REINFORCED CONCRETE BEAM DESIGN BY MATHCAD BASED ON BS 8110

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Universiti Malaysia Sarawak
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REINFORCED CONCRETE BEAM DESIGN BY MATHCAD BASED ON BS 8110

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A Project Report Submitted In Partial
Fulfillment For The Degree Of Bachelor
Of Engineering (Civil) With Honours In
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APPROVAL SHEET

This project report attached hereto, entitled "**Reinforced Concrete Beam Design By MATHCAD Based On BS 8110**", prepared and submitted by **Tan Kok Kui** as a partial fulfillment of the requirement for the degree of Bachelor in Engineering (Civil) with honours, is hereby read and approved by:

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ABSTRACT

Concrete structure is a high strength yet economy structure used commonly in the construction field. Properly design of the elements ensures the production of a durable and tough concrete structure. With the aids of computer the design work become efficient and accurate. In this project a computational worksheet was produced by using Mathcad. It concerned with the detailed design of reinforced concrete beam to BS8110. The computational worksheet showed clear steps of the design work and equations used. This project also present a case study for both manual calculation and worksheet calculation created by using Mathcad.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Concrete structure is the most common type of structure used in the construction field today. Reinforced concrete is one of the principal elements used in concrete structures where it is a composite material, consisting of steel reinforcement embedded in concrete. These two materials have complementary properties. Concrete had high compressive strength but low tensile strength. On the other hand, steel bars can resist high tensile stresses but will buckle when subjected to comparatively low compressive stresses. In economical aspect, steel is much more expensive than concrete. By providing the steel bars in a concrete member, an economical structure can be produced which are both strong in compression as well as tension. In addition, the concrete provides corrosion protection and fire resistance to the steel bars inside the concrete members.

Different reinforced concrete structures are designed in accordance with the recommendations given in various documents. One of the design codes is BS 8110 : *Structural Use of Concrete (BSI 1985)*. The BS 8110 was prepared under the direction of the Civil Engineering and Building Structures Standards Committee. It covers various categories of element design including beams, slabs, columns, walls and foundations.

1.2 OBJECTIVE

For a huge concrete structure, the design task for each of the elements can be a tedious work if it is designed manually. With the aid of computers, the design work becomes efficient. The aim of this project is to create a computational worksheet by using Mathcad concerned with the detailed design of reinforced concrete beam to BS8110. The computational worksheet will need to show clear steps of the design work and equations used, so that structural designer can easily check back at any step and recognize the equations applied. Then the design worksheet and results can be printed out for submission purposes.

CHAPTER TWO

Mathcad

2.1 INTRODUCTION

Mathcad is the worksheet computational computer program developed by MathSoft, Inc (MathSoft 1998). A powerful application to let the user perform, document, and communicate technical calculations. It also enables users to enter, edit, and solve equations, to visualize the results with sophisticated graphs, and to document and communicate their analysis. It serves the calculation, analysis and reporting needs of educators in every branch of engineering and scientific research and of students in every quantitative discipline.

Mathcad has powerful functionality and yet the outlook is same as Microsoft Office styling and template features. Mathcad is the industry standard calculation software for technical professionals, educators and college students. It provide a wide range of solution to solve the complex technical problems. It is the only calculation application that transforms the computer into a live worksheet using real math notation to solve complex technical and engineering problems.

2.2 FUNCTIONS OF MATHCAD

Mathcad is a fully Windows application with standard menus and dialogs, floating palettes. The mathematics equation can be written in real math notation and it can solve the equation on the worksheet. This lead to the advantages of designing the concrete beam since if the beam fail at deflection then resizing the beam and obtaining the satisfying results can be done in a short moment.

The program supports live calculations with units, which can be converted within a system (i.e., $kg.m/s^2$ to N). New units can be declared the same way that as a variable. Mathcad supports SI unit (International System unit), mks unit (a metric system of units based on the meter, kilogram, and second as the units of length, mass, and time; it forms the basis of the SI units.), cgs units (a metric system of units based on the centimeter, gram, and second. For scientific and technical purposes these units have been replaced by SI units.), and U.S. standard units. Switching between unit systems is as easy as pulling down the Math pull-down menu, clicking on Options, and selecting the system under the unit system tab.

Mathcad built-in programming contains standard tools such as for-while loops and recursion and features such as conditional branching and runtime error handling. All the common functions can be accessed through the programming palette.

The special object linking and embedding (OLE) components and a component wizard help to place data from other Windows-based program in Mathcad documents. The full OLE application which works as both client and server, providing drag-and-drop interchange, in-place activation and editing, and user-scriptable OLE objects.

Apart from a well-constructed conventional help file, Mathcad includes a Resource Center. This opens a window controlled by an Internet Explorer and is made to link to both local resources installed by the program and resources posted on the MathSoft Web site. In the web site included quick sheets (Mathcad samples that can drag and drop from the Resource Center window to a Mathcad worksheet), two sample chapters from the Mathcad treasury, a guide to doing statistics with Mathcad, useful reference tables, and a helpful tutorial.

2.3 REMARKS

Mathcad worksheets use live math, in the sense that a spreadsheet is live. The change of the value of a variable in a document brings the formulas that come afterward are updated. All formulas are displayed in what you see is what you get (WYSIWYG) format. Since Mathcad interface uses real math notation in an interactive and visual manner, it has replaced the spreadsheet as the computational tool of choice. In short with its powerful computational functions Mathcad is very suitable for design worksheet of concrete beam.

CHAPTER THREE

DESIGN PROCEDURE

In this chapter the notation and definition used in the structural design worksheet will be clarified. The logical path and flow chart of the design will also be presented.

3.1 NOTATIONS AND DEFINITION

Notations used in this project is generally in accordance with BS 8110 and the principal symbols are shown in table 3.1.

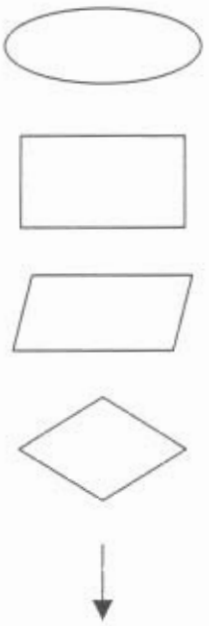
Table 3.1 Notations for the worksheet design.

$A_{s.add}$	=	Additional area of tension reinforcement required
$A'_{s.add}$	=	Additional area of compression reinforcement required
$A_{s.reqd}$	=	Area of tension reinforcement required
$A'_{s.reqd}$	=	Area of compression reinforcement required
$A_{s.\ \Sigma req}$	=	Total tension reinforcement (including torsion) required
$A'_{s.\ \Sigma req}$	=	Total compression reinforcement (including torsion) required
A_{st}	=	Additional longitudinal steel
A_{sv}	=	Area of shear reinforcement required for pure shear
$AsvOSvt$	=	Additional shear reinforcement required for torsion
b	=	Beam breadth
c	=	Minimum concrete cover
d	=	Effective depth of tension reinforcement

d'	=	Effective depth of compression reinforcement
f_{cu}	=	Characteristic strength of concrete
f_s	=	Design service stress in the tension reinforcement
f_y	=	Characteristic strength of reinforcement
f_{yv}	=	Characteristic strength of links
h	=	Beam depth
h_{max}	=	The larger dimension of the section
h_{min}	=	The smaller dimension of the section
lOd_{ratio}	=	Basic Span/effective depth ratio
L_{span}	=	Span length
M	=	Design ultimate moment
M_f	=	Modification factor
$M_{f.com}$	=	Modification factor for compression reinforcement
$M_{f.ten}$	=	Modification factor for tension reinforcement
S_c	=	Support conditions
S_v	=	Total spacing of links required
S_{vs}	=	Spacing of links required for pure shear
T	=	Maximum design torque
V	=	Maximum design shear force
v	=	Shear stress
v_c	=	Design concrete shear strength
v_t	=	Torsional shear stress
$v_{t.min}$	=	Minimum torsional shear stress, above which reinforcement is required
v_{tu}	=	Maximum combined shear stress
x_1	=	The smaller dimension of the section between link to link
y_1	=	The larger dimension of the section between link to link
z	=	Lever arm
ϕ	=	Nominal diameter of tension reinforcement
ϕ'	=	Nominal diameter of compression reinforcement
ϕ_k	=	Diameter of links
ϕ_{links}	=	Nominal diameter of links

3.2 FLOW CHART OF THE STRUCTURAL BEAM DESIGN SPREADSHEET

Flow chart is used to describe the algorithms of the structural beam design spreadsheet. In the flowchart, different graphical symbols represent the different operation in the algorithms. The functions of the graphical elements are shown in Fig. 3.1.



An oval indicates the start or stop of an algorithm.

A rectangle indicates a computation, with the result of the computation assigned to a variable.

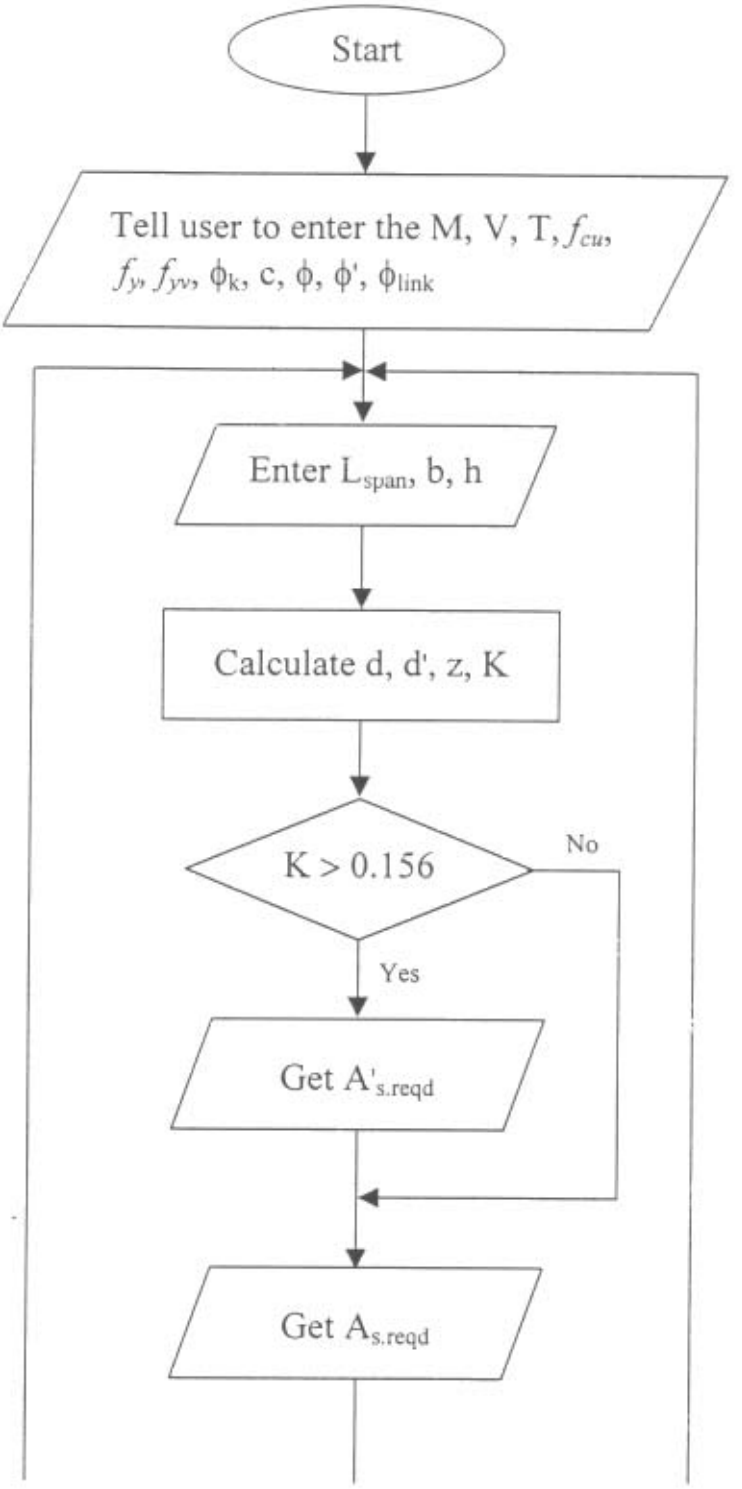
A parallelogram indicates an input or output operation.

A diamond indicates a point where a choice is made between two alternatives.

An arrow indicates the direction of program flow between steps in the algorithm.

Fig. 3.1 Graphical elements of a flow chart.

Fig. 3.2 shows the path of every step of the design work by using Mathcad.


Start
Tell user to enter the M, V, T, f_{cu}, f_y, f_{yv}, ϕ_k, c, ϕ, ϕ', ϕ_{link}
Enter L_{span}, b, h
Calculate d, d', z, K
K > 0.156
No
Yes
Get $A'_{s.reqd}$
Get $A_{s.reqd}$

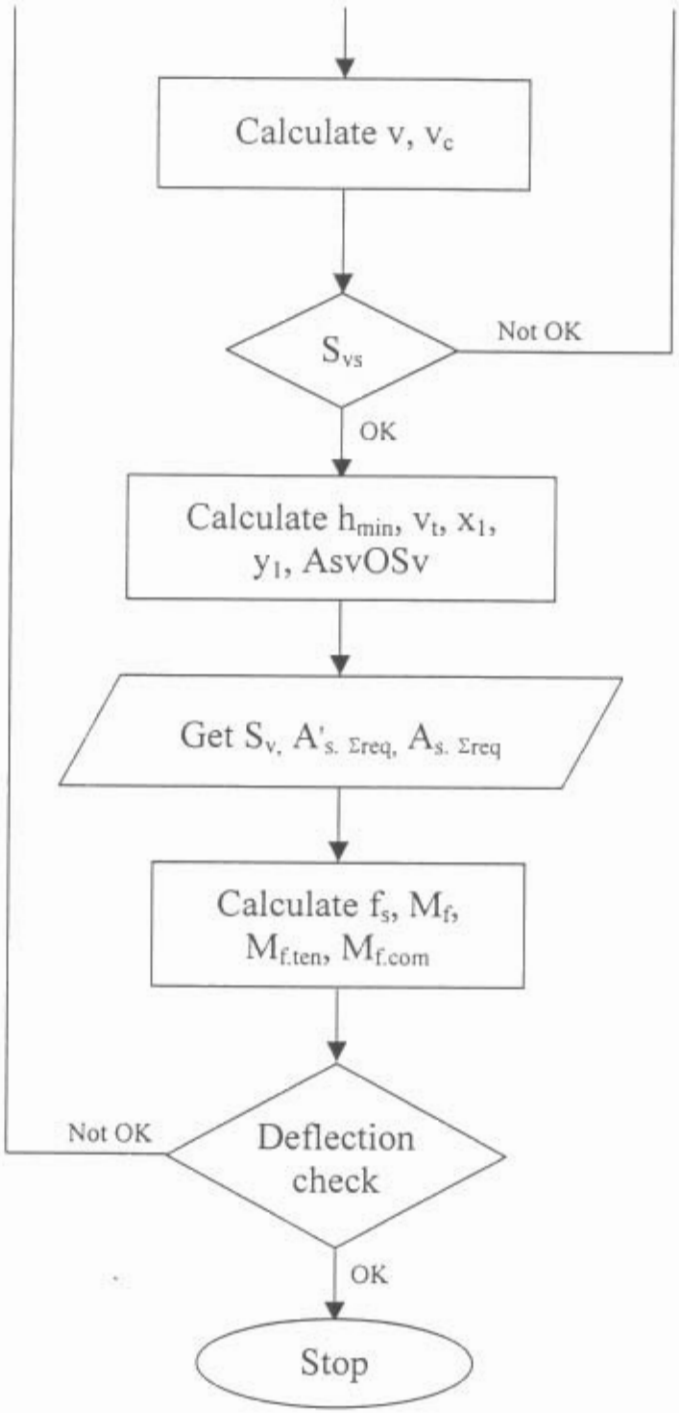


Fig. 3.2 Flowchart for structural concrete beam design.

The initial stage of the program lets the designer to enter the design moment, shear and torsion, material characteristics and beam dimensions. Then the K value will be calculated. If the value of K is greaten than or equal to 0.156, then calculation of the compression reinforcement area is carried out. Otherwise the minimum quantity of two numbers of compression bars will be provided. After that, the area of tension reinforcement is determined, and the designer has to decide on the quantity of bars needed for each of the requirement.

Secondly, the spacing for the stirrups required is determined. This value is stored until the spacing requirement for torsion is determined. The final provision for stirrups therefore takes into account of combined action of shear and torsion.

Finally, the span to effective depth ratio will be computed, if the result of span to effective depth ratio has failed, then the designer needs to redesign right from the start.

The working example for this design procedure will be presented in Chapter Four.

CHAPTER FOUR

CASE STUDY

In this chapter a simply supported beam was considered based on BS8110. Two design approaches will be taken into account to design the beam. One is by using the manual calculation and the other is by using the worksheet created using Mathcad.

The simply supported beam considered here is a reinforced concrete ground floor beam. The effective span of the beam is 8 m and it carries a uniformly distributed load (see Fig. 4.1). Bending moment and shear force diagrams are shown in Fig 4.1 and the beam is subjected to 10 kNm of compatibility torsional moment. The characteristic strengths of concrete, f_{cu}, and main steel, f_y, are taken to be 25 N/mm^2 and 460 N/mm^2 respectively. The characteristic strengths for stirrups, f_{yv}, is taken as 250 N/mm^2.

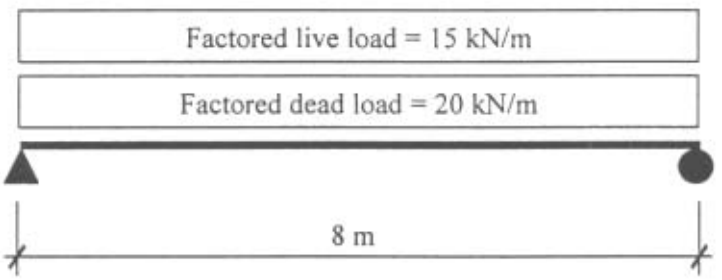
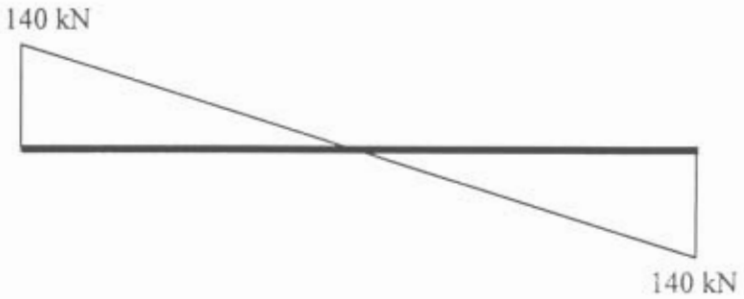


Fig. 4.1 Uniformly distribution load, shear force and bending moment diagrams.

Shear force diagram



Bending moment diagram

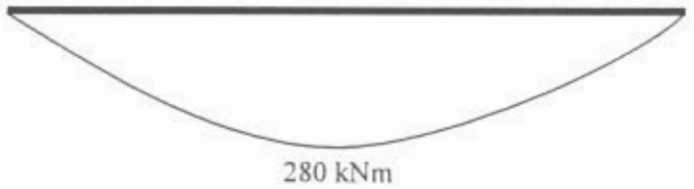


Fig. 4.1 *Continued*

4.1 MANUAL CALCULATION

Assuming effective depth, d of 500 mm and design shear stress, v of

1.12 N/mm^2, so

$$v = \frac{V}{b.d} = \frac{140 \times 10^3}{500b}$$

Rearrange the equation,

Beam breadth, $b = \dfrac{140 \times 10^3}{500(1.12)} \approx 250\ mm$

From Table 3.4 & Table 3.5 of BS8110 (BSI 1985), minimum concrete cover is taken

as 25 mm

Assume diameter of tension bars, ϕ = Y25

Assume diameter of link, ϕ_k = R10

So the beam depth, h = 500 + 25 + 10 + (25/2) = 547.5 mm (Take 550 mm)

<u>Main steel,</u>

$$K = \frac{M}{b.d^2 f_{cu}}$$

$$K = \frac{280 \times 10^6}{250(500)^2(25)} = 0.179$$

For $K > K'$=0.156, compression reinforcement is required,

$$K = d(0.5 + \sqrt{0.25 - \frac{K'}{0.9}})$$

$$K = d(0.5 + \sqrt{0.25 - \frac{0.156'}{0.9}})$$

$$K = 0.777d$$

For $\frac{z}{d} = 0.777 < 0.95$

$d' = c + \phi_{links} + \phi'/2 = 25 + 10 + (\frac{20}{2}) = 45$ mm

Compression reinforcement, $A'_{s.reqd}$

$$A'_{s.reqd} = \frac{(K - K').f_{cu}.b.d^2}{0.87.f_y.(d - d')}$$

$$A'_{s.reqd} = \frac{(0.177 - 0.156)(25)(250)(500)^2}{0.87(460)(500 - 45)}$$

$A'_{s.reqd} = 201$ mm^2

Provide 2 Y 20 ($A'_{s.prov} = 628$ mm^2)

Tension reinforcement, $A_{s.reqd}$

$$A_{s.reqd} = \frac{K'.f_{cu}.b.d^2}{0.87.f_y.z} + A'_{s.reqd}$$

$$A_{s.reqd} = \frac{0.156(25)(250)(500)^2}{0.87(460)(0.777)(500)} + 201$$

$A_{s.reqd} = 1769$ mm^2

Provide 4 Y 25 ($As_{prov} = 1960$ mm^2)

Shear Reinforcement

Shear stress, $v = \frac{V}{b.d} = \frac{140 \times 10^3}{(250)(500)} = 1.12$

$$v_c = \frac{0.79}{1.25}\left(\frac{100.A_{s\,prov}}{b.d}\right)^{\frac{1}{3}}\left(\frac{400}{d}\right)^{\frac{1}{4}}$$

$$v_c = \frac{0.79}{1.25}\left(\frac{100(1963)}{(250)(500)}\right)^{\frac{1}{3}}\left(\frac{400}{(500)}\right)^{\frac{1}{4}}$$

$v_c = 0.69$

Condition $(v_c + 0.4) < v < 0.8\sqrt{f_{cu}}$

Spacing of link, S_v

A_{sv} for R10 = 157 mm^2

Shear spacing required, S_{vs}

$$S_{vs} = \frac{A_{sv}(0.87)f_{yv}}{b(v - v_c)}$$

$$S_{vs} = \frac{(157)(0.87)(250)}{250(1.12 - 0.69)} = 318\,mm$$

Design for torsion

$h_{min} = 250$ mm, $h_{max} = 550$ mm

$$v_t = \frac{2T}{h_{min}^{\ 2}.(h_{max} - \frac{h_{min}}{3})}$$

$$v_t = \frac{2(20)}{(250)^2.(550 - \frac{250}{3})}$$

$$v_t = 1.37\frac{N}{mm^2}$$