | X | Y |
| 1 | 0 | -0.02 | 0 | 34.6154 |
| 2 | 0.0017 | -0.0313 | | |
| 3 | 0.0035 | -0.04 | | -69.2308 |
| 4 | 0.0052 | -0.0363 | | |
| 5 | 0.0069 | -0.03 | | 34.6154 |
| 6 | 0.0103 | -0.0313 | | |
| 7 | 0.0068 | -0.04 | | |
| 8 | 0.0033 | -0.0363 | | |

Figure 3: Deflections and reactions for support "settlements" example.

### Students Self-Assessment

Self-Assessment module is a friendly module where students can assess their performance themselves. In this module separate set of questions were designed for 2-D truss, Beam and Frame problems. The student has choice to take the self-assessment test on 2-D truss; beam or frame problems. The results of the test are sent to the instructor and student via E-mail. The main advantage of this module is that the student has to answer intermediate questions. This force the student to solve manually the given problem and answer the intermediate questions. The grading policy adopted in this module is as follows, For each correct answer the student gets 100%, this is also true when the student answer is around ± 3% of the correct answer. And if the student answer is incorrect, then he/she gets 35% as partial credit. At the end the average score is calculated and sent as an email along with the student answers and correct answers. The grading policy of this module can be changed according to the instructor choice. This is very helpful module to instructors as there is no grading involved.

### Educational and Research Values of the Developed Software Package.

The developed user-friendly, interactive, visualized software package VIS_SA is based on the Stiffness Matrix Method (SMM) and took fully advantages of the highly visualized and menu-driven capabilities of Macromedia FLASH computer environments [4]. Both the educational and research values offered from this work can be summarized in the following paragraphs.

***Educational values.***

(a) Special efforts have been made to explain the theoretical (and all equations derived) in a simple manner, so that the students can read and understand the materials without (or with minimum) help from the instructor.

(b) By exploiting the graphical and menu-driven capabilities, provided by FLASH environment, students can easily learn how to use the developed, powerful VIS_SA software in just few minutes.

(c) For the specific SMM topic, not only students can get the final results (such as nodal displacement, support reactions, member-end-actions…) to compare with his/her own (hand-calculated) results, but he/she can also compare the intermediate results in order to understand where he/she has made errors. For other topics in the Structural

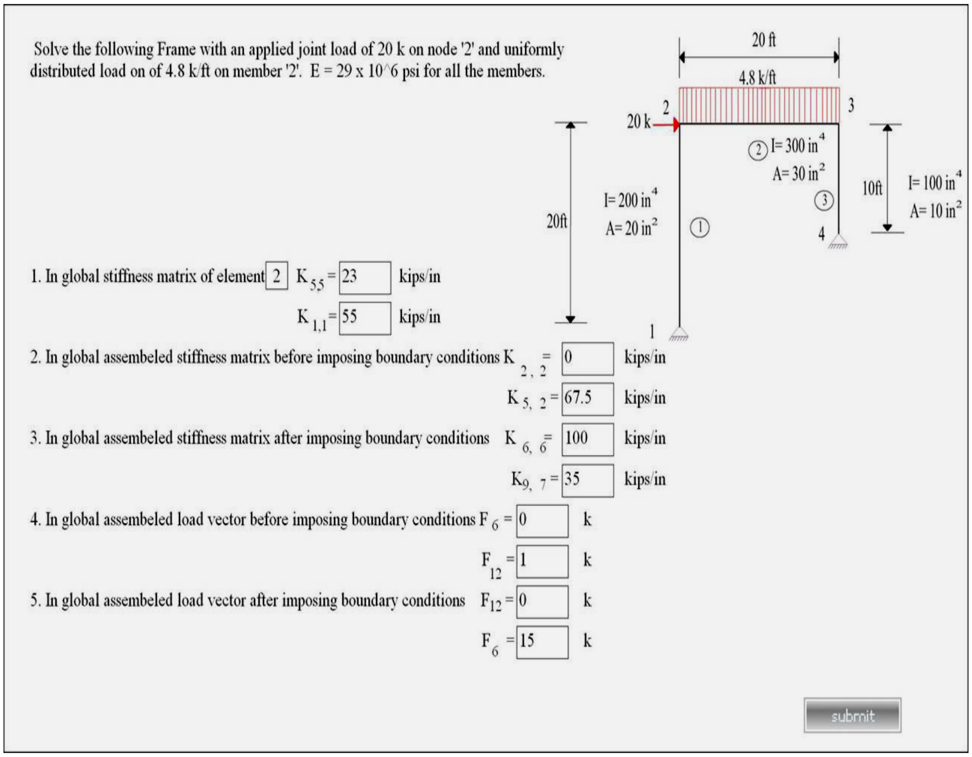



Figure 4: Self-Assessment Test: Frame problem
(Students will enter his/her answers in the textbox provided)

**Self Test CEE 310**

Name : Subhash

UIN : -1234567

Test Type : Frame

| Student Answers | Actual Answers | Score |
|---|---|---|
| 1. 23 | 1. 17.55208333 | 1. 35 |
| 2. 55 | 2. 3625 | 2. 35 |
| 3. 0 | 3. 2416.666667 | 3. 35 |
| 4. 67.5 | 4. 1.47664990e-13 | 4. 35 |
| 5. 100 | 5. 241666.6667 | 5. 35 |
| 6. 35 | 6. 1208.33 | 6. 35 |
| 7. 0 | 7. -1920 | 7. 35 |
| 8. 1 | 8. 0 | 8. 35 |
| 9. 0 | 9. 0 | 9. 100 |
| 10. 15 | 10. -1920 | 10. 35 |

Average Score : 41.5

Figure 5: Self-Assessment results and graded score in each student's email box.

Analysis 1 course (such as Virtual Work, Moment Area Theorems, Super-position methods for Indeterminate structures, Slope Deflection, Moment Distribution methods….), the developed VIS_SA code (for SMM topic) is still useful for verifying students final solutions (with VIS_SA's solutions)

(d) Students can quickly create the "extra" homework problems with known solutions (through VIS_SA) to further enhance their understanding on SMM (and other) topics. Different "what-if" scenarios (for analysis and optimal design) can be easily conducted. The students' learning enhancement can be made more fun through extensive usage of colorful, graphical and menu-driven capabilities provided by VIS_SA.

(e) The instructor using the software VIS_SA can create new homework assignments; regular tests and final examination in just few minutes. Hence, the problems of giving the same homeworks or tests every year (to save the instructor's preparation time!) and students' passing "old" homework or test to other students in subsequent years can be eliminated.

Through this work both the instructor and students are also given a set of clear explained lecture notes, presented in the attractive PowerPoint presentation and also made available on the internet website. Thus, students can freely download these instructional materials from the internet, and learn these topics in anytime and/or anywhere mode.

***Research values.***

The developed software package, VIS_SA, not only is user-friendly, interactive and highly visual, but it also has many advanced capabilities. Example #9 (see www.lions.odu.du/~amoha006, theoretical development module) clearly demonstrates VIS_SA's capabilities to handle quite general and complicated truss structures. More advanced graduate courses (such as Finite Element Analysis, Sparse High Performance Computing…), and newly created research algorithms can be quickly validated by the VIS_SA software on small to medium-scale tested examples, before conducting more testing on larger-scale problems.

## Conclusions and Future work.

In this paper, we have presented a general unified framework for developing simple, user-friendly interactive and highly visualized software VIS_SA for enhancing students' learning capabilities for the SMM module, which is one of the topics covered in the required Structural Analysis I course. The software leverages menu-driven and graphical capabilities offered by Macromedia FLASH computer environments to make the learning process more interesting. Numerous examples have been used to test different capabilities of the VIS_SA software. The VIS_SA software has significant potential for educational and research applications. Current efforts include the expansion of VIS_SA for 3-dimensional Truss, Beam and Frame for more extensive Structural engineering applications. Built-in "intelligent" learning process is being developed (such as printing some intermediate warning messages when potential errors are made by students) to help students to detect and correct the errors made, hence improving the learning process. Finally, intelligent questions and automatically graded student' answers for "assessment" purpose are also being developed, and will soon be reported in a separate paper.

## Acknowledgements.

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## Biographical Information

Ahmed Mohammed was born in Hyderabad, India on April 13, 1984. After my high school completion in summer of 1999 my father (who is in the same profession) advised me to work towards a degree in Civil Engineering. I followed my father footsteps and graduated from Osmania University, India in May 2005 with Bachelor of Science degree in Civil Engineering. Soon after my Bachelors Degree I started pursuing my Master of Science in Civil Engineering at Old Dominion University, USA in spring of 2006 and graduated in August 2007. Presently I am working as a structural engineer with Associated Consultants Inc in Portland, Oregon.

Subhash Chandra Bose Kadiam is a doctoral student in Civil and Environmental Engineering Department, Old Dominion University. He earned his Master of Technology in Civil Engineering at Acharya Nagarjuna University, India. His research interests include Cluster Parallel Computing, Finite Element Analysis etc.. As a Research Assistant at ODU, Subhash Kadiam developed "Flash based 3-D truss analysis".

Prof. Nguyen has been a Civil Engineering faculty member at ODU since 1985. His teaching (including his 3 textbooks, published in 1999, 2002 & 2006, respectively) & research activities (nearly $2 million in funded projects) in Numerical Methods, Large-scale Parallel Algorithms & Software developments, have led to several international, national and regional awards. As a "senior investigator" of the on-going NSF "educational grant", Dr. Nguyen's team has developed the Stiffness Matrix Method (SMM) modules on the internet for teaching purposes, which includes theoretical, computer simulation & computer self-assessment test (with automated grading test scores, delivered to students by Emails). More details can be found at http://www.lions.odu.edu/~amoha006.