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Electronic Spreadsheets in Concrete Design

Calcul électronique en tableaux pour le béton armé et précontraint

Elektronische Tabellenkalkulation im Stahl- und Spannbetonbau

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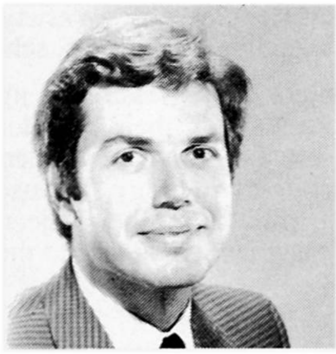

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SUMMARY
This paper shows the tremendous potential of electronic spreadsheets as a teaching tool in graduate and undergraduate courses of structural design. To demonstrate the possibilities of this tool a few advanced applications encountered in graduate level courses on behavior and design of structural elements are presented.

RÉSUMÉ
La contribution montre le grand potentiel du calcul électronique en tableaux dans les cours de projet et de dimensionnement des constructions. Les possibilités de cet outil sont présentées à l'aide de quelques exemples, présentés dans les cours avancés sur le comportement et le projet des éléments de structure.

ZUSAMMENFASSUNG
Diese Arbeit zeigt wie leistungsfähig die elektronische Tabellenkalkulation als Lehrwerkzeug sein kann. Die Möglichkeiten dieses Hilfsmittels werden anhand von einigen Beispielen vorgestellt, die in Vertiefungskursen über das Last-Verformungs-Verhalten von Bauteilen behandelt werden.

1. INTRODUCTION

The last ten years have seen a dramatic change in the way engineers perform their work. The most important factor contributing to this change was the introduction of microcomputers into the market in the late 70's. A number of related factors led to the rapid spread of microcomputers in engineering offices of any size:

- the low cost of microcomputers afforded small engineering offices access to the new technology;
- the development of powerful software packages which are easy to learn encouraged non-specialists to use the new technology;
- microcomputers help the average engineer in a variety of tasks; these include proposal and report preparation, calculations, budget preparation, scheduling, drafting, presentation etc.

The widespread use of microcomputers by professional engineers and their appearance in large numbers on university campuses necessitates their introduction in graduate and undergraduate courses. This fact presents the instructor with the challenge of adjusting course content and presentation to take advantage of the new technology. The use of microcomputers as a learning tool is, however, not an easy task. The pitfalls of the project have led many educators to reject microcomputers as a learning tool altogether and adhere to the old and established ways of teaching engineering principles.

2. ADVANTAGES OF ELECTRONIC SPREADSHEETS

Electronic spreadsheets can find many applications in the area of structural engineering [6]. The integration of a very powerful electronic calculator with database functions and easy-to-use graphics appears to be especially appealing in structural design. Engineering calculations are often organized in tabular fashion which is precisely the structure that lies at the heart of electronic spreadsheets. The power of these software packages is combined with great flexibility of use allowing the designer to readily develop procedures to fit his special needs. Modification of existing spreadsheets is extremely easy, since the spreadsheet structure is transparent to the user.

These characteristics make electronic spreadsheets an ideal tool in the instruction of structural design. While teaching tools are available in structural analysis [1], no such tools have been developed to date for structural design.

To be successful as a teaching tool a program should satisfy the following requirements:

- the amount of time the student spends learning the details of the program should be kept to a minimum; this amount of time should enable the student to actively interact with the program by modifying portions of it or developing new features and solution schemes;
- the program should be based on a language that is easy to learn and use; most engineering tasks are based on simple functions and solution schemes;
- the program organization should resemble that of the engineering notepad; this facilitates going back and forth between hand and computer calculations

Electronic spreadsheets satisfy all these requirements. Some of the most striking features are:

- ease of programming of complex formulas which include scientific functions and logical operators
- integration of calculation of complex formulas with easy-to-use graphics and basic database concepts; this corresponds to the manual "calculate and look-up" activity of design engineers; the integration of graphics into the spreadsheet allows the student to quickly check his calculations and at the same time enhances his understanding of the interrelationship between key variables of the particular design problem
- the spreadsheet is transparent to the user and can be modified with great ease; this satisfies the need for flexibility in the solution of design problems; at the same time it allows the student to follow the logical flow of the solution process in a spreadsheet that he did not develop himself

- the program does not have to be compiled and linked before it can be executed; execution rather takes place immediately; any syntax errors are flagged as they occur reducing the frustrations associated with debugging the program
- electronic spreadsheets are geared towards resources that all engineers will possess in the very near future; this fact makes their impact immediate; they illustrate to students the power of computers in a very direct way, since the organization and internal structure of electronic spreadsheets very closely resembles that of manual calculations
- electronic spreadsheets allow the user to investigate the effect of variation of key parameters on the solution of the problem under study; this can be done with a few keystrokes; this should be an important ingredient of instruction tools for structural design
- most electronic spreadsheets are very user-friendly with extensive on-line help facilities; this helps allay the fear of inexperienced users towards microcomputers.

3. APPLICATIONS IN REINFORCED CONCRETE DESIGN

3.1 Moment-curvature of rectangular sections

3.1.1 Problem statement

An understanding of the nonlinear behavior of reinforced concrete (RC) sections loaded to failure under a combination of bending moment and axial load forms an important part of a course on advanced reinforced concrete design.

The formulation of the problem is relatively straighforward: given is a rectangular concrete section reinforced with longitudinal and transverse steel. The section is subjected to a constant axial load *P* and a moment *M* which is increased until failure occurs (Fig. 1). The student is asked to develop a procedure for determining the moment-curvature relation of the section up to failure. This procedure should take into account the nonlinear behavior of the materials, the effect of confinement provided by the transverse steel and the possibility of buckling of the compression steel. It is based on the well known assumptions of the simple bending theory of RC sections [2].

Electronic spreadsheets offer an excellent set of tools for developing the procedure described above. The nonlinear material models can be described by a sequence of nested IF statements. The integration of concrete stresses is accomplished by subviding the compression zone into a number of layers (Fig. 2). Each layer corresponds to a different row in the spreadsheet with different columns displaying information on the location, the stress, the axial force and bending moment contribution of each concrete layer.

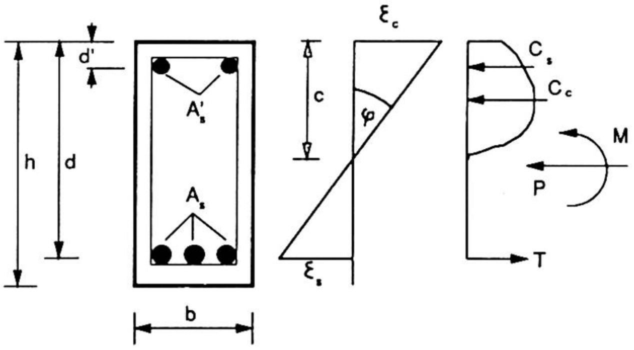


Fig. 1 Distribution of stresses and strains in a rectangular R/C section subjected to bending moment *M* and axial load *P*

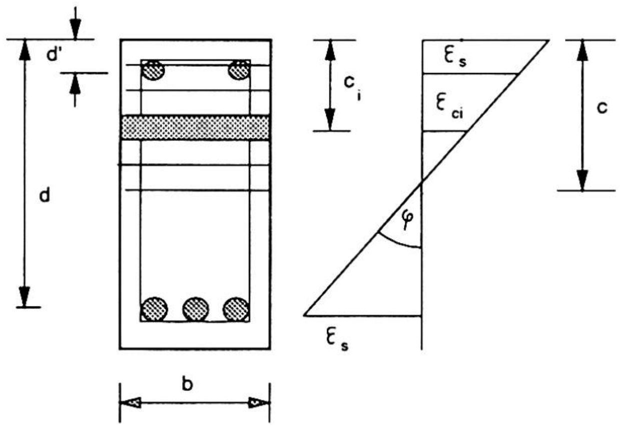


Fig. 2 Subdivision of compression zone in concrete layers

At each moment increment the location of the neutral axis needs to be established by trial and error. It is instructive to ask the students to adopt this approach for a few steps of the moment-curvature relation in order to gain a better understanding of the behavior of the section. The iterative process can, however, be automated rather easily using the macro command language that many spreadsheets support. The possibility of using the same spreadsheet in a trial and error mode and an automatic mode is an important aspect of the use of this tool in the classroom.

3.1.2 Examples

Parametric studies of the effect of various parameters on the monotonic moment-curvature relation of reinforced concrete sections can be conducted using the spreadsheet program described in the previous paragraph. A small sample of such studies are presented in Figs. 3-5.

A rectangular reinforced concrete section with top and bottom reinforcement, an effective depth of 25" and a width of 15" is used in these examples. Longitudinal and transverse reinforcement consists of Grade 60 steel. Fig. 3 shows the effect of tensile reinforcement ratio ρ on strength and curvature ductility of the section. Fig. 4 shows the effect of concrete compressive strength on strength and curvature ductility. In both cases transverse reinforcement consists of #3 bars spaced at 4" o.c. and no compression reinforcement is used.

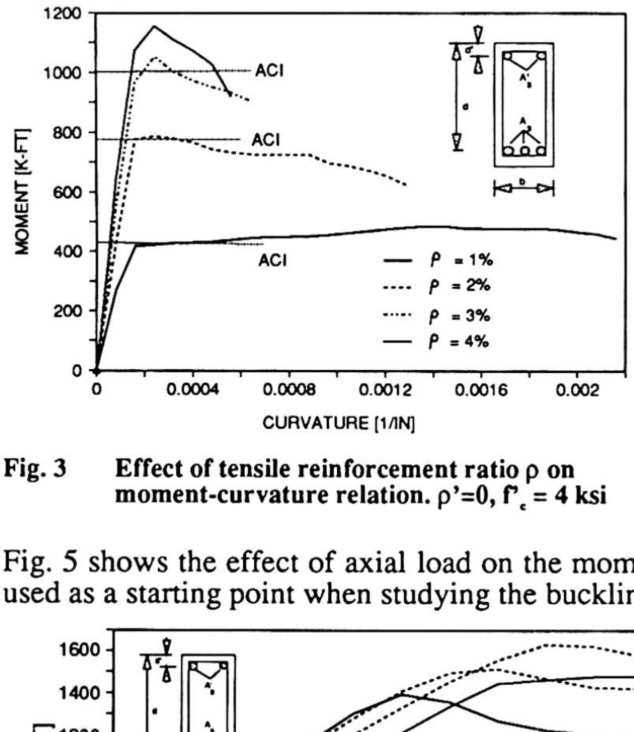


Fig. 3 **Effect of tensile reinforcement ratio ρ on moment-curvature relation. ρ'=0, f'_c = 4 ksi**

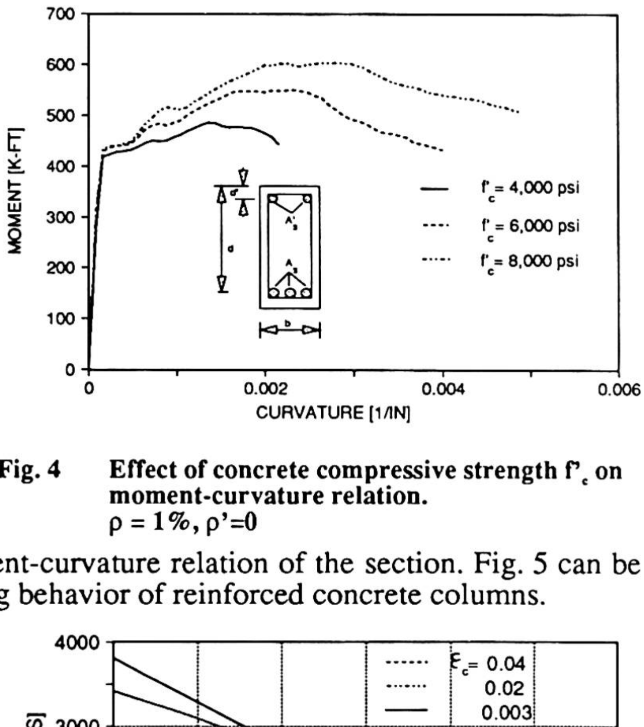


Fig. 4 **Effect of concrete compressive strength f'_c on moment-curvature relation.**
ρ = 1%, ρ'=0

Fig. 5 shows the effect of axial load on the moment-curvature relation of the section. Fig. 5 can be used as a starting point when studying the buckling behavior of reinforced concrete columns.

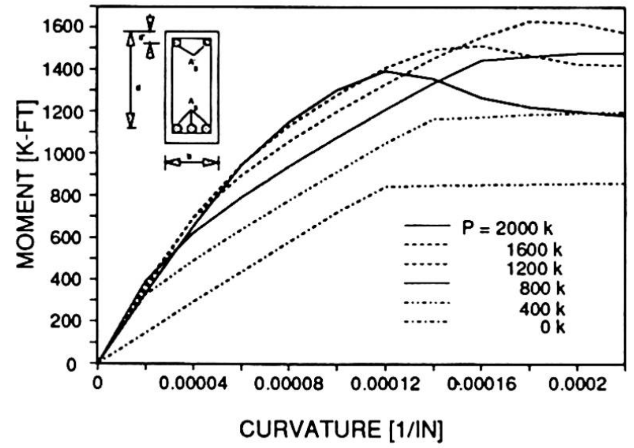


Fig. 5 **Effect of axial load *P* on moment-curvature relation. ρ = 2%, ρ'=2%, f'_c = 4 ksi**

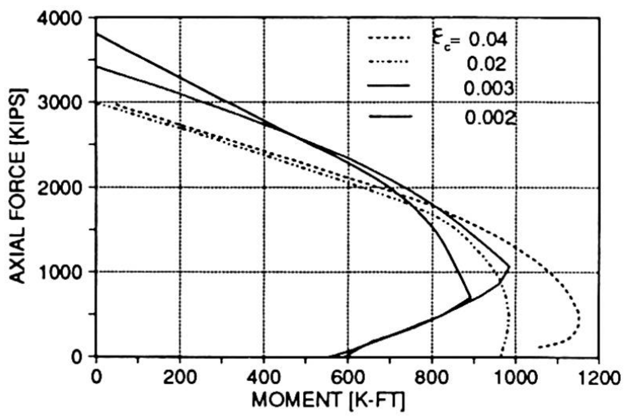


Fig. 6 **Axial load-bending moment interaction diagram for a 20" square R/C column with ρ = ρ' = 2% and transverse reinforcement of #4 bars at 2" o.c., f'_c = 8 ksi**

3.2 Interaction diagram for axial load and uniaxial bending

A slight modification of the **MOMCURV** spreadsheet can be used to derive the axial load-bending moment interaction diagrams for rectangular reinforced concrete section. An example of such an investigation is shown in Fig. 6. In this case the strain at the outermost compression fiber is kept constant and the program calculates the axial load and the bending moment of the section for a range of strains in the tensile reinforcement layer. It is interesting to note the effect of the maximum concrete strain on the shape of the interaction diagram. The actual interaction diagram is the envelope of the curves in Fig. 6.

3.3 Interaction diagram for axial load and biaxial bending

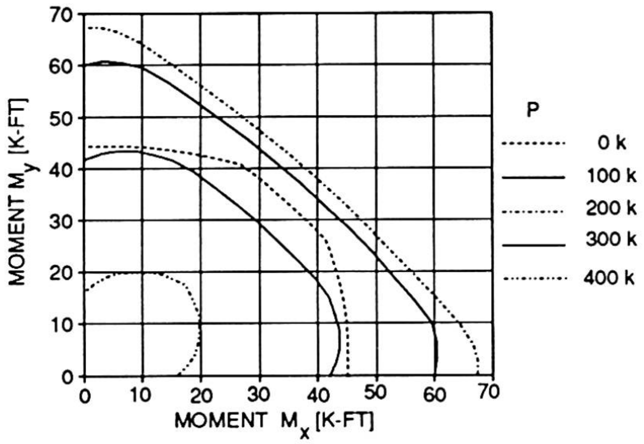


Fig. 7 Axial load-Biaxial bending moment interaction diagram for a 10" square R/C column reinforced with 4 #9 bars, f'_c = 4 ksi

Finally, it is possible to let the neutral axis of the section rotate with respect to a fixed coordinate system which is parallel to the edges of the rectangular section. In this case one can obtain the interaction diagram for biaxial bending and axial load. Such a diagram is shown in Fig. 7. Each curve represents the ultimate strength of the section for combinations of bending moments M_x and M_y and a constant value of axial load P.

4. APPLICATIONS IN PRESTRESSED CONCRETE DESIGN

4.1 Moment-curvature of rectangular sections

4.2 Design and tendon layout of simply supported beams

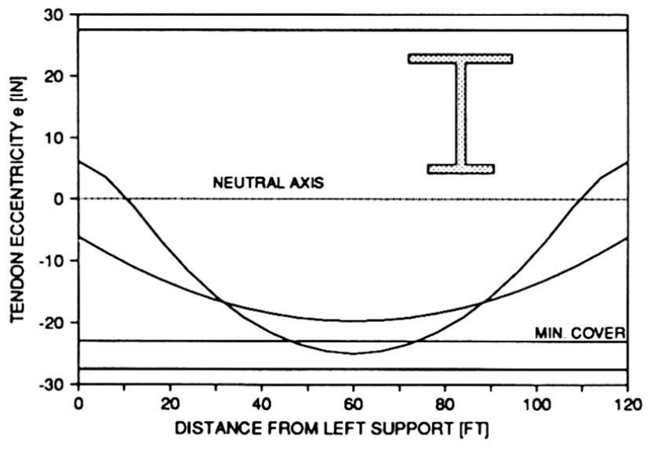
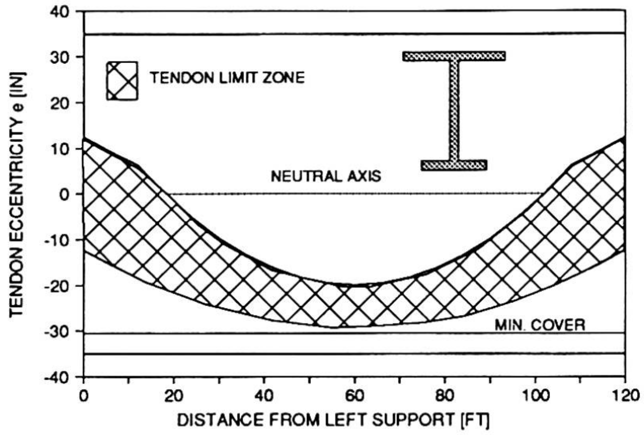


Fig. 8 Tendon limit zone for an unsuccessful trial section

Figs. 8-10 show a typical application from prestressed concrete design. The students are asked to develop a spreadsheet which will help establish the tendon layout for a simply supported beam subjected to uniform loads and prestressed with straight or draped tendons. The only given information is the type of materials used, the span of the beam and the magnitude of the superimposed dead and live loads that the beam carries.

The student can go through a trial and error procedure to determine the cross section dimensions. After he has selected a trial section he can ask for a graphic representation of the tendon limit zone. An unsuccessful trial is shown in Fig. 8 and the final section selection is shown in Fig. 9. It takes about two to three minutes to find an optimum cross section characterized by a limit zone which has shrunk to a minimum. Upon selection of the section dimensions the student can plot the Magnel diagram of the section shown in Fig. 10 which enables him to select the minimum prestressing force and the corresponding eccentricity at the critical section of the girder.



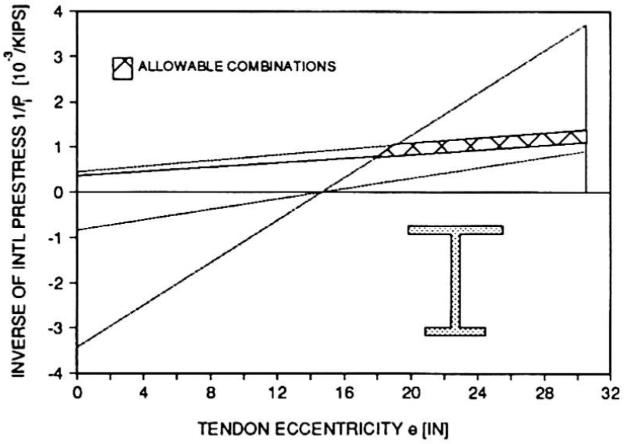


Fig. 9 **Tendon limit zone for a successful trial section**

Fig. 10 **Magnel diagram of the inverse of the prestressing force vs. the tendon eccentricity at the critical section of the girder of Fig. 9**

5. CONCLUSIONS

This paper demonstrates the possibility of innovative use of electronic spreadsheets in advanced graduate courses on reinforced and prestressed concrete design. In addition, it hopes to advocate the exposure of undergraduate and graduate students to the power offered by electronic spreadsheets in connection with desktop microcomputers in solving various design problems. These problems range from the simplest case of shear design to highly involved nonlinear moment-curvature relations of reinforced and prestressed concrete sections. Familiarity of students with electronic spreadsheets is all the more important, since these can be used to great advantage in many other engineering tasks such as construction scheduling, budget preparation, etc.

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