

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 GUIs 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.

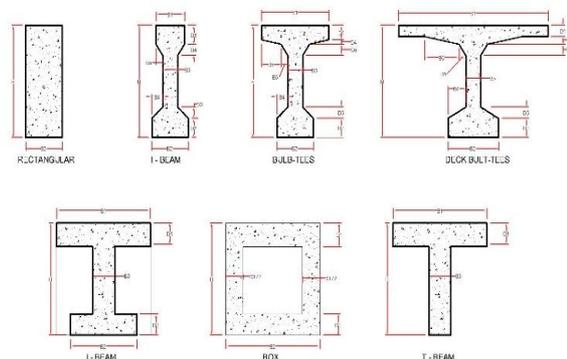


Figure 1 Beam Cross-sections

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.

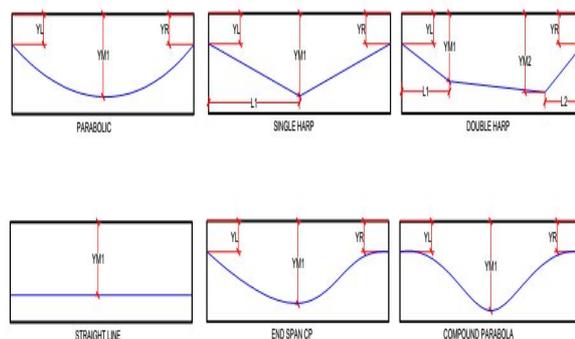


Figure 2 Tendon Profiles

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 programming, 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.

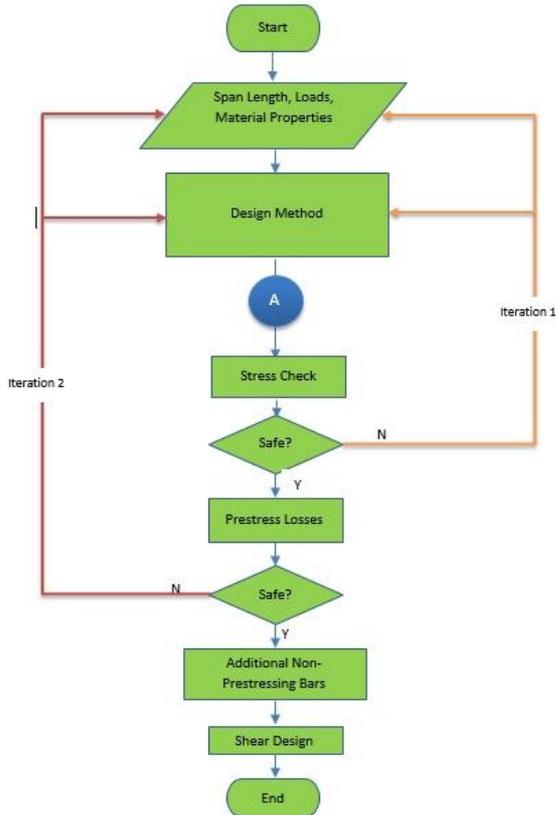


Figure 3 General Flow Chart of Design of Post-Tensioned Concrete Beam

Method A (Elastic Design)

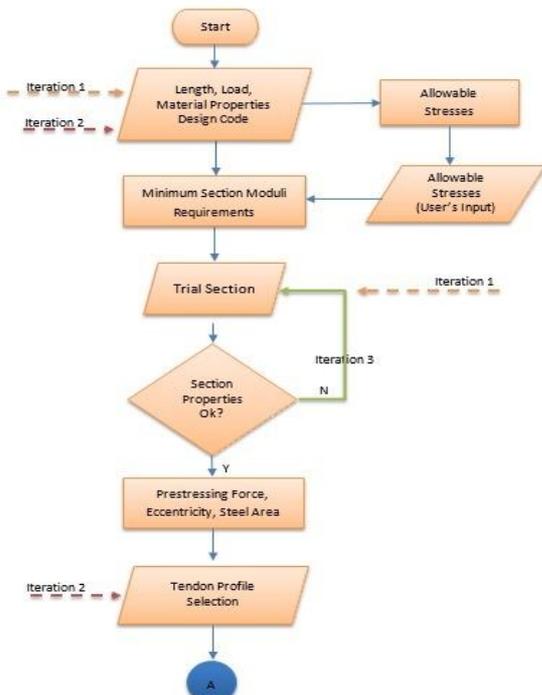


Figure 4 Elastic Design

Method B (Elastic Design by Magnel Diagram)

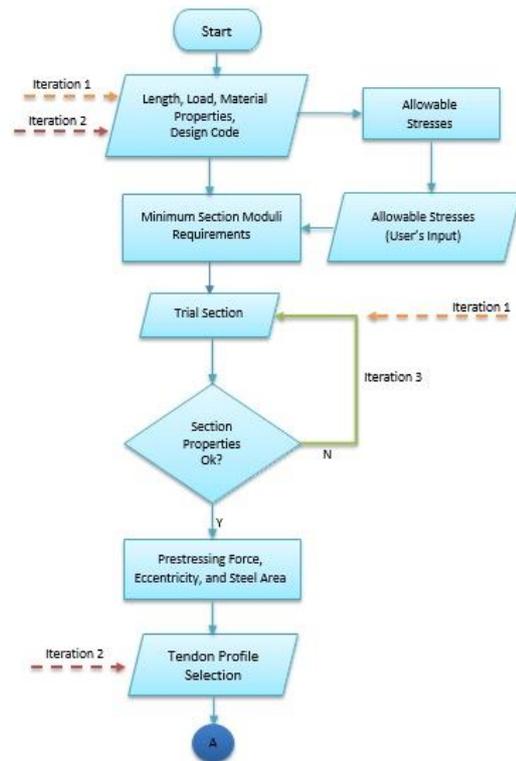


Figure 5 Elastic Design Using Magnel Diagram

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

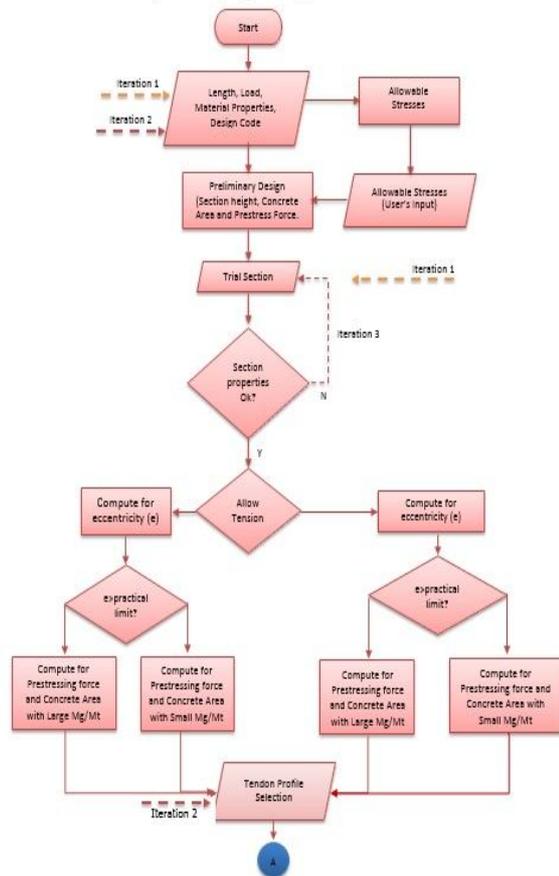


Figure 6 Elastic Design by T.Y. Lin

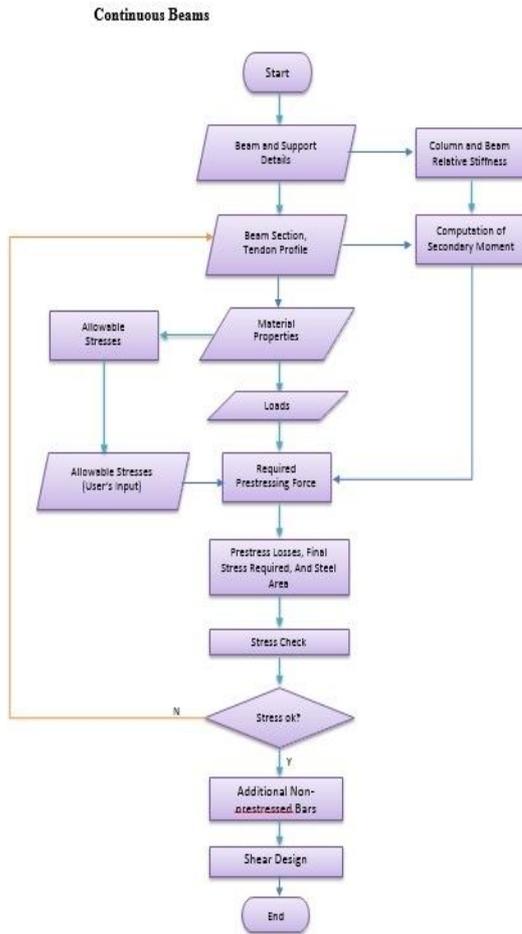


Figure 7 Continuous Beam

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.

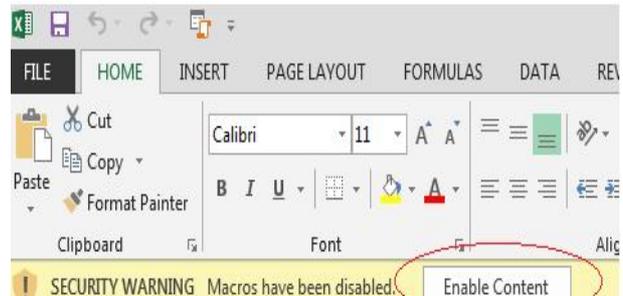


Figure 8 Enabling Macros

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.

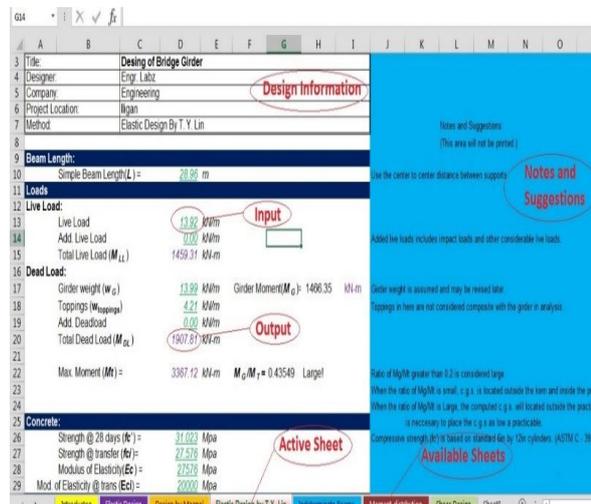


Figure 9 Workbook Layouts

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.

Required Prestress Area

Concrete centroidal stress just after transfer:

$$f_{cent} = \frac{e_c}{h} (f_{co} - f_{to}) + f_{to} = 7.13744 \text{ MPa}$$

Corresponding initial prestress, P_o :

$$P_o = A_c f_{cent} = 1837.31 \text{ KN}$$

$$P_e = P_o(\eta) = 1506.6 \text{ KN}$$

Required steel eccentricity:

$$e_1 = (f_{cent} - f_{to}) \frac{S_x}{P_o} + \frac{M_d}{P_o} = 445 \text{ mm}$$

$$e_2 = (f_{cent} + f_{to}) \frac{S_y}{P_o} + \frac{M_d}{P_o} = 156 \text{ mm}$$

considering the coverings: $e_3 = 406 \text{ mm}$

$$e = \max(e_1, e_2) \leq e_3 = 406 \text{ mm}$$

Required Prestress Area: $A_s = P_e / F_{so} = 1409.6 \text{ mm}^2$

Figure 10 Detailed Computation

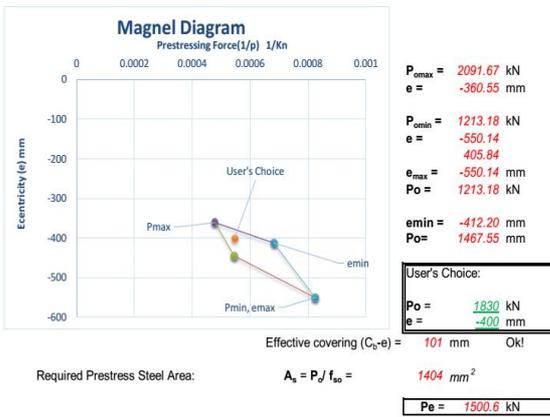


Figure 11 Graphical Method Magnel Diagram

DESIGN OUTPUT SUMMARY

Profile Type: Single Harp

Prestressing Tendons, Non-prestressed Bar

$L = 19.81 \text{ m}$
 $L_1 = 9.906 \text{ m}$

Distance	From the Top Fiber (mm)	From the Neutral Axis (mm)
@Left Support =	515	0 Above
@Right Support =	515	0 Above
@L1 =	921	406 Below
@L2 =		0

Tendon Profile

Prestressing Force:
 P_o (Transfer) = 1672 KN
 P_e (Final) = 1371 KN

Total Steel Area:
 $A_{ps} = 1283 \text{ mm}^2$

Number of Tendons: 13 pieces of Tendons

Non-prestressing Bar diameter: 16 mm
Number of Bars: 4 bars

Design Code: ACI

Beam Cross-Section: Std. I - Beam

H = 1016 mm
B1 = 457.2 mm
B2 = 457.2 mm
B3 = 152.4 mm
B4 = 152.4 mm
B5 = 152.4 mm
B6 = 0 mm
D1 = 114.3 mm
D2 = 101.6 mm
D3 = 152.4 mm
D4 = 88.9 mm
D5 = 0 mm

Figure 12 Design Output Summary

Design Example

The following series figure shown is an example of beam design using elastic design method.

Design of Bridge Girder

Designer: Engr. Labz
Company: Engineering
Project Location: Itan
Method: Elastic Design

Beam Length: Simple Beam Length(L) = 20.00 m

Loads

Live Load:
Live Load = 15.00 KN/m
Add. Live Load = 0.00 KN/m
Total Live Load (M_{LL}) = 750.00 KN-m

Dead Load:
Girder weight (w_g) = 7.00 KN/m
Toppings ($w_{topping}$) = 0.00 KN/m
Add. Deadload = 1.00 KN/m
Total Dead Load (M_{DL}) = 400.00 KN-m
Max. Moment (M_t) = 1150.00 KN-m

Girder Moment (M_d) = 350 KN-m

Material Properties

Concrete:
Strength @ 28 days (f_c') = 34.47 MPa
Strength @ transfer (f_{ci}') = 25.853 MPa
Modulus of Elasticity (E_c) = 27576 MPa

Prestressing Steel:
Ultimate tensile (f_{pu}) = 1852 MPa
Ultimate yield (f_{py}) = 1500 MPa
Modulus of Elasticity (E_{ps}) = 193032 MPa

Tendon Strand Type: Stress-Relieved Low Relaxation

Post Tensioning System: Bonded Unbonded

Stressing Type: One End Stressing Both Ends Stressing

Allowable Stresses

Design Code: ASD/FTD

Concrete:

At Transfer (F_{ca})
Compression (F_{ca}) = 0.55 f_{ci} $F_{ca} = 14.22 \text{ MPa}$
Tension (F_{ta}) = 0.25 $\sqrt{f_{ci}'}$ $F_{ta} = -1.47 \text{ MPa}$

At Final Stage
Compression (F_{cs}) = 0.40 f_c' $F_{cs} = 13.79 \text{ MPa}$
Tension (F_{ts}) = 0.25 $\sqrt{f_c'}$ $F_{ts} = -1.47 \text{ MPa}$

Steel:

Jacking Stress (F_{js}) = 0.94 f_{py} $F_{js} = 1489.6 \text{ MPa}$
At Transfer (F_{sa}) = 0.82 f_{py} $F_{sa} = 1312 \text{ MPa}$

At Final Stage (F_{sa}) = 0.7 f_{pu} $F_{sa} = 1303.4 \text{ MPa}$

Prestressing efficiency (η_{eff}) = 0.82

Coverings:

Min. Cgs of tendons from Bot. fiber = 95.25 mm

Minimum Section Modulus required:

Variable Tendonity Constant Eccentricity

$S_x \geq 57,565,652 \text{ mm}^3$
 $S_y \geq 65,739,948 \text{ mm}^3$

Trial Section:

Std. I - Beam

Input Dimensions:
H = 1200 mm
B1 = 400 mm
B2 = 400 mm
B3 = 150 mm
B4 = 150 mm
B5 = 150 mm
B6 = 0 mm
D1 = 150 mm
D2 = 150 mm
D3 = 150 mm
D4 = 100 mm
D5 = 0 mm

Section Properties:

Concrete Area (A_c) = 285000.00 mm^2
Moment of Inertia (I) = 4.76E+10 mm^4
Section Modulus (S_b) = 79,395,832 mm^3 OK!
Section Modulus (S_t) = 79,395,832 mm^3 OK!
Centroid from Bottom (C_b) = 600.00 mm
Centroid from Top (C_t) = 600.00 mm
Bottom Kern Point (k_b) = 278.58 mm
Top Kern Point (k_t) = 278.58 mm

Required Prestress Area:

Concrete centroidal stress just after transfer:

$$f_{cent} = \frac{e_c}{h} (f_{co} - f_{to}) + f_{to} = 6.3757 \text{ MPa}$$

Corresponding initial prestress, P_o :

$$P_o = A_c f_{cent} = 1817.1 \text{ KN}$$

$$P_e = P_o(\eta) = 1490 \text{ KN}$$

Required steel eccentricity:

$$e_1 = (f_{cent} - f_{to}) \frac{S_x}{P_o} + \frac{M_d}{P_o} = 535 \text{ mm}$$

$$e_2 = (f_{cent} + f_{to}) \frac{S_y}{P_o} + \frac{M_d}{P_o} = 193 \text{ mm}$$

considering the coverings: $e_3 = 505$ mm
 $e = \max(e_1, e_2) \leq e_3 = 505$ mm
 Required Prestress Area: $A_p = P_j / F_{ps} = 1385.0$ mm²

Number of Tendons	
Tendon Area =	98.7 mm ²
Number of Tendons =	14.03
Preferred Num. of Tendons =	14
Total Steel Area(Aps) =	1381.8 mm ²
Actual P _s =	1812.92 MPa
Actual P _s =	1486.60 MPa

Stress Check:

General Equation: $f = \frac{P}{A} \pm \frac{Pe}{Z} \pm \frac{M}{Z}$

Initial Stage: (P = P ₀ , M = Mg)	ft =	fb =	Allowable (MPa)	
Top fiber:	-0.76 MPa	-1.47 MPa	14.22	Ok!
Bottom fiber:	13.48 MPa	14.22 MPa		
Final Stage: (P = P _s , M = Mt)	ft =	fb =		
Top fiber:	10.25 MPa	13.79 MPa	13.79	Ok!
Bottom fiber:	0.18 MPa	13.79 MPa	13.79	Ok!

Check for Cracking Moment

Resisting Moment up to zero stress in bottom fiber:
 $M_r = P(e + k_r) = 1420.12$ KN-m
 Modulus of rupture:
 $f = 0.14f_c' = 4.83$ MPa
 $M = \frac{fI}{C_b} = 383.15$ KN-m
 Total Resisting Moment for cracking:
 $M_{CR} = M_r + M = 1803.27$ KN-m
 Factor of Safety for Cracking:
 $F_s = \frac{M_{CR}}{M_T} = 1.57$
 Factor of Safety for LiveLoad:
 $F_s = \frac{M_{CR} - M_D - M_D}{M_L} = 1.87$

This would mean that the beam starts to crack if live load is increased to 87%.

Additional Non-prestressed Bars

Fy = 314 MPa
 Diameter (mm) = 16 mm
 Min. Conc. Cover = 125 mm
 Ultimate Moment Fact Mu = 1.4 DL + 1.7 LL = 1835.00 KN-m
 $\rho = \frac{A_s}{bd} = 0.003127$
 $f_{ps} = f_{pu} \left[1 - \frac{1}{2} \left(\rho \frac{f_{ps}}{f_c'} \right) \right] = 1704.74$ MPa
 $\omega_p = \rho \frac{f_{ps}}{f_c'} = 0.15$
 $M_{u,prov} = \phi A_s f_{ps} d (1 - 0.5\omega_p) = 2161.03$ KN-m No Req. Steel Reinforcement.
 $A_{s,req} = \frac{M_u - M_{u,prov}}{\phi f_y d} = 0.00$
 Ash_{req} = 570.00 mm²
 Number of Bars = 3

Shear Design

Concrete:
 Strength @ 28 days (f'c) = 34.47 MPa
 Tendon Fpu = 1882 MPa
 Total Prestressing steel Area = 1381.8 mm²

Prestressing Force P_s = 1486.60 kN

Critical Distance:
 from the support (x) = 0.90 m
 Eccentricity (e_x) = -49.70 mm
 Tendon Angle (θ) = 0.05891604 radians

	@ U 5	@ U 3
Loads @ Critical Distance:		
M ₀ = w _u (x/2)(L-x) =	224.00 KN.m	311.11 KN.m
V ₀ = (w _u 2)(L/2-x) =	21.00 KN	11.67 KN
M _{DHL} = W _{DHL} (x/2)(L-x) =	512 KN.m	711.11 KN.m
V _{DHL} = (W _{DHL} 2)(L/2-x) =	48 KN	26.667 KN
Shear load Factor:	1.4 DL 1.7 LL 220.20 KN	1.4 DL 1.7 LL 122.33 KN
Vu =	344.98 KN	

Beam Section
 H = 1200 mm
 bw = 150 mm
 Cb = 600.00 mm
 Ct = 600.00 mm
 Ac = 285000.00 mm²
 Ic = 4.76E+10 mm⁴
 I_{cr} = 167149.122 mm⁴
 Effective depth: d1 = C₁ + e_s = 550.30 mm
 750.84 mm 908.14 mm

Tendon Profile Type Type:

Select Tendon Profile Type: Single Harp

Tendon Profile:	Suggested	User's Preferred Dist from N.A. (mm)	
YL =	600 mm	515 mm	85 Above
YR =	600 mm	515 mm	85 Above
YM1 =	1105 mm	N.A.	505 Below
L1 =	10 meters	N.A.	

(Note: User's preference will be used in the computation if applicable.)

Compute Initial Steel Jacking Force (Pi)

Friction Losses
 Curvature Coefficient (μ) = 0.14
 Wobble Coefficient (k) = 0.001 rad/m
 Friction Factor: α = 0.12 radians
 (μk + kL)% = 3.65%
 $\Delta f_f = (\%loss)(f_{so}) = 11.97$ MPa Divided by two since midspan is considered Also divided by two if stressed both sides.

Anchorage Slip Losses
 Estimated Anchorage Slip (ΔA) = 4 mm
 $\Delta f_A = \frac{\Delta A}{L} E_{ps} = 38.61$ MPa
 Anchorage Slip Loss will govern rather than Friction Loss.

Additional Jack Loss (Freyssinet jack)
 $\Delta f_j = 55$ MPa

Maximum Jacking Force Needed:
 fsi = 1405.61 MPa
 Allowable = 1486.60 MPa
 Remarks: Safe!

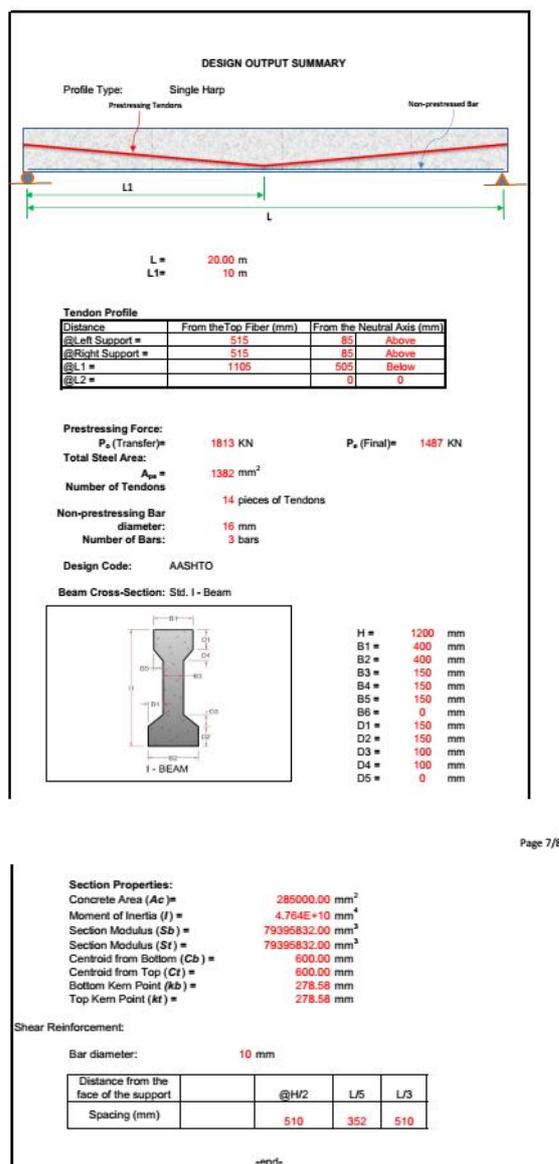
Reinforcement
 Shear Rein. Fy (f_{sv}) = 275 MPa
 Diameter = 10 mm
 No. of Leg = 2
 Rein. Area (A_{sv}) = 157.08 mm²
 C₂ = C₃ = 600.00 mm
 $f_{2sv} = \frac{F_y}{A_s} \left(1 + \frac{C_2}{L} \right) = 4.29$ MPa
 $f_{2sv} = M_{CR} / C_2 = 0.51$ MPa

Cracking Moment (M_{cr}):
 $M_{cr} = \frac{1}{6} (0.5 \sqrt{f_c'} + f_{sv} - f_{sv}) = 532.58$ KN.m
 $V_{cr} = 0.05 \sqrt{f_c'} b_w d + V_u + \frac{M_{cr}}{L} V_{cr} = 505.26$ KN
 limit: $0.14 \sqrt{f_c'} b_w d = 118.36$ KN
 therefore V_{cr} = 505.26 KN
 V_p = P_s sin θ = 87.53 KN
 f_{sv} = P_s / A_{sv} = 5.22 MPa
 $V_{cr} = (0.29 \sqrt{f_c'} + 0.3 f_{sv}) b_w d + V_p = 558.05$ KN
 Shear Force V_c = Min(V_{cr}, V_{sw}) = 505.26 KN
 Factored shear force V_u at section = 344.98 KN
 Vu < φVc
 No Reinforcement Required!

Spacing of Stirrups:
 $s = \frac{\phi A_s f_{sv} d}{V_u - \phi V_c} = 0.00$ mm
 $s_{max} = 0.75h$ or 600mm = 600 mm

Minimum Steel Area:
 $A_s = \frac{b_w s}{3 f_{sv}} \Rightarrow s = 863.94$ mm
 $A_s = \frac{A_c f_{cr}}{80 f_{sv} d} \Rightarrow s = 509.68$ mm

	510 mm	352 mm	510 mm
Final Spacing (s) =	510 mm	352 mm	510 mm



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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