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An Excel Application for Analysis and Design of RC Low-Rise Structural Elements using British Standards and European Codes

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Abstract: There is an increasing demand for tools that can simplify the design process and improve the accuracy and efficiency of the design calculations in structural engineering. This paper presents an Excel application for the design and analysis of reinforced concrete low-rise structures using British standards and European codes. The application aims to assist structural engineers in the design process as it provides a set of pre-programmed calculations for the analysis of slabs, beams, columns, footings and stairs. The application incorporates the relevant design equations and guidelines from both standards and allows the user to input the required parameters and generate concise design outputs such as load capacity, stress analysis results and design recommendations. In developing the application, a combination of VBA programming and yield line method was used. The application has been tested using different design scenarios and the output compared to manual calculations. The application offers significant time savings, increased accuracy, and improved efficiency over manual methods.

Keywords: Beam, British standards, Columns, European codes, Excel application, Footing, Slabs, Stairs, structural engineering, low-rise structures, VBA programming, yield line method, design, analysis.

1. Introduction

The design and analysis of structures, such as buildings, bridges, and tunnels, require complex calculations to ensure their safety and durability [1]. Structural analysis can be done quickly using commercial software like SAP 2000 and ETABS [2], other software includes RISA 3D, Prokon, SAFE, Tekla structural designer among others [3]. Manual calculations are time-consuming, prone to error, and require a great deal of experience and expertise. As a result, there is a need for a user-friendly tool that can assist engineers and designers in their design calculations. Several excel applications have been previously developed for the design of structural elements [4].This study presents an Excel application that that has been developed to perform analysis and design of reinforced concrete low-rise structural elements using British Standards [5] and European Codes [6].The Application comprehensively performs reinforced concrete structural analysis and design as per Eurocode and British Standards by calculating reactions, displacements, bending moments, shear forces and axial forces for static loads on a plane frame structure using the specified tables and Moment distribution method of analysis. Only distributed gravity loads are considered. The structural elements designed by the application are slabs, beams, columns, footings and stairs.

We built the application in Microsoft Excel using Visual Basic for Applications (VBA) programming language, which allowed us to automate the calculations and generate the output data automatically[7].VBA was used by[8] to design reinforced cement concrete beams using spreadsheets, however, spreadsheets can be used to design several elements[9].

There are several advantages to using this Excel application for the design of structural elements using British Standards (BS) and Eurocodes (ECs). Firstly, time-saving: This application significantly reduces the time required for structural design as it automates the calculations and provide immediate results. Secondly, accuracy: there is reduced risk of calculation errors that are common in manual calculations. This is because they use built-in formulas and functions that have been designed to minimize calculation errors. Thirdly, consistency: all calculations done by the application are consistent and follow the same design procedures because they are programmed to use the same design codes and procedures for all calculations. Also, flexibility: this application can be customized to suit the specific needs of the user. This means that users can design structures based on their own preferences and design criteria. Another advantage is portability: the application can be easily shared among team members and clients. Lastly, documentation: the Excel application can generate detailed reports of the design calculations. This can help users to keep track of the design process and provide documentation for future reference. The results of the spreadsheets can be compared to manual calculation for validation purposes as done by [10].

The main objectives include:

- To develop an excel application

- To develop design sheets for slabs, beams, columns, footings and stairs.
- To use structural engineering concepts in the excel sheets.
- To incorporate the use of British Standards and European codes in the design sheets

2. Methodology

2.1 Overview of the Developed Application

The developed Excel application is an excel workbook that consists of 8tabs.Relevant design equations and guidelines in the application have been obtained from British Standards European code. The green cells in each of the tabs requires the user to enter or select data from the dropdown. The user can also print the entire tab or select the cells to print using the "SELECT" and "PRINT PDF" options in each tab.

Tab 1: Home.

This contains the RCC workbook information. It also allows the user to select the desired code between the British Standards and European codes.

Tab 2: Solid Slab

Presents the design of slabs according to the code previously selected. The sheet designs solid slabs both one way and two-way slabs which can be continuous, simply supported slab and the cantilever slabs. The excel performs deflection and cracking checks.

Tab 3: Beam design

Entails the design of beams upto 15 spans. The Excel carries out analysis and design of simply supported and continuous beams which can either be T-beam, L-beam and R- beam using Moment Distribution Method for analysis and yield line method to calculate the slab areas. The user can input moments and shear forces obtained from third party software. The application does design for the critical span and the same reinforcement details provided for all the spans and also the critical support in which the same reinforcements are also provided for all the supports.

Tab 4: Beam shear design

Presents the design of shear reinforcement. Maximum shear forces are used in the design and the reinforcements obtained provided for all spans. The user then checks for deflection and cracking

Tab5: Columns size

The program recognizes three types of columns; perimeter column, internal column and corner column. Tributary area method is used to determine the load carried by the column. The user should note if the structure has a roof or roof slab. The user can also perform calculation of tank load on the roof slab if their structure has any. The user is allowed to selects the type of column section to adopt from either a rectangular, circular section

Tab6: Column design

This tab deals with column design. The user can perform analysis and design of axially loaded columns with no significant moments acting on them. The program sums up the loads from slabs, beams, walls, parapet if any and even the column self-weights to get the cumulative axial loads of columns in each story levels. The reinforcement areas of steel can be directly obtained and the user can directly print the output and start detailing. The program can be used in column design up to eight story levels.

Tab7: Pad footing

The tab deals with the design of pad footing. Presents the design of rectangular or square footing. The user is required to check if the punching shear, transverses hear and face shear are satisfactory.

Tab8: combined bases

Besides the calculations, the sheet presents a visual representation of a combined footing.

Tab9: staircase

The tab presents the design of staircases. The strip method (1m width strip) is used for the design. This Excel also incorporates the check for deflection upon entering the required fields. This tab also shows staircase plan and side elevation for visual interrogation.

2.2 Operating the Application

Upon installing and opening the application, a message box is displayed. The user then clicks "OK" to enable the program.

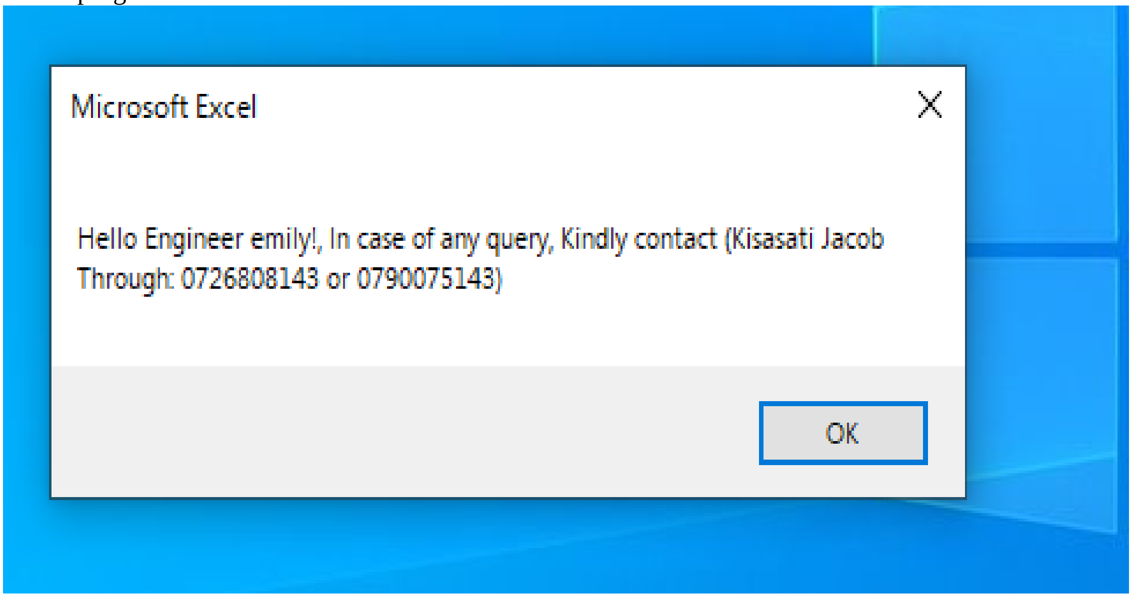


Fig 1: Snapshot the Message box

Tab 1: Home.

This tab displays the RCC workbook information button and the code to select button. Upon clicking the RCC workbook information button, more information is displayed. The user then selects the code to use from the dropdown.

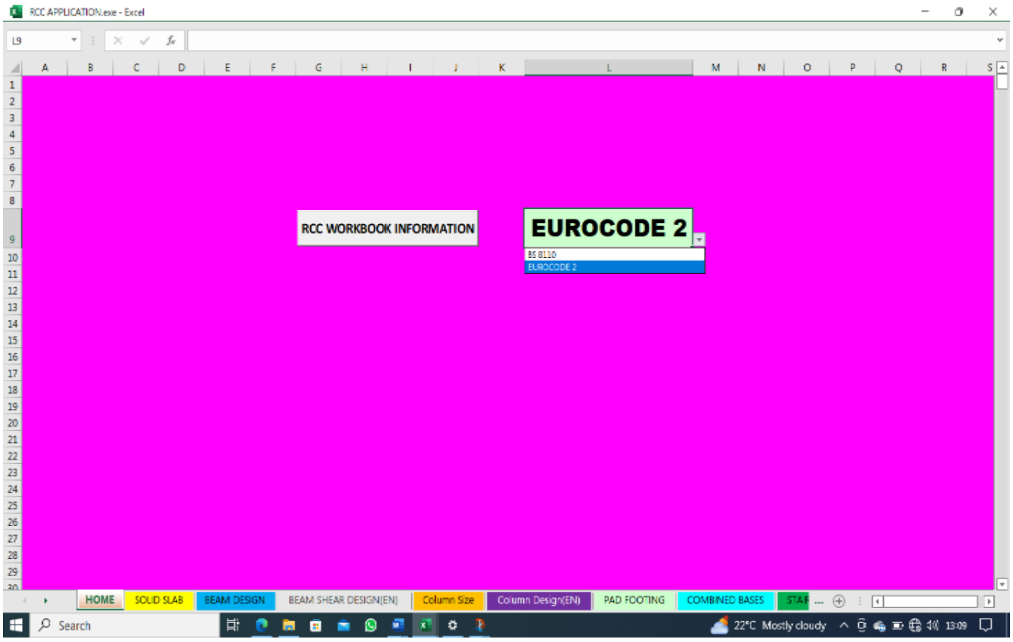


Fig 2: Snapshot of the Home Tab

2.2.1 Design of Slabs

Tab 2: Solid slab.

This is the first element to design. The user performs the following steps:

1. Enter the story height, average diameter of coarse aggregate, h_{agg}
2. Select whether to calculate the slab thickness or input as per your engineering experience
3. Enter the span length, select cover and then enter the assumed diameter.
4. Select the class of concrete, and the strengths of the reinforcing bars and the density of concrete.

5. Input the loads on partitions, services and finishes and also the live loads
6. Select the type of panel to design for. Enter the dimensions of the slab. The excel determines the type of slab based on load distribution i.e., two way or one way
7. Enter the length of the shorter span when designing for a one way or cantilever solid slab.
8. Select the required areas to determine the size and spacing of the reinforcement.
9. The excel does the overall checks for deflection and cracking then advises if the reinforcements provided are satisfactory or not.

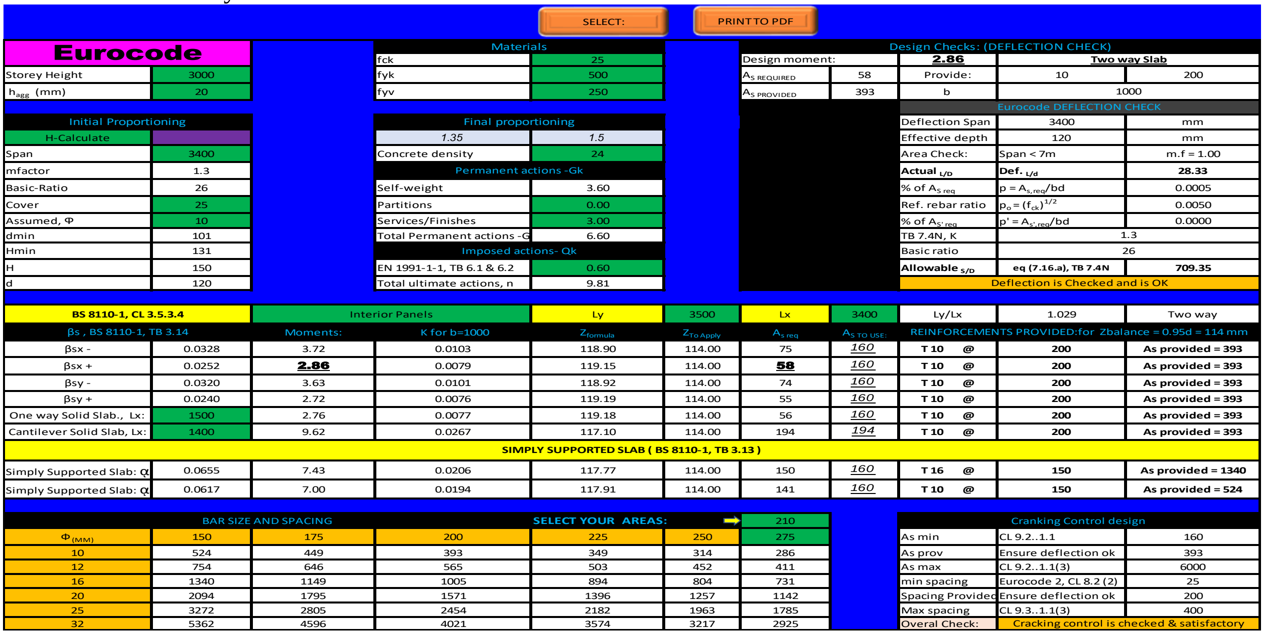


Fig 3 : Snapshot of the solid slab Tab

2.2.2 Design of Beams

When designing for a beam, the user is required to:

Tab 3: Beam Design

1. Type in the beam number intended for design, the height of the beam, width of the beam web, width of the wall, the unit weight of wall material used
2. Select
   - if the beam to design is a T-beam, L-beam or R-beam
   - select the number of spans in the beam
3. Enter the span widths of the beam. If L-beam, enter the widths of one side and if T- beam or R-beam enter the widths of both sides. The program generates the maximum sagging moments, maximum hogging moments and the maximum shear force in the entire beam.
4. Incorporate Moments and shear forces obtained from third party software if need be. Select whether to use the moments obtained by excel or the inputted moments.
5. Select design of sagging reinforcement to design for spans. Select design of hogging reinforcement to design for supports.
6. Enter the class of concrete to use
7. Provide reinforcement details using the area provided. Select the area required to determine the number of bars and the diameter that can be used.
8. Enter the details of the reinforcement bars as preferred in the first and second layer.

COMPLETE DESIGN AND CHECKS FOR BEAMS AS PER EUROCODE 2

BEAM 1	h_{beam}	450	H_{slab}	150	γ_{wall}
Eurocode	bweb	200	Beam h_{web}	300	
	bwall	200	H_{wall}	2550	18
	Gk-slab	6.60	n- slab	9.81	kN/m^2
	Masonry Load: (Gk	9.18	Masonry Load: (n	12.393	kN/m
	Beam load: (Gk)	1.44	Beam load: (n)	1.944	kN/m

6	T-BEAM (Designed as T)			1.35	Analysis type	MDM
	SPAN LENGTH	ONE SIDE LENGTH	OTHER SIDE LENGTH	YieldLine-AREAS	1.35GK: Loads	N: Loads
1	3.50	3.40	2.80	6.00	29.61	31.15
2	3.00	3.40	2.80	4.49	27.67	29.02
3	3.50	3.40	1.00	4.56	25.95	27.12
4	4.00	5.00	5.00	8.00	32.16	33.96
5	5.10	5.00	5.00	13.00	37.05	39.34
6	5.00	5.00	3.00	11.50	34.83	36.90

CONFIRM & SELECT

0.87

M_{span} MDM:	68.64	$M_{SUPPORT}$: =	105.36	V_{MAX}: =	113.32
M_{span} User:	46.00	$M_{SUPPORT}$: =	72.00	V_{MAX}: =	75.00
M_{SPAN}: =	46.00	$M_{SUPPORT}$: =	72.00	V_{MAX}: =	75.00
Continuous Beam			Φ_{bar}	16	mm
Selected Beam Section		T SECTION	Φ_{link}	8	mm
Beam Longest Span (mm)		5100	Cover, C	25	mm
Beam flange Width, b_f		1755	d	409	mm
Designing a Continuous Beam T SECTION			d'	41	mm
DESIGN OF SAGGING REINFORCEMENT: SPAN MOMENT = :					46

BEAM DESIGN TO EUROCODE 2					
fyk	500	N/mm^2	fyv	250	N/mm^2
fck	25	N/mm^2	b_{eff}	1755	mm
K	0.006	K_{bal}	0.167	No Comp. rebars	
Z	406.73	Z_{bal}	388.55	$Z_{TO\ USE}$	388.55
X	51.13	X_{CHECK}	251.54	Yielding checked & OK	
$A_{S'}$	**0**	$A_{S\ REQ}$	**273**	mm^2	

Select bars for $A_{S\ REQ}$	First Layer:	2	16	$A_{S\ PROVIDED}$:	**402**
	Second Layer:	0	12		
Number of Bars			Select the required Area		273
Bar Size	**2**	**3**	**4**	**5**	**6**
12	226	339	452	565	679
16	402	603	804	1005	1206
20	628	942	1257	1571	1885
25	982	1473	1963	2454	2945
32	1608	2413	3217	4021	4825

Figure 4: Snapshot of the Beam Design Tab

Tab 4: Beam shear design

9 Enter the assumed column height and width.
10 Select the number of legs, the diameter and the spacing to use in providing the details of the links.
11 Check if the deflection and cracking control check are satisfactory.

SHEAR REINFORCEMENTS DESIGN AND CHECKS TO EUROCODE 2:

SHEAER REINFORCEMENTS DESIGN		
d	409	mm
fyk	500	N/mm^2
fck	25	N/mm^2
As req	273	mm^2
First Layer:	2	16
Second Layer:	0	12
$A_{S\ PROV}$	402	mm^2
Assumed Col:	200	200
N_{Ed}	75.00	kN
N_{MAX}	26.95	kN/m
$\gamma_{concrete}$	1.5	
V_{Ed}	61.28	kN
SHEAR GEOMETRY IN DEGREES		
θ	45	
Cot	1	
tan	1	
DIMENSIONS CHECK		
V	0.54	N/mm^2
$V_{Rd\ MAX}$		kN
Beam dimensions satisfactory		
$V_{Rd,c}$	48.718	kN
$A_{SW/S\ MIN}$	0.16	N/mm^2
$A_{SW/S}$	0.38	N/mm^2

DEFLECTION CHECKS AND VERIFICATION		
Deflection Span: L	5100	mm
Effective depth: d	409	mm
b_{web}	200	mm
ACTUAL CONDITIONS OF THE BEAM		
Actual L/d	**12.47**	
PERMISSIBLE CONDITIONS UNDER SERVICE		
fck	25	N/mm^2
$A_{S\ REQUIRED}$	273	mm^2
$A_{S\ PROVIDED}$	402	mm^2
$p_o = (f_{ck})^{1/2}$	0.005	
$p = A_{s,req}/b_w d$	0.0033	
$p' = A_{s',req}/b_w d$	0	
Factor for structural system, K		1.3
Checks:	Use equation (1)	
L/d	36.2206843	
σ_S	210.4575443	N/mm^2
Allowabe L/d	**53.35**	
DEFLECTION CHECK IS SATISFACORY		

CRACKING CHECKS AND VERIFICATION		
Total height, h	450	mm
b_{web}	200	mm
b_{eff}	1755	mm
Cover, C	25	mm
Φ_{LINK}	8	mm
AREA CHECKS $ VERIFICATIONS		
Eurocode 2, & TB 3.1(Row 5)($A_{S\ MIN}$)		
f_{ctm}	2.56	mm^2
As min	109	mm^2
Eurocode 2, CL 9.2.1.1(3) ($A_{S\ MAX}$)		
AS max =4.0%	3600	mm^2
$A_{S\ REQ}$:	273	mm^2
$A_{S\ PROVIDED}$	402	mm^2
AREA OF REBARS CHECK & VERIFICATION		
AS MIN < AS PROV < AS MAX		***PASS***
SPACING CHECKS $ VERIFICATIONS		
BS 8110-1, TB 3.28 (Maximum Spacing)		
No moment redistribution, Smax		155
Spacing $_{minimum}$	Eurocode 2, CL 8.2 (2)	25
Spacing of our Rebars:		102.00
Min Space< Prov Space< Max Space)		***PASS***
Cracking control checked and is satisfactory		

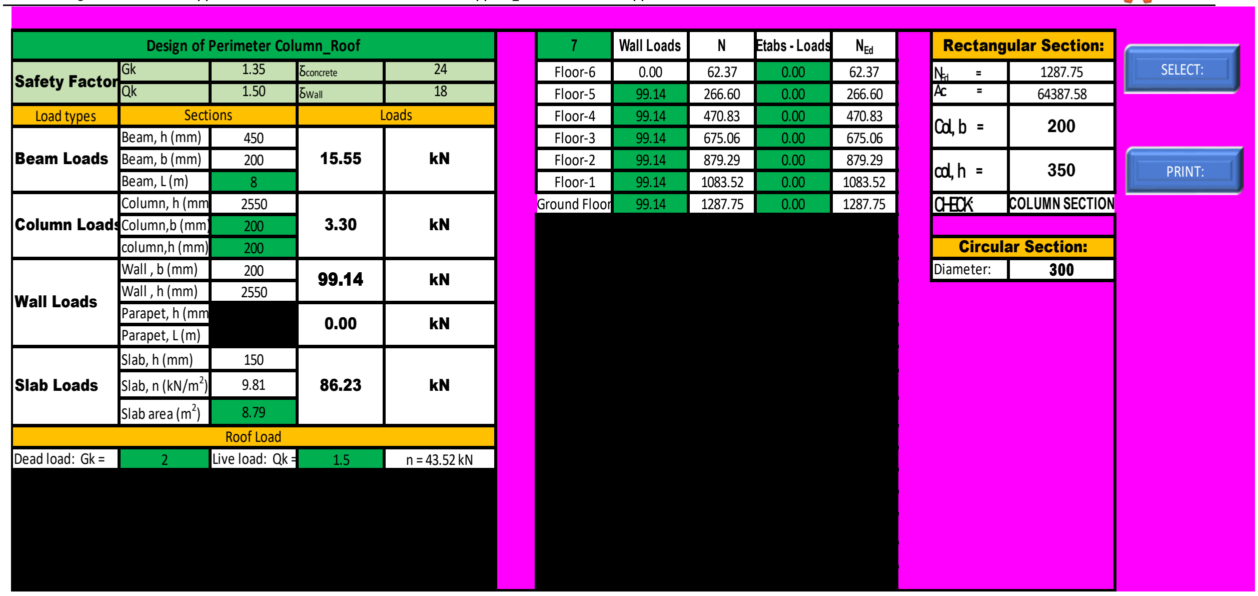
Provide 4 Legs of T	No. of legs:	4	Link spacing							
8	Φ LINKS:	**100**	**125**	**150**	**175**	**200**	**225**	**250**	**275**	**300**
@	**8**	2.02	1.60	1.34	1.14	1.00	0.90	0.80	0.74	0.68
200	**10**	3.14	2.52	2.10	1.80	1.58	1.40	1.26	1.14	1.04

Figure 5: Snapshot of Shear Design Tab

2.2.3 Design of Columns

Tab 4: Column Size

1. The user is required to enter the beam length (m) supporting the slab the column will carry.
2. The initial size of the column b and h are assumed in mm
3. Enter parapet wall height(mm) and length(m)
4. Enter slab area(m^2)
5. In case of tanks supported on the roof slab, enter the tank volume, roof slab thickness and finishing loads (kN/m^2) and live load (kN/m^2).



Design of Perimeter Column_Roof					
Safety Factor	Gk	1.35	$\delta_{concrete}$	24	
	Qk	1.50	δ_{Wall}	18	
Load types	Sections		Loads		
Beam Loads	Beam, h (mm)	450	15.55	kN	
	Beam, b (mm)	200			
	Beam, L (m)	8			
Column Loads	Column, h (mm	2550	3.30	kN	
	Column,b (mm	200			
	column,h (mm)	200			
Wall Loads	Wall , b (mm)	200	99.14	kN	
	Wall , h (mm)	2550			
	Parapet, h (mm		0.00	kN	
	Parapet, L (m)				
Slab Loads	Slab, h (mm)	150	86.23	kN	
	Slab, n (kN/m^2)	9.81			
	Slab area (m^2)	8.79			
Roof Load					
Dead load: Gk =	2	Live load: Qk =	1.5	n = 43.52 kN	

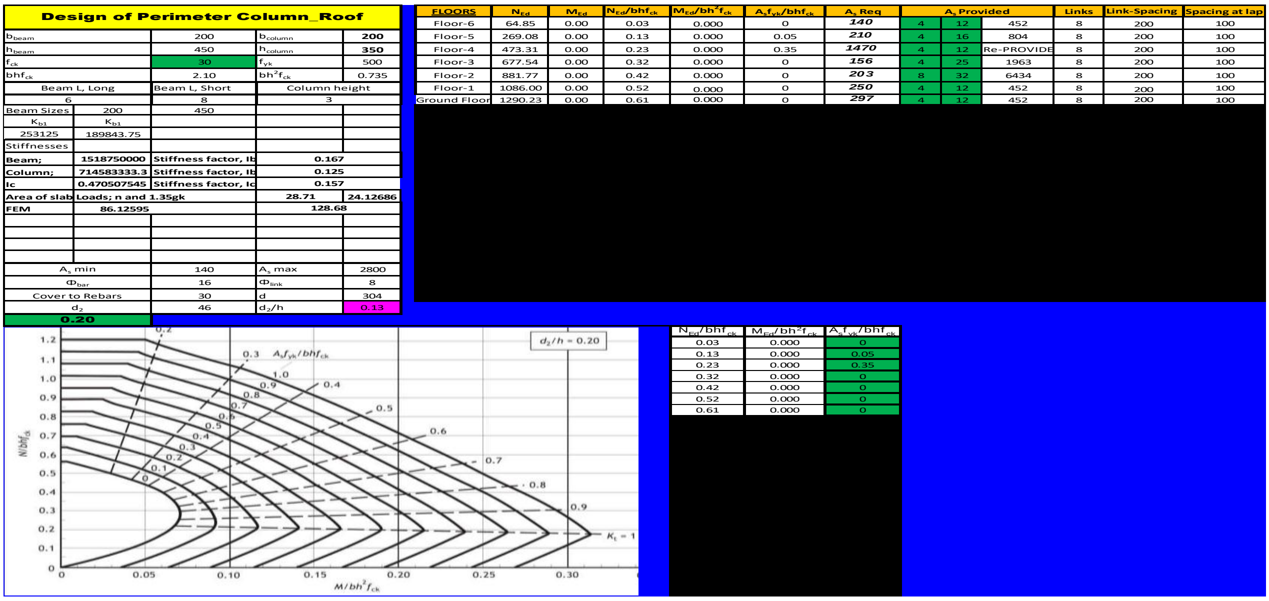
7	Wall Loads	N	Etabs - Loads	N_{Ed}
Floor-6	0.00	62.37	0.00	62.37
Floor-5	99.14	266.60	0.00	266.60
Floor-4	99.14	470.83	0.00	470.83
Floor-3	99.14	675.06	0.00	675.06
Floor-2	99.14	879.29	0.00	879.29
Floor-1	99.14	1083.52	0.00	1083.52
Ground Floor	99.14	1287.75	0.00	1287.75

Rectangular Section:		
N_{Ed}	=	1287.75
Ac	=	64387.58
Col, b	=	200
col, h	=	350
CHECK		COLUMN SECTION
Circular Section:		
Diameter:		300

Figure 6: Snapshot of Column Size Tab

Tab 5: Column Design

1. Class of concrete to be used.
2. The cover of the column based on durability and exposure conditions of the column.
3. The type of column selected from the dropdown arrow.
4. End conditions of the column
5. The reduction factor from the dropdown arrow provided.
6. The area to be used in providing reinforcement in mm^2.



Design of Perimeter Column_Roof				
b_{beam}		200	b_{column}	200
h_{beam}		450	h_{column}	350
f_{ck}		30	f_{yk}	500
bhf_{ck}		2.10	bh^2f_{ck}	0.735
Beam L, Long		Beam L, Short	Column height	
6		8	3	
Beam Sizes	200	450		
K_{b1}	K_{b1}			
253125	189843.75			
Stiffnesses				
Beam;	1518750000	Stiffness factor, Ib	0.167	
Column;	714583333.3	Stiffness factor, Ib	0.125	
Ic	0.470507545	Stiffness factor, Ic	0.157	
Area of slab	Loads; n and 1.35gk		28.71	24.12686
FEM	86.12595		128.68	
A_s min		140	A_s max	2800
Φ_{bar}		16	Φ_{link}	8
Cover to Rebars		30	d	304
d_2		46	d_2/h	0.13
0.20				

FLOORS	N_{Ed}	M_{Ed}	N_{Ed}/bhf_{ck}	M_{Ed}/bh^2f_{ck}	A_sf_{yk}/bhf_{ck}	A_s Req	A_s Provided			Links	Link-Spacing	Spacing at lap
Floor-6	64.85	0.00	0.03	0.000	0	140	4	12	452	8	200	100
Floor-5	269.08	0.00	0.13	0.000	0.05	210	4	16	804	8	200	100
Floor-4	473.31	0.00	0.23	0.000	0.35	1470	4	12	Re-PROVIDE	8	200	100
Floor-3	677.54	0.00	0.32	0.000	0	156	4	25	1963	8	200	100
Floor-2	881.77	0.00	0.42	0.000	0	203	8	32	6434	8	200	100
Floor-1	1086.00	0.00	0.52	0.000	0	250	4	12	452	8	200	100
Ground Floor	1290.23	0.00	0.61	0.000	0	297	4	12	452	8	200	100

N_{Ed}/bhf_{ck}	M_{Ed}/bh^2f_{ck}	A_sf_{yk}/bhf_{ck}
0.03	0.000	0
0.13	0.000	0.05
0.23	0.000	0.35
0.32	0.000	0
0.42	0.000	0
0.52	0.000	0
0.61	0.000	0

Figure 7: Snapshot of Column Design Tab

2.2.4 Design of Footing

Tab 6: Pad Footing

In the design of pad footing, the user undertakes the following steps:

1. Select the ultimate service conversion factor from the options 1.37, 1.4, 1.45, 1.5
2. enter the allowable bearing pressure of the site location
3. select the desired shape of footing, either the square footing or the rectangular footing
4. enter the desired dimensions of the footing bearing in mind the calculated areas

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5. enter the class of concrete, cover and the assumed diameter.
6. Enter the eccentricity values
7. Select the reinforcement bars and spacing
8. Check if the punching shear, transverse shear and face shear are satisfactory

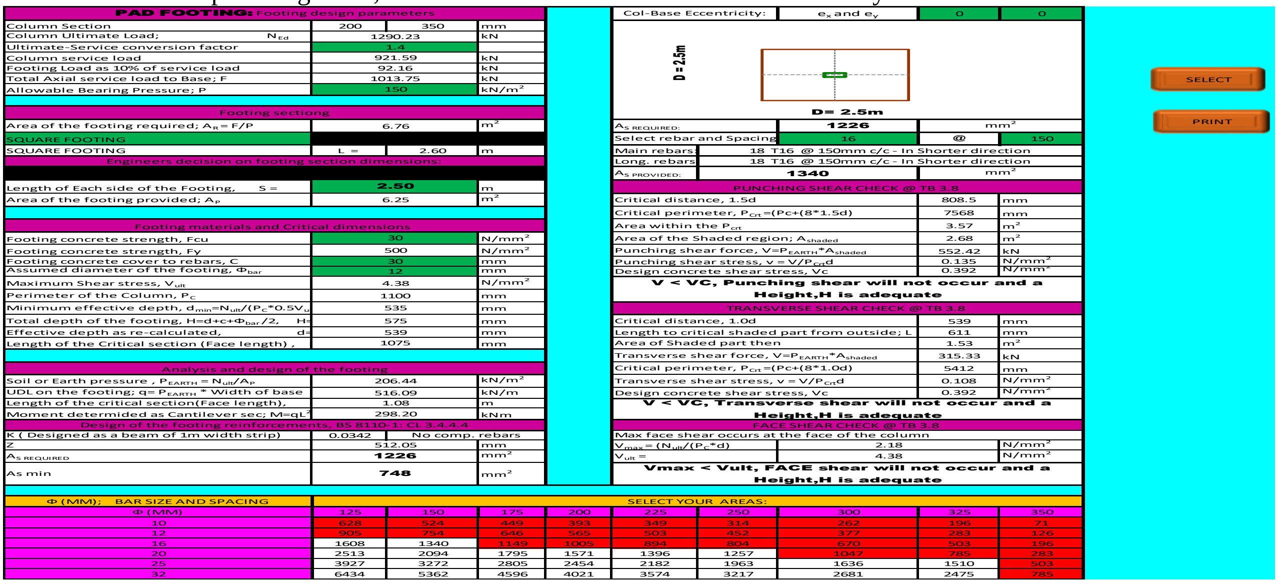

Figure 8: Snapshot of Pad Footing Tab

Tab 7: Combined Bases

The user is required to:

9. Select the class of concrete and the cover
10. Enter the distance between the column centers
11. Enter the column loads from the two columns
12. select the ultimate service conversion factor, enter the bearing capacity of the area
13. enter the desired dimensions of the rectangular footing bearing in mind the dimensions calculated by the software
14. In the preliminary proportioning, enter the size of the first and second column, the assumed diameter of the bar.
15. Enter the diameter and spacings in the design of reinforcement

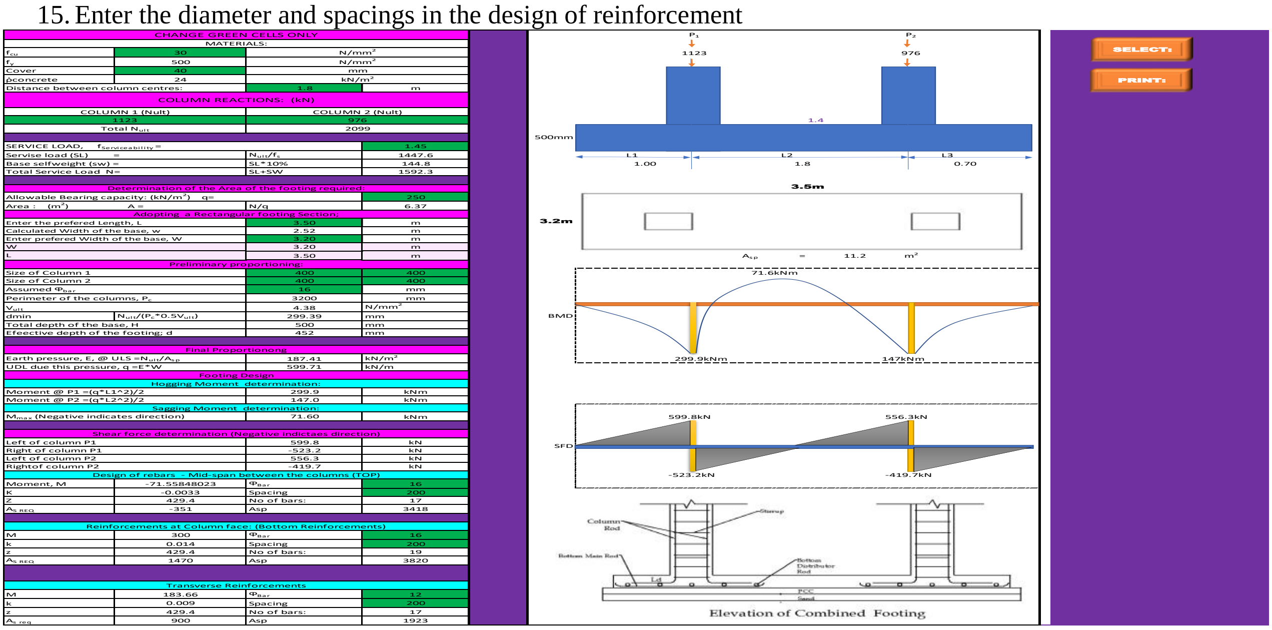

Figure 9: Snapshot of Combined Bases Tab

Tab 8: staircase

1. The user is required to input the following data
    - The number of risers in one side of the stairs
    - Height of each riser
    - Length of each thread
    - Effective span
    - Concrete density to be used
    - Live load
    - Strength of steel reinforcement
    - Strength of shear reinforcements
    - Strength of concrete
2. Depending on the area of steel reinforcements required and minimum reinforcement needed, the user chooses the diameter of bar to be used and the spacing of reinforcement to be provided.
3. The distribution reinforcements are provided based on the minimum required area of reinforcement. The excel checks the deflection and confirms it satisfactory or not.

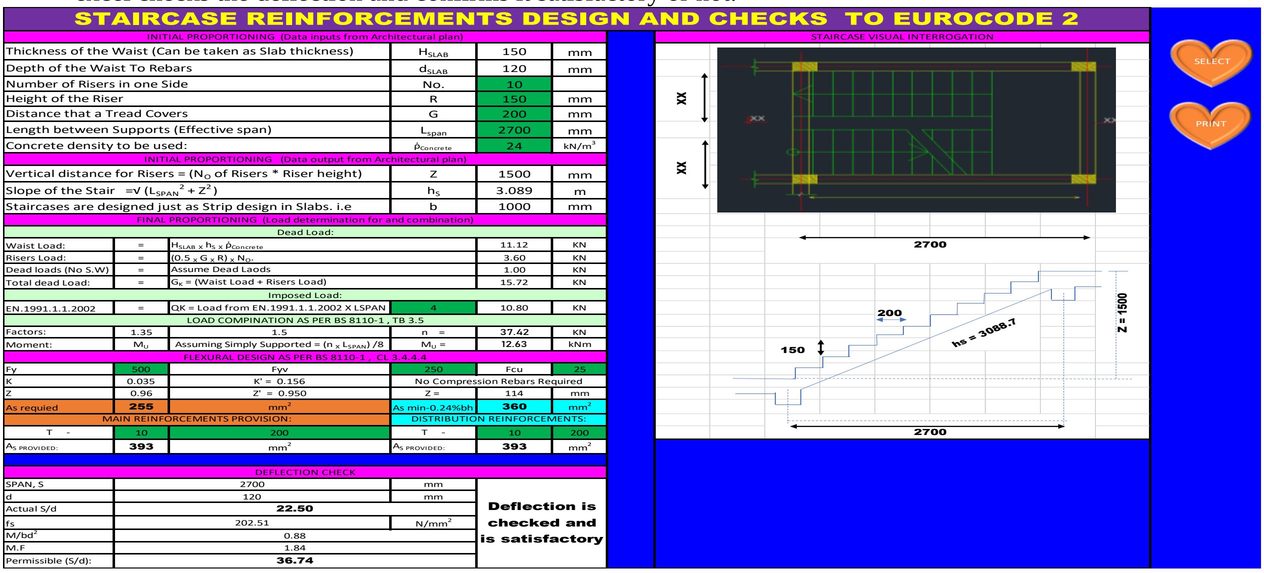

Figure 10: Snapshot of Staircase Tab

3. Conclusion

The Excel Application is a very useful tool in the design of reinforced concrete lowrise structural elements such as the slabs, beams, columns, footings and stairs using British standards and Eurocodes. This application has been tried using different scenarios and has not only proven to be user- friendly but also is more accurate, saves a lot of time and paper when compared to manual calculations. Also, the user has the liberty to input data obtained from other design tools and softwares during the design process to aid in their design.

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