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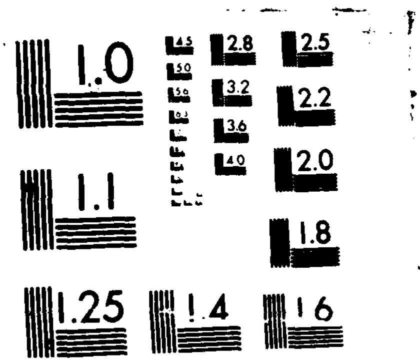


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# AIR COMMAND AND STAFF COLLEGE

## STUDENT REPORT

A DIFFERENT LOOK AT COMPUTERS IN ENGINEERING EDUCATION

MAJOR GREGORY E. RIGGS REPORT # 87-2115

*"insights into tomorrow"*

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This article traces the efforts of the Department of Civil Engineering at the United States Air Force Academy to improve its use of computers as educational tools. The efforts were motivated by changes to criteria of the Accreditation Board for Engineering and Technology and by the desire to produce better engineers. The results include in-class use of micro-computers for demonstration of parameter sensitivities as well as more conventional use for large project course work. The article presents both applications and philosophies of computer use.


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# PREFACE

This article was written for publication. Subject to clearance, the manuscript will be submitted for consideration to Engineering Education magazine, the journal of the American Society for Engineering Education. The length of the article was recommended by the magazine. Additionally, elements of style (such as using first person), the format (such as double spacing and placing all figures at the end of the article), and the footnoting and documentation system were all specified by the magazine.

United States universities or colleges are usually accredited as an institution to award general degrees, for example Bachelor of Arts or Bachelor of Science degrees. Many universities go further and receive additional, more stringent accreditation for specific programs within their curricula, for example Chemistry or Civil Engineering programs. The Accreditation Board for Engineering and Technology (ABET) is the organization charged with accrediting specific engineering programs.

In 1985, ABET made a subtle yet significant change to one of its accrediting criteria. The change drove universities throughout the nation to reconsider the role of computers in engineering education. This report outlines the efforts of the Department of Civil Engineering at the United States Air Force Academy to meet the challenges of the revised accreditation requirements.

# ABOUT THE AUTHOR

Major Greg Riggs served at both base and major command headquarters in the United States Air Force Security Service (now Electronic Security Command) from 1973 to 1977. He was a member of the United States Air Force Academy faculty from July 1977 to July 1986 with an interim AFIT assignment. As an Associate Professor of Civil Engineering, Major Riggs was responsible for developing and implementing the concepts for computer use presented in this article. He received a BSCE degree from the Air Force Academy, and an MS degree in civil engineering from the University of Illinois. He earned a PhD degree in civil engineering from the Oklahoma State University, performing research on aircraft structures for the Joint Technical Coordinating Group for Munitions Effectiveness. He is a registered Professional Engineer in Colorado.

Other articles by Major Riggs include:

"The Role of Computers in Engineering Design Education"
1985 ASEE Annual Conference Proceedings, "Partnership With Industry and Community"

"If The Computer Fits"
The Military Engineer, May/June 1986, Volume 78, Number 507

"Using Microcomputers to Improve Civil Engineering Education"
Proceedings on Microcomputers in Civil Engineering, 1985

"Using Microcomputers as a Classroom Teaching Tool"
Proceedings of the International Conference on Computers in Civil Engineering

"How to Incorporate Micros into a Civil Engineering Curriculum"
Proceedings of the International Conference on Computers in Civil Engineering

"Using Microcomputers to Multiply Learning"
1986 ASEE Annual Conference Proceedings, "Computer Aided Engineering"

"Analysis of Progressive Collapse of Aircraft Structures", coauthor
Joint Technical Coordinating Group for Munitions Effectiveness
61-JTCG/ME-84-2, 1 June 1984

"Final Interim Technical Report on USAFA Solar Test House Project"
Coauthored for the Engineering and Services Center, June 1980

# INTRODUCTION

This article explains how the Department of Civil Engineering at the United States Air Force Academy increased computer use in a four year undergraduate curriculum without sacrificing a thorough schooling in the engineering fundamentals. This past decade saw major advances in expanded computer use for engineering education, yet the advances were not without turbulence. I attended professional conferences across the country and talked to the players, learning of efforts and hearing concerns both in industry and academia.

Industry wanted graduates literate in the use of computers. Some students and professors sought more computer use which, in this age of computers, seemed to make sense. Yet others cautioned that undergraduate students did not fully understand the engineering fundamentals even with traditional teaching techniques. As universities surrendered more course work to computers, surely things would only get worse. The debate waxed on. Then, the Accreditation Board for Engineering and Technology (ABET) made a subtle change to its accrediting criteria. It moved the evaluation of computers from "Facilities" to "Curriculum."[1] Emphasis moved from what equipment was available to how available equipment was used! The discussion among educators, at least within civil engineering, shifted from "if" to "how."

Our department grappled with the same difficult questions facing other universities concerning educational applications, software, hardware, funding, and implementation. To complicate the matter, the answers were all intricately interrelated. Pursuing "best educational applications," we finally settled upon a tiered concept for introducing computers. The result was a tri-level program of graduated computer use, identified simply as Level I, Level II, and Level III.

## APPROACH

We began by discussing issues and ideas for computer use during professional conferences. Following leads from those conversations, we telephoned individuals at many universities in pursuit of ideas. In addition to ideas, we also stumbled onto unpublished surveys which a few schools had conducted on their own behalf. From the surveys and conversations, we acquired a reasonably comprehensive picture of computer use in universities across the country.

Simultaneously, we conducted a literature search keying on the words "computer" and "education." We were deluged with references! We narrowed our search to "microcomputer" and "education" and received a more workable response.* Although many interesting concepts surfaced, none fully tapped the potential we felt was lurking within the computer.

We attempted to identify target areas for expanded computer use. Our own experiences and conference discussions directed our attention to two general areas. One was improving our students' understanding of fundamental concepts beyond memorization and rote application. The other was giving our students modest experience using computers in a practitioner-like scenario.

Although details of the three levels are presented later, a brief introduction is appropriate. Level I introduced students to the computer as a useful tool with emphasis on the qualitative relationships among problem

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* Unfortunately, by narrowing our literature search from "computer" to "microcomputer," we eliminated one of the most powerful sources we could have hoped for. Through our own struggling efforts, we identified and implemented many of the concepts prescribed in a study by the Carnegie Commission on Higher Education, The Emerging Technology.[2] The study was published in 1972, long before the term "microcomputer" was in use and long before the computer capabilities existed to support its recommendations.

parameters. Level II was a transition level. It required most of the student decisions, and provided most of the intermediate results, of a manual solution. The computer simply performed the calculations quickly enough to permit time for alternative design comparisons. Level III provided students with hands-on professional-level Computer Aided Design and Drafting (CADD) experience.

Developing in-class Level I teaching tools received our priority attention. We felt it was there we could make the most dramatic improvements in student understanding by building upon the standard derivations and example problems generally presented in engineering classroom sessions.[3] Concurrently, we began developing Level II software, and throughout our first year of effort, we also studied the commercial CADD systems for their suitability and availability.

## SOFTWARE

Once we had identified the fundamental applications, we focused our attention on software. The majority of commercially available engineering software was written for the professional practitioner, not for the educator and student. The practitioner wants a usable design while minimizing the number of decision points and extraneous output. The educator and student, on the other hand, benefit from knowing the results of intermediate calculations, and use intermediate decisions to ensure the student understands the material being taught.

Acquiring appropriate software for Level I and Level II was our biggest challenge; we found less than half a dozen suitable programs, which we modified for our use. Consequently, we authored much of our own software, a task requiring extensive support and encouragement from university administrators.[4] The large overhead for developing software is well known, but we developed a system of authoring quality custom software without an exorbitant investment of our professors' time, a system we have shared.[5]

Because Level III was primarily for capstone courses, practitioners' software was acceptable. We evaluated proficiency in prerequisite fundamentals prior to entry into the capstone courses. Thus, the fact that calculations were transparent to the software user was of less concern than in the prerequisite studies. The benefit was the student's ability to evaluate many design alternatives and to practice making engineering decisions. At Level III, we authored custom software only to supplement commercial software or to bridge the gap between prerequisite and capstone course needs.

## HARDWARE

Hardware had to be considered right along with applications and software. The project demanded choices among microcomputers, minicomputers, and main frames. We chose microcomputers for all three levels, satisfying the long-recognized need for reliability and economy.[6] The benefits of that decision were fantastic.[7] The only limitation we faced was in computer memory. Occasionally, large Level III engineering or architectural drawings had to be stored in parts.

Level I in-class demonstrations used a mobile cart for a microcomputer and a large-screen monitor, with the computer driving several monitors if class size warranted. Each mobile unit could support two or three courses or could be used in a work area for self-paced tutoring or for Level II projects.

For Level III, we used a micro-based CADD system dedicated to the Civil Engineering Department. This system, smart terminals connected to a central file server, provided operational independence for those courses not needing massive data bases. A future system supporting all five engineering departments will combine minicomputer work terminals with networked, stand-alone microcomputers. The obvious advantage will be the ability to access larger data bases.

# LEVEL I COMPUTER USE

Level I targeted student understanding of fundamental engineering relationships. I heard frequently echoed concerns among professors that undergraduate students tend to focus on memorization of equations, routines, and procedures, rather than on actual understanding of the underlying concepts. Level I shifted student emphasis from memorization to the sensitivity and interrelationships among problem parameters.

To illustrate this process, consider student use of a tool such as a design procedure. Many students apply the steps of a procedure as rigid rules. Usually, any reasonable series of decisions converges to an acceptable solution but may require many lengthy iterations. However, the student with a sufficient grasp of the principles at work makes better decisions and obtains an acceptable solution in fewer iterations.

The student with an even better understanding uses the steps of a procedure not as rigid rules but as general guidelines. This student not only makes good choices at each decision point but usually does not iterate in the strict sense of the word. An inadequate initial design does not send him back to some entry point in the procedure to repeat the process with revised data. Instead, he makes direct modification of his initial design based upon his understanding of the engineering principles. He is freed, as he should be, from a purely iterative approach to engineering design. It is that student "feel" for behavior which Level I helped us achieve.

Level I brought the computer right into the classroom as a teaching tool similar to a chalkboard, overhead projector, or movie projector. The objective was to introduce a topic then move beyond rote application of equations into the realm of fuller understanding. As we adjusted parameters, what happened? And why?

The students' anticipation was heightened upon entering the classroom because the portable microcomputer and monitor were there. This was just one advantage of a mobile unit.[8] With computer speed, we worked many variations of the example problem presented during the lesson. Believing "a picture is worth a thousand words," we viewed each behavioral change graphically to tie a mental picture of the change to its governing equations.

Developing reinforced concrete column interaction diagrams illustrates this application of the microcomputer. Using student handouts, we derived key equations and relationships in class and applied them to a specific example column. Near the end of the lesson, I started the program and typed in data for the example column. Figure 1 shows what the students saw at that point. Four seconds later they saw the completed interaction diagram as shown in Figure 2. Next the testing of parameters began. If we doubled the column width, what would happen to the interaction diagram? They offered their predictions. We made the change and viewed the new result as shown in Figure 3, automatically rescaled if necessary.

If they were correct in their predictions, I would probe for the "whys" behind their reasoning. If they were wrong, we would turn to the equations on the chalkboard and relate them to the picture on the monitor. They developed a better understanding of behavior and saved pages of calculations doing it. At the touch of a key, Figure 2 returned to the screen, and we were ready for the next change. We tested other parameters following a similar ritual each time. "What will happen and why?" "Why were you right?" or "Why were you wrong?" The equations and the relationships took on new significance, and behavior started becoming a part of the students' knowledge. We could do many such comparisons in a very few minutes of classroom time!

There are points to emphasize. The computer did not replace engineering.

The principles were presented as before. The equations and relationships were derived and explained as before. Even the long-hand example solution remained to demonstrate the use of those equations. Nothing of substance was replaced! But the microcomputer allowed many variations of that example problem in just a few minutes.

The changes in behavior and the relative importance of the various parameters became more obvious for several reasons. First, the changes were presented in a comparative format using graphics. The pictorial representation of behavior appealed to the right side of the student's brain.[9,10] Second, those changes in behavior were not obscured by pages of manual calculations; the results were available in seconds. Third, the professor was present to ensure the changes were noticed and explained, addressing the left side of the brain.[11,12] The derived equations were on the chalkboard so that the graphic portrayal of behavior was directly related to the governing equations. The combination of verbal and pictorial presentation took advantage of the different strategies the two brain hemispheres employ in processing information.[13,14] The result appeared to be better retention and understanding.[15]

Level I was adopted for any "introductory" course regardless of material complexity. The examples for concrete columns are from a junior-level course. We put comparable classroom software into a freshman-level statics and dynamics course. A final-semester, senior-level structural dynamics design course added software enhanced by animation! The important consideration for Level I was first-time student exposure to a topic. It was the Level I emphasis on qualitative relationships among the various problem parameters that forced the student out of memorization and calculation and into a better understanding of engineering behavior.[16]

There are other aspects of Level I that are not detailed in this article.

Level I is not difficult to incorporate into an existing curriculum; we needed only ten to fifteen minutes every third or fourth lesson. This technique is also effective in the laboratory, giving the ability to conduct the equivalent of many laboratory tests for the time price of only one.[17] And with relatively simple modifications, Level I software can assist in building quantitative proficiency through self-paced tutoring, allowing students to review not only qualitative results but also the specific calculations producing those results.[18]

## LEVEL II COMPUTER USE

Level II put a student, or a team of students, to work on a comprehensive project. This level was one step closer to what a graduate might find in a professional engineering office. He defined the problem, entered appropriate data, and let the computer provide an answer. But Level II required more user decisions and provided more intermediate and final values than do professional packages. Using concrete beam design as an example, Figure 4 shows some of the decisions required to obtain a preliminary design. Figure 5 shows how Level II software provided the location of the neutral axis, the percent of maximum allowable tension steel being used, and a calculation of material costs. That additional information helped the Level II user make wiser design revisions. Figure 5 also shows how a student may have used that information to revise his design.

The computer's speed and ease of use encouraged students to make many design revisions and select the "best" design for the criteria. For example, in designing a concrete floor system, students saw the effects a thicker floor slab eventually had on the beam and girder designs. The manual calculations were so lengthy that in past years even the best students had time to produce only one acceptable design. With Level II, students could develop several comparative designs and make qualitative decisions about their alternatives, a capability noted as a primary potential for the instructional use of computers.[19] Students became more aware of how the engineering parameters within their control affected the overall design. Thus, they became more adept at making efficient design decisions on the first trial design, perhaps a true measure of their newly developing "engineering judgment."

## LEVEL III COMPUTER USE

Level III employed a commercial "professional-level" software package, and students completed a comprehensive design project during the semester. Students met intermediate submittal deadlines but worked primarily at their own pace with the professor filling the role of consultant. As with Level II software, students were again encouraged by the speed and ease of use to make comparative design revisions. But Level III did not provide the additional intermediate and final values available at Level II, and the scope of each project was much broader. Thus, the students further refined their engineering judgment to make efficient design revisions.

The heart of the initial Level III effort was AUTOCAD software running on A.T.&T. microcomputers, both of which were on educational loan. With that sophisticated combination, students tackled more complex projects than ever before. Even the drafting capabilities of the software encouraged creative thinking since design changes did not precipitate painstaking drawing revisions.

## OBSERVATIONS

Recall that our primary interest was to produce better quality engineers, and our principal concern was that the computer might actually mask the fundamentals involved in analysis or design. Our goal, then, was to use computers to enhance our students' appreciation of engineering behavior and to develop their engineering judgment. A precise evaluation of our effectiveness is extremely difficult at best and may be impossible based only on our brief experience with this effort.[20] However, the observed increase in student competence probably justifies our satisfaction with this tri-level approach.[21] Some specifics are noted below.

Level I Applications

The principal objective of Level I was to focus student attention on qualitative relationships with the possibility of also improving quantitative proficiency. The qualitative goal was realized, but we observed no significant improvement in manual calculation skills. These results mirror those of John Cowan at the Heriot-Watt University in Edinburgh, Great Britain, in his use of ascending order questions.[22] We also observed an unexpected improvement in student attitude, measured through circumstantial factors such as interest, participation, and level of effort on assigned work.[23]

Better Student Performance The change in performance was more subtle than the increase in interest. Student performance on traditional work-out-the-numbers type of exams improved only slightly, but on questions of a more conceptual nature they did much better. But the major noticeable differences appeared in classroom responses and homework solutions.

During lectures, I asked many questions probing student understanding. Student responses were of a significantly higher quality! They recalled the principles more easily and applied them more correctly in new situations. Also, their ability to extract behavioral information out of new equations and relationships improved. In short, their ability to think and converse in terms of engineering behavior improved!

Solutions to homework design problems also improved. They produced better preliminary designs, and they made more efficient preliminary-to-final design revisions. They still made errors reading tables and using calculators, but the quality of their engineering decisions was better.

Heightened Student Interest Student interest truly did improve which may alone have made the effort worthwhile.[24] Their heightened interest came in part because a special piece of equipment in the classroom signaled a change of pace. Thus, a portable system increased effectiveness by stimulating interest while also increasing economy and flexibility. The big TV-like screen demanded their attention, just as TV does for my generation. Perhaps idealistically, I also like to think they looked forward to a richer understanding of the material.

Increased student involvement was another factor. I usually started with a few examples to illustrate specific behaviors and to get the students' mental gears in motion. Then I let the students select which parameters to change and how radically to change them. It became their problem. They predicted the results, and they explained why their prediction did or did not prove to be correct. There was an element of video games in matching wits with the computer. It was entertaining, but more importantly, it was educational. The method provided frequent feedback, reinforcement, and personal interaction, all characteristics of successful instructional strategies.[25]

## Level II Applications

Level II enabled us to demand more mature thinking from our students. By removing the burden of tedious manual calculations (once proficiency had been established), the students concentrated on developing engineering judgment by speeding up the process of design. The only important difference between Level II and manual calculations was the time required to complete a design. The same decisions were required of the students, and the same numerical results were provided as a basis for making those decisions. The students were not frustrated by careless mathematical errors (although we still stressed the importance of error-free work), and they enjoyed the opportunity to compare design alternatives.

Level III Applications

Level III debuted during the 1985-86 academic year with very limited availability; therefore, these conclusions are drawn from more limited observation. However, both professors and students were pleased with the program. Our students found the ability to compare designs and produce professional-quality work, both in substance and appearance, rewarding. They graduated from Level III confident in their decision-making abilities and proficient on at least one widely-used professional-level CADD system. We intend to expand Level III into other courses as quickly as funding permits.

## SUMMARY

In an effort to enhance student learning, the Department of Civil Engineering at the United States Air Force Academy made a concerted effort to increase computer use in its undergraduate courses. We developed a tri-level approach to computer use that helped our students progress from fundamental equation solving to professional-level design. We initiated the program in the Fall semester of 1984, and the results have been positive. We watched our students develop an improved understanding of the engineering fundamentals and saw them become more excited about their studies. We are continuing our efforts to expand the use of all three levels while ensuring that computers enhance understanding, not replace it. We are convinced that our approach to using computers gives our students a smooth and solid transition from beginning engineering student to practicing professional!

```
1) CONCRETE STRENGTH (F'C) IN KSI            =  4
2) STEEL STRENGTH (FY) IN KSI                =  60
3) COLUMN WIDTH (B) IN INCHES                =  12
4) COLUMN HEIGHT (H) IN INCHES               =  24
5) AREA OF COMP. STEEL (A'S) IN SQ. IN.      =  3.0
6) EFFECTIVE DEPTH (D') IN INCHES            =  2.5
7) AREA OF TENSION STEEL (AS) IN SQ. IN.     =  3.0
8) EFFECTIVE DEPTH (D) IN INCHES             =  21.5
```

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DO YOU WANT TO CHANGE ANY OF
THE ABOVE INPUTS (Y/N) ?
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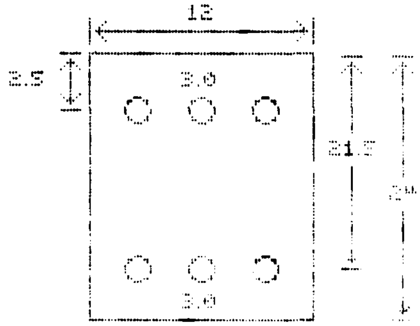


Figure 1. Column Definition

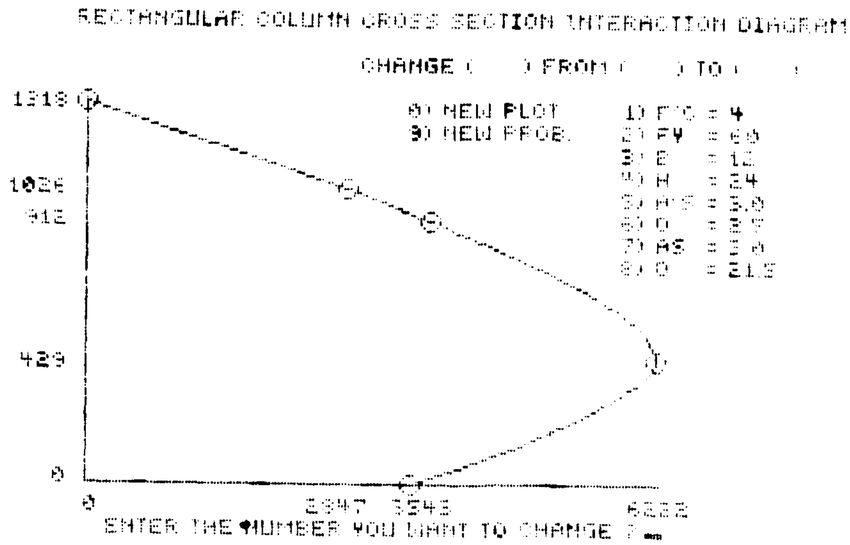


Figure 2: Original Results

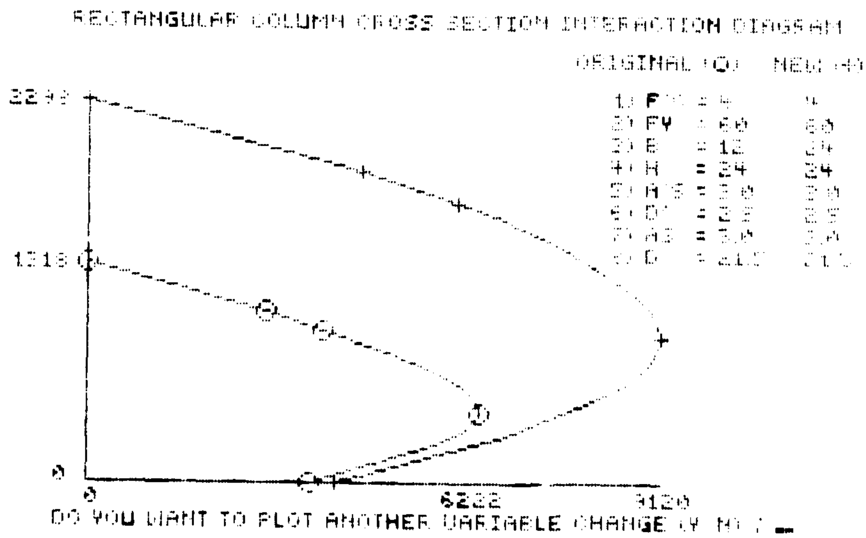


Figure 3: Comparison

```
SINGLY REINFORCED RECTANGULAR BEAM DESIGN

ENTER REQUIRED MOMENT CAPACITY (IN-KIPS) = ? 4500

        YOUR MAX STEEL RATIO =                    .0213
        ENTER DESIGN STEEL RATIO =              ? .92

        ENTER DEPTH TO WIDTH RATIO =            ? 1.75

        YOUR CALCULATED WIDTH (IN) =              11.62
        ENTER DESIGN WIDTH (IN) =               ? 12

        YOUR WIDTH (IN) =                         12
        YOUR EFFECTIVE DEPTH (IN) =               20.74
        YOUR REQUIRED STEEL (SQ IN) =             4.93

        DO YOU WANT TO: ?
            1.) ANALYZE THIS BEAM?
            2.) DO ANOTHER DESIGN?
            3.) RETURN TO THE MAIN MENU?
```

Figure 4 : Initial Design

```
SINGLY REINFORCED RECTANGULAR BEAM ANALYSIS

1) ENTER REQUIRED MOMENT CAPACITY (IN-KIPS) = 4500
2) ENTER BEAM WIDTH (IN) =                    12
3) ENTER BEAM HEIGHT (IN) =                   24
4) ENTER AREA OF STEEL (SQ IN) =              4.93      5.00
5) ENTER EFFECTIVE DEPTH (IN) =               20.74     [illegible]
6) ENTER CONCRETE STRENGTH (KSI) =            4
7) ENTER STEEL STRENGTH (KSI) =               60

*************************************************************************

   ACTUAL MOMENT CAPACITY (IN-KIPS) =         [illegible]   [illegible]
   REQUIRED MOMENT CAPACITY (IN-KIPS) =       4500      [illegible]
   PERCENT OVERDESIGN (%) =                   [illegible]   [illegible]
   PERCENT OF MAXIMUM STEEL (%) =             [illegible]   [illegible]
   THE NEUTRAL AXIS (IN) =                    [illegible]   [illegible]
   COST PER LINEAL FOOT ($) =                 [illegible]   [illegible]

      DO YOU WANT TO ANALYZE ANOTHER SINGLY
      REINFORCED RECTANGULAR SECTION (Y/N) ?
```

Figure 5 : Revision Process

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