DESIGN OF POST-TENSIONED PRESTRESSED CONCRETE BEAM USING EXCEL SPREADSHEET WITH VISUAL BASIC APPLICATIONS

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Abstract- The design of pre-stressed beams is more complicated problem specially when dealing with continuous beams. It is basically a trial-and-error process in an effort to reach the best proportions. Manual computations of the design may take a time for the engineers to arrive in best design. The study on spreadsheet design on post-tensioned prestressed concrete using Excel spreadsheet with Visual Basics applications was developed. The program calculates the required prestressing force, concrete area, steel area, and tendon eccentricities. The developed spreadsheet can compute secondary moments on indeterminate beams, additional non prestressing bars and shear reinforcement designs. The objective of the study to simplify the design computation of post-tensioned prestressed concrete were achieved. The traditional approach of iterative and distinct phases of the design of post-tensioned prestressed concrete was considerably enhanced. The design process had reduced in its duration and complexity by the interaction of the designer at various stages of the design, and the ability to selectively automate those components of the design process that were repetitive and time consuming. Proper judgment from the user/designer could be applied and can be rectified almost instantaneously. The developed program may serve as academic aid since the computation process was systematically reflected on the spreadsheet. The presence of VBA applications has improved the program development capability of Excel spreadsheet. The use of VBA GUls inside the spreadsheet somehow should be limited because it can result to higher file size and may cause overflow during the execution.

Key words: Prestressed Concrete, Post-Tensioned, Excel Visual Basics

I. INTRODUCTION

Prestressed concrete is a method for overcoming concrete's natural weakness in tension. Prestressing results in lighter members, longer spans, and an increase in the economical range of application of reinforced concrete. It can be used to produce beams, floors or bridges with a longer span than what is practical with ordinary reinforced concrete. Prestressed concrete could be pre-tensioned or post-tensioned. The design of prestressed beams is more complicated problem specially when dealing with continuous beams. The design of prestressed concrete is basically a trial-and-error process in an effort to reach the best proportions (T. Y. Lin, 1981). Manual computations of the design may take a time for the engineers to arrive in best design. Somehow, with the possible iterations in steps, some values are assumed, the engineer may lose patience and come up with a non-economical proportion.

The Excel Spreadsheet on the other hand is a powerful tool not only in Accounting but also in Engineering. Spreadsheet is mostly used in modification of the traditional hand written method of calculations. The equations are solved exactly the same way in the computer. The computer only makes it easier by doing the calculations and keeping a record for reuse. One has only to become familiar with the Excel functions, many of which are similar to Microsoft Word. In addition to Excel's extensive list of worksheet functions and array of calculation tools for scientific and engineering calculations, Excel contains a programming language Visual Basic and it allows users to create procedures sometimes referred to as macros, and build a Graphical User Interface (GUI) icons, that can perform even more advanced calculations or that can automate repetitive calculations.

This study seek to enhance the lengthy and trial-and-error design computation of post-tensioned prestressed concrete beams by developing a spreadsheet with Visual Basic applications. Also, the study attempted to develop an automated design process wherein the user may see and interact on the flow of the design and a design computations that can be used not only by the designer but also can serve as classroom instructions for professors handling the subject matter.

The study aimed the following:
1. Simplify the trial and error manual calculation of post-tensioned prestressed concrete design by developing a spreadsheet program that will enhance the design of post-tensioned prestressed concrete beam.
2. In the spreadsheet developed, user can change the design parameters and immediately see the effect on the results, and the capability to instantly view the acceptable results.
3. Develop a design aid that adapts to changes on design codes.
4. Show almost entire computations, procedures and formula to the user that he/she may have proper judgement and understanding in the design of post-tensioned prestressed concrete.
5. Develop a design aid that can be used for classroom instructions.
6. Take advantages of the capabilities of today’s spreadsheet specifically MS Excel 2013 spreadsheet in the design of post tension prestressed concrete. The lengthy and trial-and-error computation will be simplified by simple clicks of Graphic User Interface (GUI) through Visual Basic which is embedded in today’s MS Excel software and by simply scrolling the spreadsheet to easily go back to the inputted parameters that needs to be rectified.

The following were the set limitations of the developed spreadsheet.
1. Prestressing force are assumed constant all throughout the tendon length.
2. The program can only compute moment loads based on given distributed loads of beam on simple span beams.
3. For indeterminate beams, live load moments and any service loads were input parameters from the user.
4. Critical points on shear design were all user defined.
5. Only practical tendon layout which is compound parabolic drapes were available for continuous beams.
6. Double shaped beams and unsymmetrical sections with respect to vertical axis were not considered.
7. The spreadsheet was saved as MS Excel 2013 Macros Enabled. Hence, it will run only to MS excel with VBA applications.

II. METHODOLOGY

Program Description
The program developed was a MS Excel Spreadsheets with Visual Basics forms and macros that computes the required prestressing force for the given loads, tendon profile, concrete section and material properties. It can check the adequacy of the design and can allow user to have trial-and-error process and instantly see the effect on the design upon input change.

Analysis Method
A constant force approach was used in the design or analysis, in which the effective prestress force was assumed to be constant throughout the member. This design employed the concept of moment distribution method in determining the secondary moment due to prestressing force. The concept of Elastic Design in prestressed concrete was used in flexural design while Ultimate Design concept was used for shear design.

Design Code
The user could choose from ACI, AASHTO, or PCI Code in determining the maximum allowable stresses of concrete and Prestressing steel. The user could also accept the suggested value or change the allowable stresses on his/her preferences.

Cross-section Types
Beam cross-section types available are shown in the figure below. The sections were pre-drawn with corresponding dimensions which requires an input from the user. Only symmetrical sections were considered.

Tendon Profiles
The program supports only four types of tendon profile. Any of these tendon profile may be used but has constraints on profile elevation at end-span of the beam. For simple beam end-span profile elevation was always assumed to be at the elevation of the centroid of the concrete. For indeterminate beam only continuous compound parabolic profile elevation was available considering the practical and realistic elevation of tendon.

Programming of Procedure
The programming platform was Microsoft Office 2013 Professional Edition, specifically Excel. The analysis were done through macros specially programmed for prestressed concrete design. The user may not see the step by step computation but may follow through the necessary step by step output reflected in the spreadsheet cells. Programming was done by developing functions or formula inside the cell or using the Visual Basic Editor. The latter was used on procedures that are iterative or procedures cannot be found on Excel list of functions. Also for simplicity of programing, the Visual Basic Editor is more preferable especially on cells that varies formula.
Software Development Flowchart

The design of Prestressed Concrete is generalized in following flowchart shown in the figure below. The process differs on different design method used.

Figure 3 General Flow Chart of Design of Post-Tensioned Concrete Beam

Method A (Elastic Design)

Method B (Elastic Design by Magnel Diagram)

Method C (Elastic Design by T.Y. Lin)

Figure 4 Elastic Design

Figure 5 Elastic Design Using Magnel Diagram

Figure 6 Elastic Design by T.Y. Lin
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Debugging
Just like human creation, computer programs are less than perfect. A series of sample problems different books were tried and compared in order to attain a satisfactory results and find out source code errors. Transferring files to other computer were also done to detect compatibility problems.

III. RESULTS AND DISCUSSIONS

General
The developed spreadsheet program is capable of computing for the design of post-tensioned prestressed concrete beam. It can give the required prestressing force, tendon eccentricities, and shear reinforcements based on the user’s preferences. The spreadsheet program (workbook) is composed of seven sheets. Each sheet contained one design method.

1. Sheet 1 (Introduction)
2. Sheet 2 (Elastic Design)
3. Sheet 3 (Elastic Design by Magnel)
4. Sheet 4 (Elastic Design by T.Y. Lin)
5. Sheet 5 (Indeterminate Beam)
6. Sheet 6 (Shear Design for Indeterminate Beam)
7. Sheet 7 (Moment Distribution)

Opening the Workbook
The spreadsheet uses macros and Visual Basic language programming and thereby saved as Macro Enabled Workbook. Thus, the user must click first the “Enable Content” Button located below the ribbon of the spreadsheet. Some program procedures run upon opening of the workbook, thus the user is suggested to always enable the macros content of this program.

4.1.2 Workbook Layout
Figure 4.1 shows the main program (sheet) view as it appears once it is opened. Design method to be selected appears on the active sheet name located below the sheet screen as shown in the figure marked by red annotations. The right side of the screen were notes and suggestions. Notes and suggestions were not be printable but will served as a guide and manual for the user.

Input Cells
The cells of spreadsheet were protected. Only cells allocated for user input can be edited. Input cells were formatted green and italic fonts, and underlined while output cells are italics and has a red color font.

Output Cells
The output cells are protected and cannot be altered. Output results were preliminary computations, prestressing force, tendon eccentricity, tendon profile type, non-prestressing bars, and section properties. A summary of all design output was formed on the latter part of the program. A detailed step by step computation with shown formula is shown for the user to follow.
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Design Example
The following series figure shown is an example of beam design using elastic design method.

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Number of Tendons:

- Tendon Area: $A_t = \frac{F_{pt}}{F_{c,lt}}$
- Tendon Stress: $F_{pt} = \frac{F_{pt,lt}}{A_t}$
- Ultimate Moment Factor: $M_u = \frac{F_{pt} A_t}{2 F_{c,lt}}$

Check for Cracking Moment:

- Resisting Moment at crack location: $M_{cr} = \frac{4}{3} F_{pt} A_t$
- Factor of Safety for Cracking: $F_{sfs} = \frac{M_{cr}}{M_u}$

Concrete:

- Compressive Strength: $f_{c,lt} = 31.5$ MPa
- Elastic Modulus: $E = 38,000$ MPa

Steel:

- Yield Strength: $f_{y} = 440$ MPa
- Ultimate Strength: $f_{u} = 620$ MPa

Connections:

- Tendon Anchor: $A_{anch} = 0.0025 F_{pt}$
- Reducing Factor: $k = 0.85$

Splice Length:

- Splice Length at crack location: $L_{sp} = 200 a_c$

Prestressed Steel Area:

- Tendon Area: $A_t = 0.002 F_{pt}$
- Prestressing Force: $P_{pt} = 486$ MPa

Loads @ Critical Distance:

- Dead Load: $W_{dl} = 2.0 F_{pt}$
- Live Load: $W_{ll} = 1.5 F_{pt}$

Shear Load Factor:

- Shear Load: $V_s = 0.3 F_{pt}$

Beam Section:

- Total Length: $L = 1200$ mm
- Width: $b = 100$ mm
- Depth: $d = 400$ mm
- Shear Span: $2 b$

Compressive Stress in Concrete:

- Compressive Stress: $f_{c} = \frac{M}{b d^2}$
- Effective Depth: $d_e = \frac{f_{c}}{f_{c,lt}}$

Fibers:

- Fiber Diameter: $d_{f} = 0.0015 mm$
- Fiber Volume: $V_{f} = 0.0015 m^3$

Other Calculations:

- Archural Formulas:
  - $f_{c} = f_{c,lt}$
  - $E = E_{lt}$

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IV. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The study on spreadsheet design on post-tensioned prestressed concrete using Excel spreadsheet with visual basis applications was developed. The program requires the user to input loads, dimensions, and design codes, and material properties. The program then calculates the required prestressing force, concrete area, steel area, and tendon eccentricities. The developed spreadsheet can compute secondary moments on indeterminate beams, additional non prestressing bars and shear reinforcement designs. The objective of the study to simplify the design computation of post-tensioned prestressed concrete were achieved. The traditional approach of iterative and distinct phases of the design of post-tensioned prestressed concrete was considerably enhanced. The design process had reduced in its duration and complexity by the interaction of the designer at various stages of the design, and the ability to selectively automate those components of the design process that were repetitive and time consuming. Proper judgment from the user/designer could be applied and can be rectified almost instantaneously. The developed program may serve as academic aid since the computation process was systematically reflected on the spreadsheet.

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