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On-Site Structural Design Capacity Checker for Reinforced Concrete Beams

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Abstract. This paper presents a structural design capacity checker that has been developed by using Microsoft Excel in order to carry out the calculations of simply supported beam as based on Eurocode 2. The purpose of this research is to develop an Excel User Interface and to perform structural design adequacy check of simply-supported beam under construction at the site. Besides, the required formulations for main reinforcement, shear, deflection and cracking checks are also programmed. The results of maximum shear force, maximum bending moment, tension and compression bars provided in Excel User Interface and STAAD Pro are compared. There are four main parts in Excel User Interface which are input, output, detailed calculation and data sheet. Input and output are the visible parts whereas detailed calculation and data sheet are hidden. In the output sheet, graph of shear force and bending moment, tension and compression bars provided, adequacy of main and shear reinforcement, deflection and cracking checking are shown. Another design of simply supported beam is designed by using STAAD Pro. The results that obtained from Excel User Interface and STAAD Pro is compared. This research helps users to carry out a structural capacity checking of simply supported beam in simple, precise and quicker.

1. Introduction

In the building construction, substructure and superstructure are the two-basis part of the building. Superstructure is the part of structure that located above the ground level. The structure which is known as superstructures include column, beam, slab, brick wall and roof [1]. Thus, every single important step in the building design and construction need to be measured so that the structure of the building is in the safety limits.

The criteria in designing the current capacity of structure are the strength and service ability. The strength of the structure is the adequacy of the structure to withstand the applied load without beyond the limit of any part of the structural member system. For the serviceability of the structure, it is normally defined as deflection which meant structure's fitness which used for specific design loadings. There are allowable limits for all the structural elements. It is a risk when it is required to find the present capacity of the structure [2].

The safety of the structural buildings and other facilities are the most concern issues for the clients, contractors and engineers. It is a human tragedy which includes high human suffering and monetary loss such as injuries, death, suffering and loss of productivity. In the construction site, safety issues due to the failure of structure need to be taken in order to eliminate the destruction of building during construction time [3]. Eurocode 2 (EC2) is the standard of structural design of concrete structure which is proposed by European. There are 9 separate documents which is related to concrete design in Eurocode 2 and it is published by the British Standard Institution [4]. EC2: Part I is about the building's design. The principle of Eurocode 2 stated any alternatives are not allowed and the designer must comply with the standard [5].

2. Methodology

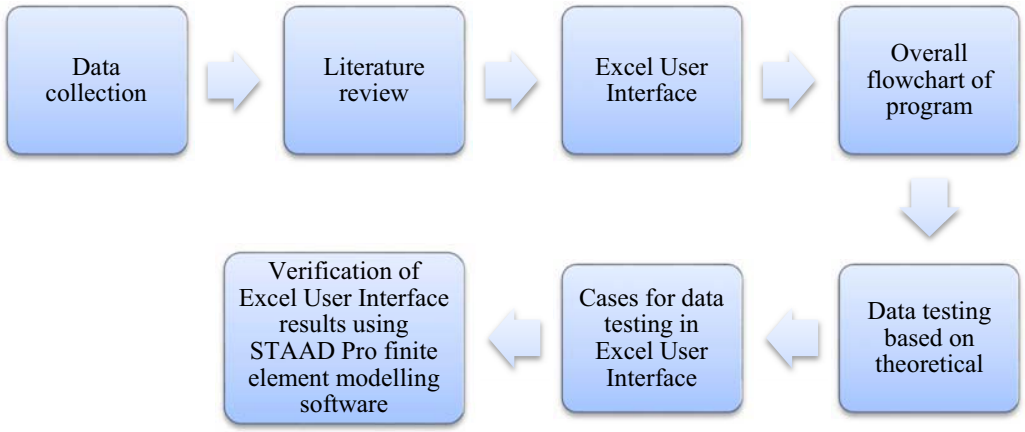


Fig.1: Overall process of flow chart

Data Collection. The software that is used to develop the user interface is by using Microsoft Excel 2013. Data collection such as all the function library of Microsoft Excel 2013 is determined. There are hundreds of functions in Excel but only some of the function is used which depend on the type of data that are needed. Excel Easy, Excel Exposure, YouTube such as Excel Tutorial and ExcellsFun are the medium that provide tutorial of using Microsoft Excel on the network. Besides, Function Library is on the Formula tab and it is a place which can explore the functions of Excel.

Literature Review. Once the data collection has been completed, online database is familiarized and identified in the field of study. Google Scholar, e-resources and Science Direct are the sources which are used to search the relevant databases about the topic of the study. Firstly, the articles are identified and located before starting to write the literature review. The objective and content of the articles are analyzed. The articles are arranged in categories. Then, the literature in table or idea of flowchart is summarized. An outline of the final overview is developed and written the review of literature. Finally, a coherent essay is developed. The reference of databases which is used in the thesis is also written.

Excel User Interface. Excel User Interface was a program for reinforced concrete simply supported beam design as per Eurocode 2. The main purpose was to help user who do or do not have any structural background but need to do structural calculation of checking the capacity of simply supported beam. Thus, the program is established with simple and easy to use interface. User only need to key or select the data of simply supported beam to input and the results of calculations is showed on the output sheet. The user interface was the program designed by using Microsoft Excel 2013. Excel is the most easy and simplest program to use by the user. Therefore, good user interface is produced.

Overall Flowchart of Program. A program which is used to check the capacity of the simply supported beam is developed by using Microsoft Excel 2013. In the excel user interface, formulation flow for the simply-supported beam is designed as per Eurocode 2 (Design of Reinforced Concrete Structure). The excel user interface is divided into 3 main parts which are input, detailed calculation and output while data sheet was the subpart of the program. Some of the function of input is depended to the detail value of data sheet while the function of detailed calculation is connected by the input which is chosen by the users and value of data sheet which related to the input of data. Lastly, the output is only connected to the detailed calculation part. Anybody can use the user interface included user who do not have any structural knowledge. When the data of the simply supported structure is put into the input sheet of excel user interface and the results of calculations is shown on the output sheet automatically.

In Excel User Interface, input sheet and output sheet were visible by users whereas detailed calculation and data sheet were not visible by users. The worksheets of both detailed calculation and data sheet were make it very hidden by using Microsoft Visual Basic. It was to prevent hidden worksheet appearing in hidden sheet dialog. The worksheet and the workbook of Excel User Interface is protected the structure of Excel User Interface with a password. There are two processes in worksheet protection. The first step was to unlock cells that needed to be editable and then the worksheet is protected with a password. The workbook protection was to prevent users from viewing hidden worksheet, adding, moving or deleting worksheets of Excel User Interface. Figure 3.2 showed the overall flowchart for the excel user interface.

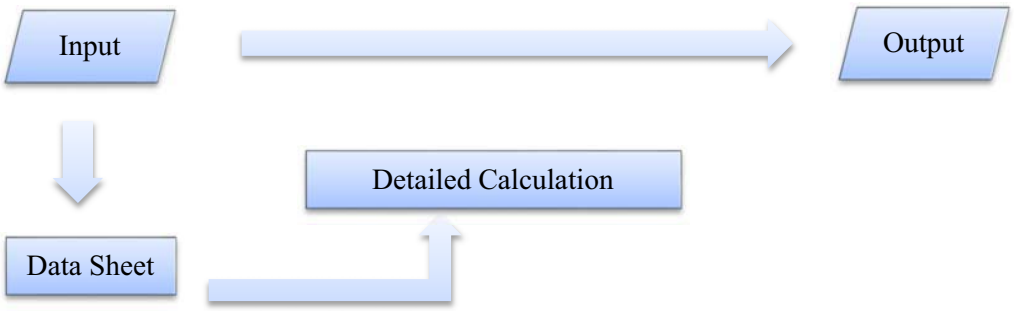


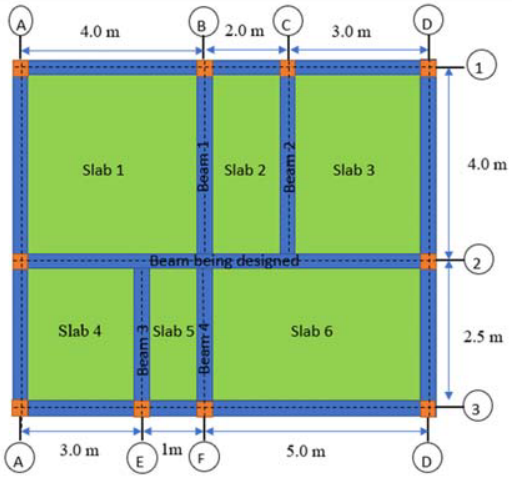
Fig. 2: Overall flowchart of Excel User Interface

Data Testing Based on Theoretical. Data testing based of Excel User Interface is tested based on the theoretical with my supervisor. All of the formulation in the Excel User Interface is checked in order to ensure that the accurate results and readings are given to the user.

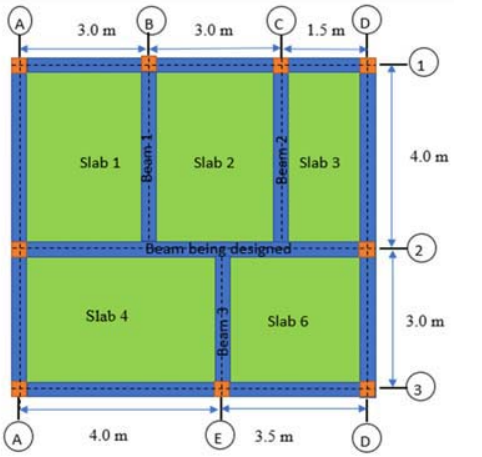
Cases for Data Testing in Excel User Interface. There are 8 possible cases that can be used for the simply supported beam in the Excel User Interface, considering maximum of two beam on each size of the simply supported beam being considered.

Table 1: Cases for data testing in Excel User Interface

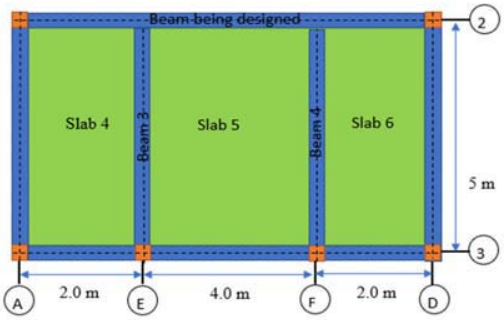
Case 1: Simply Supported Beam Subjected to 4 Point Loads and Distributed Load	Case 2: Simply Supported Beam Subjected to 3 Point Loads and Distributed Load Simply Supported Beam Subjected to 3 Point Loads and Distributed Load

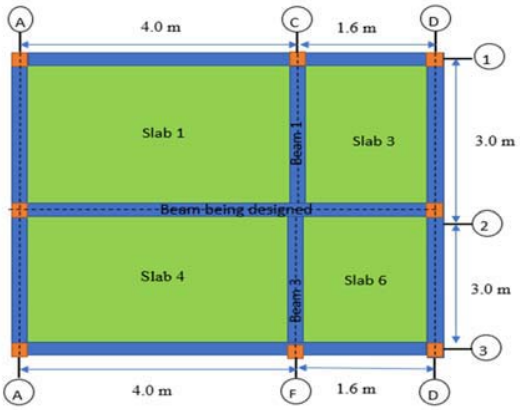


Case 3: Simply Supported Beam Subjected to 2 Point Loads at the Same Side and Distributed Load

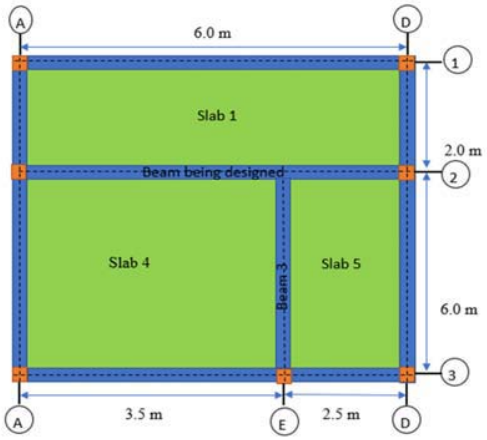


Case 4: Simply Supported Beam Subjected to 2 Point Loads from Two Different Sides and Distributed Load

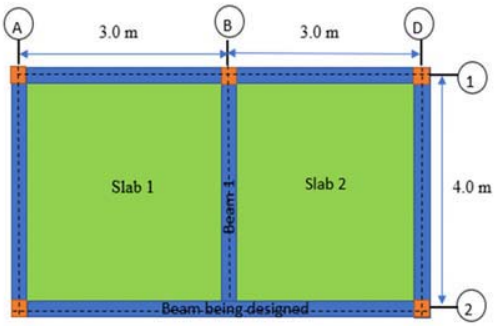




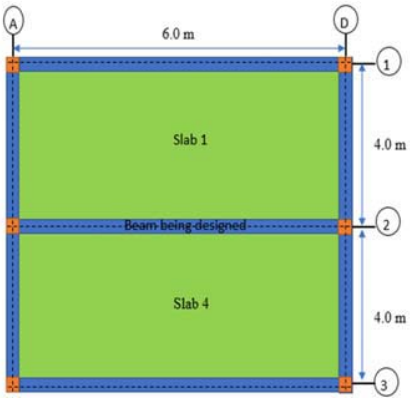
Case 5: Simply Supported Beam Subjected to 1 Point Loads and Distributed Load from 2 Different Sides



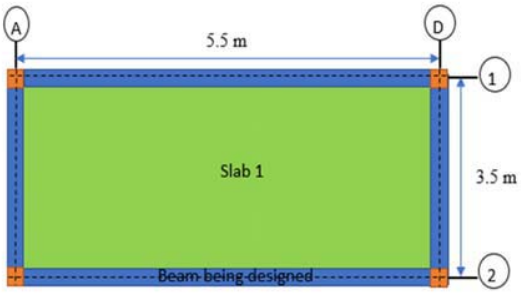
Case 6: Simply Supported Beam Subjected to 1 Point Loads and Distributed Load from Same Side



Case 7: Simply Supported Beam Subjected to Distributed Load with 2 Slabs



Case 8: Simply Supported Beam Subjected to Distributed Load from 1 Slab



Verification of Excel User Interface Results Using STAAD Pro Finite Element Modelling Software. Lastly, data verification is performed by comparing the output that Excel User Interface and results of STAAD Pro. By performing the checking, functionability of the Excel User Interface can be determined and the analysis is done in order to check the accuracy of the Excel User Interface.

3. Results and Discussions

3.1. Maximum Shear Force

Table 2 showed the maximum shear force and percentage of difference which was obtained from Excel User Interface and STAAD Pro.

Table 2: Maximum shear force

Maximum shear force (KN)

Case	Excel User Interface	STAAD Pro	Percentage of difference (%)
1	374.272	375.650	0.3668
2	363.499	363.498	0.0003
3	153.464	153.465	0.0007
4	197.157	197.156	0.0005
5	157.893	157.894	0.0006
6	134.818	134.817	0.0007
7	93.085	93.086	0.0011
8	78.686	78.684	0.0025

From Table 2, it was clearly showed that there was only small percentage of difference in the value of maximum shear force which was obtained from the Excel User Interface and finite element software STAAD Pro. For the maximum shear force, all the percentage of difference for both Excel User Interface and finite element software STAAD Pro for 8 cases was below 1%. The highest difference percentage of maximum shear force was case 1 which was about 0.3668% while the lowest difference percentage of maximum shear force was case 2 which was about 0.0003%. The percentage of difference for maximum shear force in 8 cases were quite low and thus the results of maximum shear force which obtained from Excel User Interface were quite accurate when compared with the STAAD Pro.

3.2. Maximum Bending Moment

Table 3 showed that the maximum bending moment and distance of maximum bending moment that obtained from the Excel User Interface and STAAD Pro. The percentage of difference for both values that obtained were calculated.

Table 3: Maximum bending moment

Case	Length of simple supported beam (m)	Excel User Interface		STAAD Pro		Percentage of difference (%)
		Maximum bending moment (KNm)	Position of maximum bending moment (m)	Maximum bending moment (KNm)	Position of maximum bending moment (m)	
1	9.0	-959.764	4.056	-956.707	4.500	0.3195
2	7.5	-734.634	3.833	-734.398	3.750	0.0321
3	8.0	-293.608	3.461	-306.930	4.000	4.3404
4	5.6	-264.988	3.337	-264.872	3.270	0.0438
5	6.0	-288.356	3.500	-288.359	3.500	0.0010
6	6.0	-255.525	3.000	-255.524	3.000	0.0004
7	4.0	-93.085	2.000	-93.086	2.000	0.0011

8	6.0	-118.027	3.000	-118.026	3.000	0.0008

In the maximum bending moment, there was only one of the percentage difference was above 1% and the others was below 1%. Case 3 had the highest difference percentage of maximum bending moment (4.304%) while case 6 had the lowest difference percentage of maximum bending moment (0.0010%). The distance of maximum bending moment for first 4 cases which obtained from Excel User Interface and finite element software STAAD Pro were different. This was because bending moment is obtained from shear force in Excel User Interface. However, in STAAD Pro, the shear force is obtained through finite element matrices. The values of shear force along the distance different to manual calculation. Therefore, there had some difference on the maximum bending moment and the position of the maximum bending moment between Excel User Interface and the finite element software STAAD Pro. However, the percentage of difference for both maximum bending moment and distance of maximum bending moment occur are not much different. It concluded that the results of maximum bending moment and distance of maximum bending moment that shown in Excel User Interface are accurate.

3.3. Tension Bars

Table 4 showed that the tension bars provided and difference number of bars provided between the Excel User Interface and finite element software STAAD Pro.

Table 4: Tension bars provided

Case	Excel User Interface	STAAD Pro	Difference of tension bars provided
1	8H32	7H32	1H32
2	7H32	5H32	2H32
3	4H25	3H25	1H25
4	5H25	3H25	2H25
5	5H25	4H25	1H25
6	7H20	5H20	2H20
7	5H16	3H16	2H16
8	4H20	3H20	1H20

In Table 4, the tension bars that provided by Excel User Interface and finite element software for 8 different cases were different. It showed that the tension bars provided by Excel User Interface had higher number of tension bars provided than the results obtained by the software. This is because additional longitudinal reinforcement due to shear were included in the calculation of Excel User Interface while STAAD Pro limitation in considering the additional longitudinal reinforcement on simply supported beam. Thus, Excel User Interface was more emphasis on the safety factor of design. Excel User Interface took the higher number of tension bars provided in order to consider the worst-case scenario.

3.4. Compression Bars

Table 5 showed that the compression bars provided and difference number of bars provided between the Excel User Interface and finite element software STAAD Pro.

Table 5: Compression bars provided

Case	Excel User Interface	STAAD Pro	Difference of compression bars provided
1	2H25	2H25	0
2	2H25	2H25	0
3	-	-	-
4	-	-	-
5	3H16	3H16	0
6	-	-	-
7	-	-	-
8	-	-	-

From Table 5, it showed that there were same number of compression bars provided between Excel User Interface and finite element software STAAD Pro in case 1, case 2 and case 3. There was not any difference of compression bars provided for case 1, case 2 and case 3. Thus, it can be concluded that the results of compression bars provided which obtained by Excel User Interface was same with the results that obtained from STAAD Pro. The results of compression bars provided in Excel User Interface were accurate.

4. Conclusions

Excel User Interface has been developed for everyone with or without the structural background. The main purpose of this program is to help users with or without the structural background to perform structural design adequacy check of simply supported beam under construction at the site based on Eurocode 2.

In Excel User Interface, the formulation of main reinforcement, shear reinforcement, deflection and cracking checks are programmed. It is a simple program and it provides some basic information to users in the input and output sheets. The maximum concentrated forces that subjected to simply supported beam is four. It is a worst-case scenario when the simply supported beam is subjected with 4 points loads and uniform distributed loads. There are 8 possible cases for checking the adequacy of simply supported beam. An “ERROR” is showed when the incorrect input used in the calculation. Excel User Interface is produced an output about the graph of maximum shear force and maximum bending moment, adequacy of main reinforcement and shear reinforcement provided and lastly checking the deflection and cracking of the simply supported beam.

Lastly, the results of maximum shear force, maximum bending moment, tension and compression bars provided in Excel User Interface and STAAD-Pro are compared. The results that obtained between Excel User Interface and finite element software STAAD Pro had highest percentage of accuracy. Therefore, Excel User Interface had higher safety factor of design.

In conclusion, it showed that the results that obtained from Excel User Interface were accurate. Excel User Interface is a user-friendly interface and it was safe to be used by everyone. Everyone can design simply supported beam based on Eurocode 2 in a simple and quick manner.

References

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