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LIMIT STATES DESIGN OF MASONRY STRUCTURES BASED ON CSA S304.1 USING MICRO-COMPUTERS

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ABSTRACT

The micro-computer software developed herein is intended to relieve design engineers of laborious computations inevitable in the iterative masonry design process. Computations may be performed for the design and analysis of all commonly occurring masonry elements consisting of either concrete block or clay brick units. Included in the software are options for the analysis and design of beams, columns, load-bearing walls, slender walls, pilasters, and shear walls. Elements may be either plain or reinforced.

The software operates in the Windows™ environment and it incorporates a highly interactive graphic user interface. In addition, ample graphical illustrations are available to guide users to enter the proper input while output information is presented in graphical and tabular forms. All input can be entered without ambiguity by referring to graphical illustrations. Because of the high speed calculations, the practising design engineer can investigate several options for a particular design application in just a few minutes. Additionally, the self-explanatory and interactive nature of the software also make it a suitable teaching tool.

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INTRODUCTION

Engineers designing in masonry must deal with a variety of structural components such as beams, load-bearing walls, columns, pilasters, shear walls, slender walls and composite walls. Optimum structural design of masonry elements is essentially an iterative process and the tedium of this process provides an ideal opportunity for computerization. Computer software for masonry design should include the elements noted and at the same time provide a comprehensive and straightforward user interface.

The micro-computer based software developed herein is designed to relieve structural designers of the repetitive computational effort involved in the design process. The high speed of computation also allows designers to investigate various design options in order to achieve the most satisfactory design. In addition, graphical illustrations are used extensively to enhance the readability of information displayed on the screen. This feature effectively reduces to a minimum the need for referring to an accompanying manual.

The limit states design of masonry is set out in the Canadian Standards Association standard CSA S304.1-94 - Masonry Design for Buildings (Limit States Design). The current version of the software is based on this code. Included in the software are the evaluation of f'm for design, design and analysis of masonry beams, load-bearing walls, columns, pilasters, shear walls and slender walls. All designs are checked for their conformance with CSA S304.1-94. The overall structure and mode of operation of this software are described in this paper and important features are highlighted.

The software operates in the Window™ environment and it was created using Borland C++ in an OOP (Object-oriented programming) environment. The use of OOP for program development provides a great savings in time and allows the software to be easily maintained, upgraded, and enhanced in the future.

PROGRAM STRUCTURE

The eight different program modules, each individually accessed via a main window, are shown in Figure 1. The currently available modules are:

1. Determination of f'_m for the purpose of design.
2. Properties of hollow concrete blocks.
3. Design of beams and lintels.
4. Design of load bearing walls.
5. Design of columns.
6. Design of pilasters.

7. Design of shear walls.
8. Design of slender walls.

Once a selection is made, a self explanatory window with appropriate pop-up menus is shown (Figure 2) and the user can randomly select any of the available tasks from the menu. A task selection is typically accompanied by a new window with appropriate graphic illustration and an array of buttons. The graphics shows the currently undertaken task while the buttons allow a user to enter design information. As shown in Figure 3, a mouse click of a button will activate a dialog box which allows a user to enter new data or to change existing design data. All data entries are organized in blocks and a user can verify and make changes to any data within a block before proceeding to the next block. Changes in design data will be upgraded instantaneously and illustrated graphically on the screen. Intermediate computations and checking of Code requirements are made concurrently and any data change that affects design will be processed and the design upgraded immediately.

Within each module, general utilities such as saving and retrieving files, printing, and printer set-up are available in the first pop-up menu shown in Figure 4. In addition, a user is given the option to work in either SI or Imperial units and to switch between the two units at any time during the design process (Figure 5).

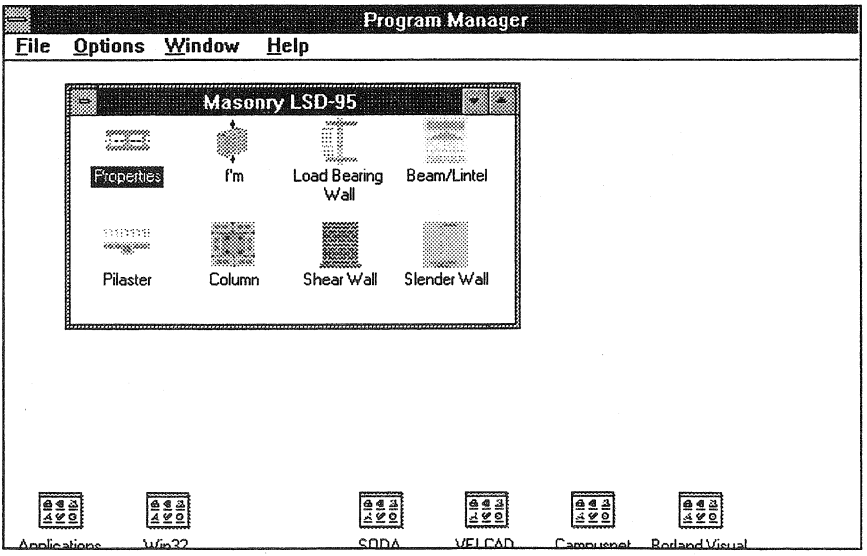

Figure 1: Main Window

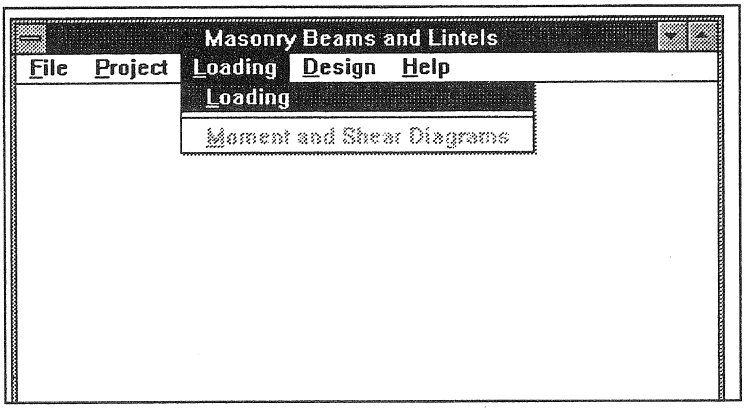

Figure 2: Typical Pop-up Menu

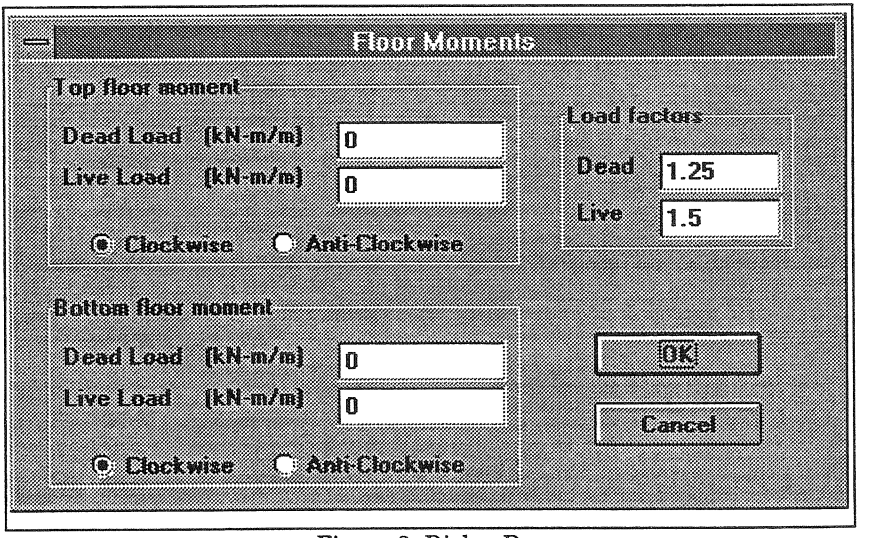

Figure 3: Dialog Box

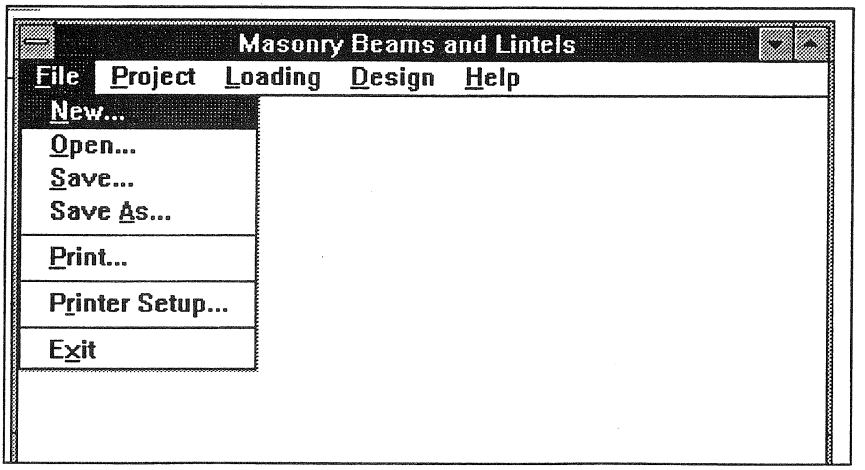

Figure 4: General Utilities

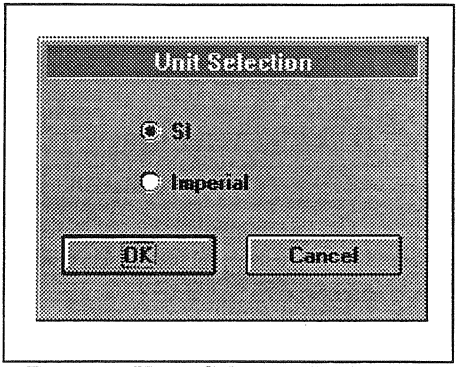

Figure 5: Units Selection Dialog Box

DETERMINATION OF f'_m FOR THE PURPOSE OF DESIGN

The compressive strength of masonry, f'_m, is the most commonly used design parameter in engineered masonry. Clause 9.2 of CSA S304.1-94 outlines two methods for the determination of f'_m. Prism Test permits determination of f'_m from prism test specimens and Unit and Mortar Test infers an f'_m value for design based on the strength of units and type of mortar used. The former calls for the testing of at least 5 prisms while the later requires that the unit

strength be determined from at least 5 test specimens.

This program accepts prism and unit test data as input and performs a statistical analysis of the input data in accordance with CSA S304.1-94. Results of the analysis are shown on screen and the user is instructed to take appropriate action. As an example, if the coefficient of variation of test data exceeds 15%, the user will be asked to use at least 10 test samples as required by the Code (CSA,1994). If the sample size exceeds 5, the program automatically performs a statistical analysis to determine outliers in the test data and the user is given the option of accepting or rejecting any outlier in the samples.

The user is given the option of using either or both of the above methods for assessing f'm values. If Unit and Mortar Test is selected, the user will be required to enter additional information such as unit type and construction procedure. The dialog box shown in Figure 6 illustrates the required input data and results. The program interpolates f'_m based on values given in Tables 3, 4 and 5 of CSA S304.1.

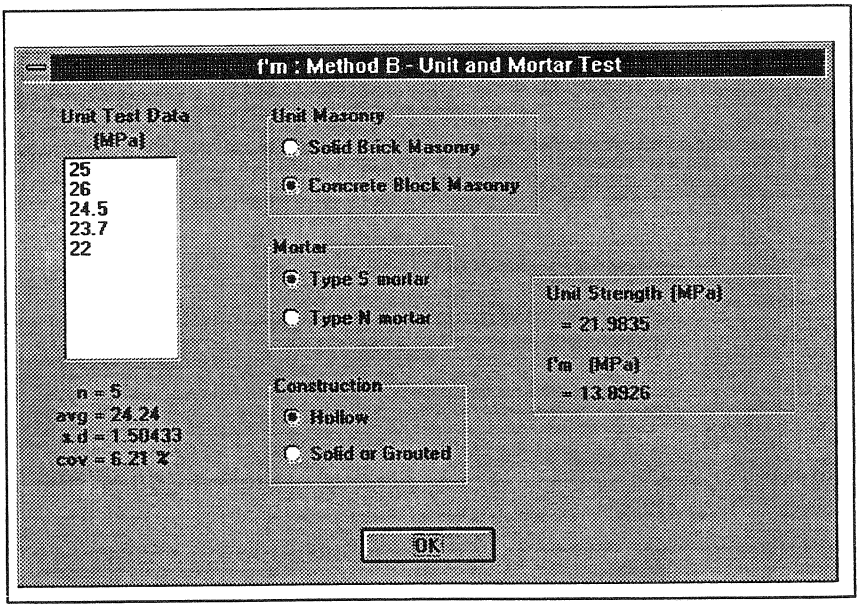

Figure 6: Unit and Mortar Test for the Evaluation of f'm

GEOMETRICAL PROPERTIES OF HOLLOW CONCRETE BLOCKS

This module contains a data base of geometrical and physical properties of concrete masonry blocks commonly used in Canada. Designers may obtain information such as dead weight, mortar bedded area, face-shell thickness and section modulus of concrete masonry block walls. As shown in Figure 7, selection of wall sizes and grout spacing is accomplished by highlighting the appropriate item in the list box with a mouse click.

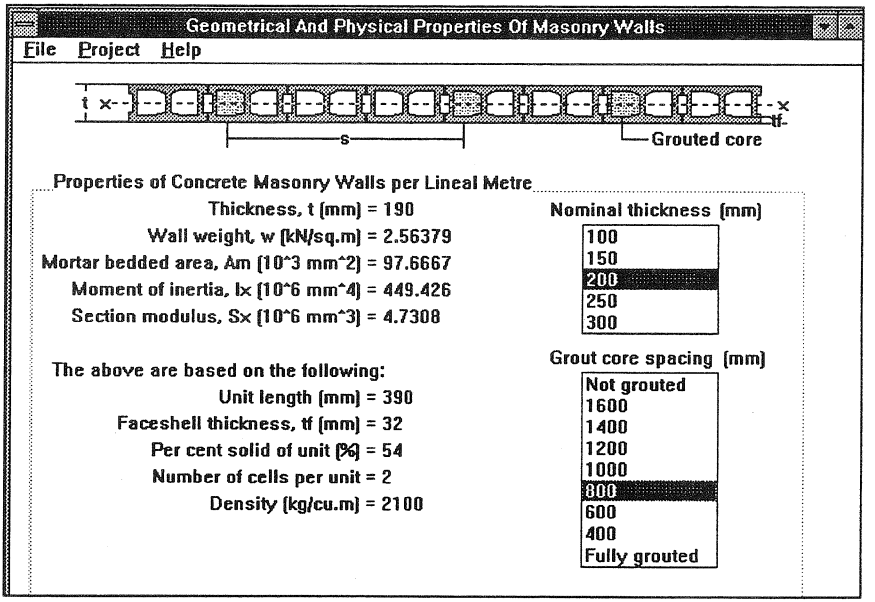

Figure 7: Properties of Concrete Masonry Units

DESIGN MASONRY BEAMS AND LINTELS

This module allows a user to design masonry beams and lintels in conformance with CSA S304.1. Extensive graphics interpretation of input and output data are available in this module. By activating the loading pop-up menu, a user can define the span, boundary conditions, beam self-weight, beam loading, and the appropriate load factors. As shown in Figure 8, the program accepts uniform loading, symmetrical triangularly distributed loading and an unlimited number of point loads while boundary conditions may be one of the following: (1) both ends pinned, (2) both ends fixed, (3) one end pinned and one end fixed or (4) one end fixed and one end free. Moment and shear are

computed for each loading type and the total moment and shear are obtained by superposition. Critical moment and shear are checked and stored internally as design values. A user can view plots of bending moment and shear force diagrams for both specified and factored loads by selecting Bending Moment and Shear Force Diagrams in the pop-up menu (Figure 9).

In the Design pop-up menu shown in Figure 10, a user can begin the design process by selecting any of the listed options. Typically, a design would require user input of beam geometry and material properties. Factored resistance is computed and compared with the appropriate factored forces as changes are made. Effects of user decisions are shown on the screen instantaneously. Typical results of flexural and shear design are shown in windows presented in Figures 11 and 12, respectively.

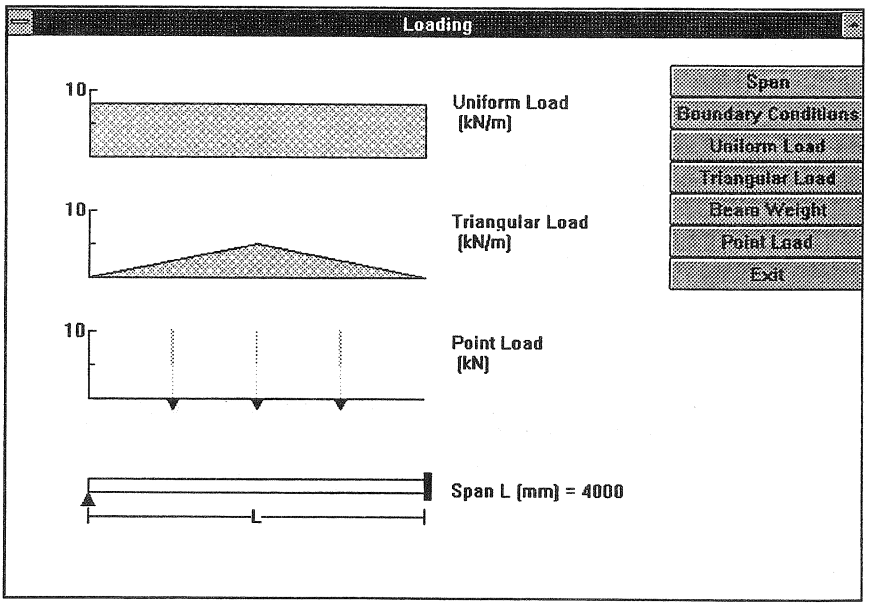

Figure 8: Beam Loading

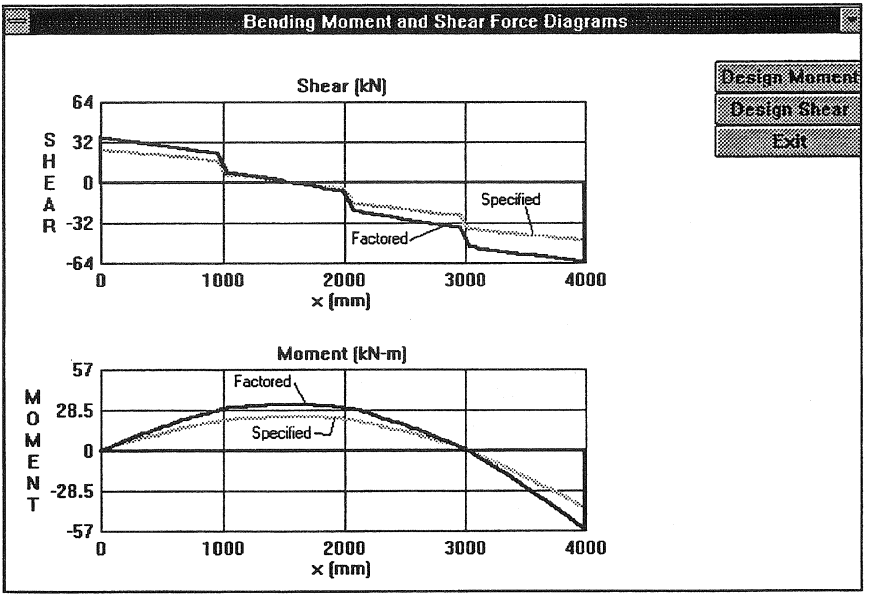

Figure 9: Bending Moment And Shear Force Diagrams

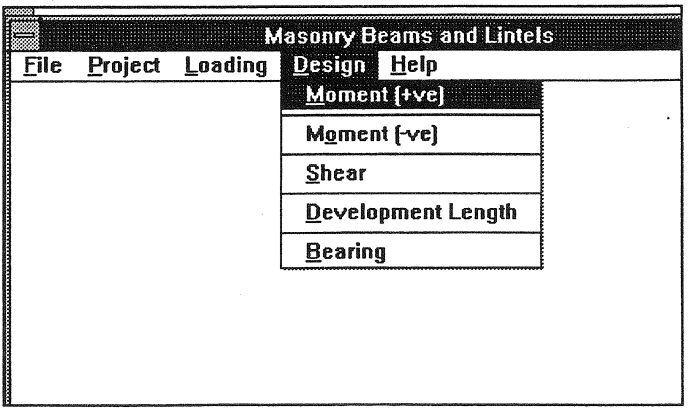

Figure 10: Design Menu - Masonry Beams and Lintels

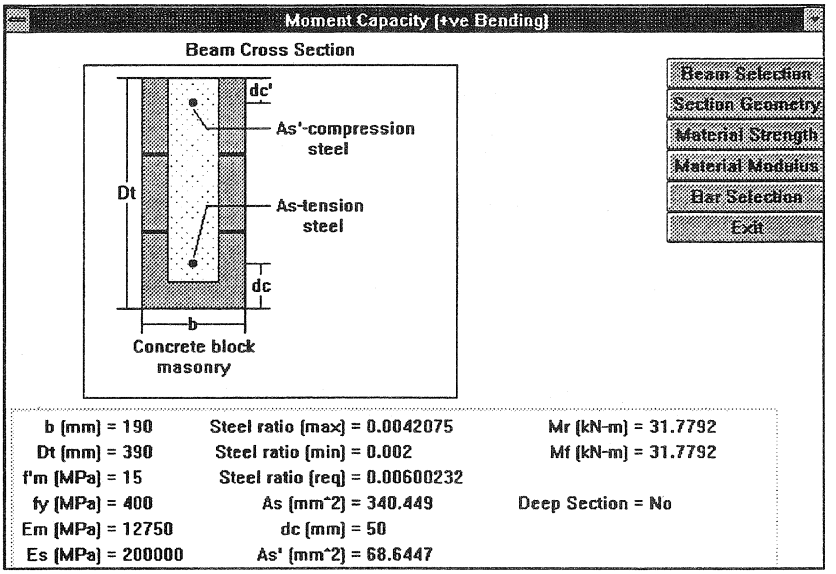

Figure 11: Flexural Design

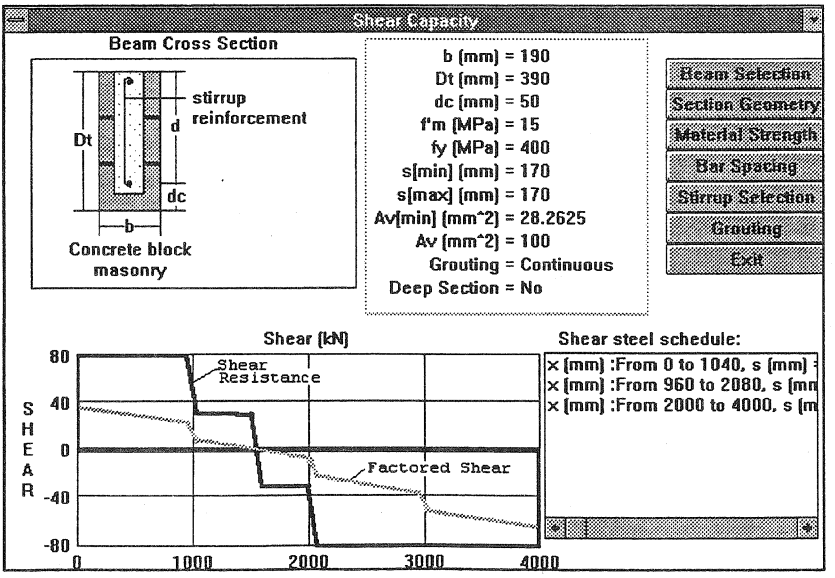

Figure 12: Shear Design

DESIGN OF LOAD BEARING MASONRY WALLS

This module enables users to design non-reinforced and reinforced load-bearing masonry walls with slenderness ratio, kh/t (ratio of effective wall height to wall thickness) not exceeding 30. Again, a pop-up menu is available for the user to enter the geometry, loading, and boundary conditions of the wall. The adequacy of the wall can then be checked with respect to P-Δ method or the moment magnifier method outlined in Clause 11.2 of CSA S304.1-94. A typical window showing a wall design as shown in Figure 13 consists of an interaction curve showing the factored resistance of the wall section and the design point (axial load and moment), a table of design data, and an array of buttons for the user to make design changes. The user can click on any of the buttons to make the required changes to the design.

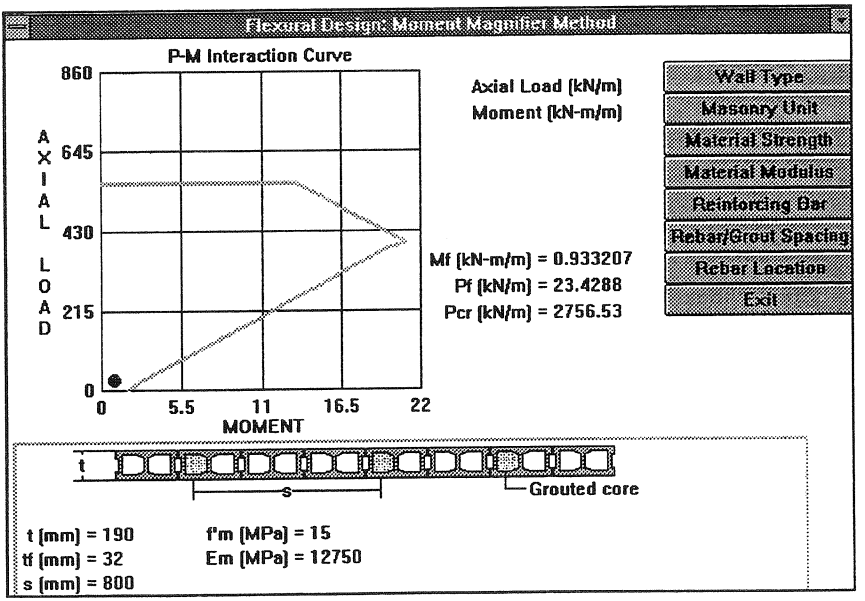

Figure 13: Wall Design Window

DESIGN OF SLENDER WALLS

If the slenderness ratio of a wall is greater than 30, the module described in the preceding section is no longer applicable. The slender wall module as described herein is indented for the design for tall, slender walls under relatively low axial load. The provisions in Clause 11.2.5.6 of CSA

S304.1-94 are used to evaluate wall capacity. This provision is similar to that outlined in chapter 24 of the Uniform Building Code (UBC, 1991). Design methods for slender walls are based on results of an extensive research program and principles of engineering mechanics (Amrhein and Lee, 1984). There is no limitation for the slenderness ratio except that the height is limited by maximum lateral deflection and strength of the wall. Strength of slender walls is calculated based on Clause 10.2.3 of CSA S304.1 for reinforced masonry.

DESIGN MASONRY COLUMNS, PILASTERS AND SHEAR WALLS

Modules for the design of columns, pilaster, and shear walls are currently under development and details on specifics are not available. However, all these modules will incorporate program design and user interfaces similar to those described in the preceding sections.

CONCLUSIONS

A user-friendly, highly interactive computer program for the design of masonry structures has been presented. The comprehensiveness of this software allows engineers to design and analyze most masonry elements in a short time. In addition, the high speed of computation allows designers to investigate different design options in order to obtain the most satisfactory design.

LIST OF REFERENCES

Amrhein, J.E., Lee, D.E. (1984), Design of Reinforced Masonry Tall Slender Walls. Western States Clay Products Association, San Francisco.

Canadian Standards Association (1994), CSA S304-94 - Masonry Design for Buildings (Limit States Design), Rexdale, Ontario.

International Conference of Building Officials (1991), Chapter 24, Masonry of the Uniform Building Code. Whittier, California.

AUTHOR SURNAME INDEX