Teaching two-way ribbed slab analysis and design using the *MathCAD* program

Mohammed S. Al-Ansari

University of Qatar
Doha, Qatar

ABSTRACT: In this article, the author presents a parallel approach to the traditional teaching method of two-way ribbed slabs. In this approach, the emphasis has been shifted to the use of the *MathCAD* program in developing a better understanding of the analysis and design of two-way ribbed slabs. *MathCAD* possesses efficient computation and presentation capabilities. It holds strong potential as a teaching tool, as well as a learning aid for education and training. By using the presentation and programming features available in *MathCAD*, interactive teaching and learning devices in the analysis and design of two-way ribbed slabs have been produced. A case study is used in order to demonstrate the application of the *MathCAD* program and to demonstrate its impact on teaching the analysis and design of two-way ribbed slabs.

INTRODUCTION

Engineering students have used computers for many years in order to assist them in performing complicated analysis, design and drafting tasks. Unfortunately, the use of computers has also been greatly limited to routine tasks. The author believes that the emphasis must be shifted to enabling students to better understand the engineering problem for which the computer is being used. The utilisation of the power of computers to promote a better understanding of structural analysis and design should be essential in teaching structural engineering students.

MathCAD is an efficient learning environment for technical topics such as reinforced concrete design [1]. Its computational and presentation capabilities not only lend themselves to the solution of mathematically-based problems, but also to the effective communication of both the problem and solution. *MathCAD* enables information to be clearly presented, allowing for user interaction in a logical and uncomplicated manner. It contains powerful presentation capabilities, which include the use of charts, graphic objects and animation effects. *MathCAD* can also easily import objects from other application programs, such as images and digital photographs. These capabilities offer significant learning enhancements to students of technical subjects.

MathCAD makes possible new learning strategies for students and teachers. *What-if* discussions, trend analyses, trial and error analyses, and optimisation are all valuable learning activities that take more time than the traditional technical problem-solving approach permits. Taking advantage of the computational power and speed of *MathCAD*, instructors and students can quickly cycle through problem scenarios, observing trends in the analysis and design behaviours of two-way ribbed slabs. More importantly, *MathCAD* enables students/designers to carry out parametric studies to explore possible design solutions and gain a better understanding of the process through the interactive presentation of information.

MathCAD greatly enhances a better understanding of a problem, its constraints and limitations. By using the *MathCAD* program, the student/engineer will have a better understanding of various aspects of the problem. Such aspects have not been readily available in previously developed powerful computer packages that assist students/designers in their structural analysis and design.

The main objective of this article is to demonstrate that the use of *MathCAD* can promote a better understanding of the analysis and design of two-way ribbed slabs. A case study is utilised in order to demonstrate the application of the *MathCAD* program and show its impact on teaching the analysis and design of two-way ribbed slabs.

OVERVIEW OF REINFORCED CONCRETE DESIGN PHILOSOPHIES

A large number of structures are built of reinforced concrete: bridges, viaducts, buildings, etc. Reinforced concrete is a logical union of two materials: plain concrete, which possess high compressive strength but little tensile strength, and steel bars embedded in the concrete, which can provide the needed strength in tension.

Two philosophies of design have been prevalent. The working stress method, which focuses on conditions at the service load (ie when the structure is being used), was the principal method used from the early 1900s until the 1960s. Today, the strength design method is used, which focuses on conditions at loads greater than service loads when failure may be imminent.

In the strength design method, the service loads are increased sufficiently by factors in order to obtain the load at which

failure is considered to be *imminent*. This load is called the factored load. The structure or structural element is then proportioned so that the strength is reached when the factored load is acting. The computation of this strength takes into account the non-linear stress-strain behaviour of concrete. The strength design method may be expressed by the following equation:

$$\text{Strength provided} \geq \text{strength to carry factored loads} \qquad (1)$$

where the *strength provided* (such as moment strength) is computed in accordance with the rules and assumptions of the behaviour prescribed by a building code, and the *strength required* is that obtained by performing a structural analysis using factored loads.

The factored loads (including moments, shears, axial forces, etc) are obtained by multiplying the service loads by load factors so as to cover possible overloads and variations in design assumptions. The design strength of a section by multiplying the nominal strength (based on static equilibrium and compatibility of stress and strain) by a strength reduction factor ϕ to account for adverse variations in material strengths, workmanship, dimensions, control and the degree of supervision, even though they are within accepted tolerances.

OVERVIEW OF TWO-WAY RIBBED SLAB ANALYSIS AND DESIGN

Two-way ribbed slabs consist of beams spaced at regular intervals in perpendicular directions, which are monolithic with a slab. They are generally used for architectural reasons for large rooms like auditoriums, vestibules, theatre halls and shop showrooms where column free space is often the main requirement. The rectangular or square voids formed in the ceiling can be advantageously utilised for concealed architectural lighting. The sizes of the ribs running in perpendicular directions are generally kept the same. Instead of rectangular beam grids, diagonal grids can also be used with the ribs inclined at 45° to the sides.

A two-way ribbed slab with ribs at close intervals in two mutually perpendicular directions can be considered as an orthotropic plate that is freely supported on four sides. Timenshenko's analysis may be used to evaluate the moments and shears in the grid depending upon the deflection surface.

Rankine-Grashoff Approximate Analysis Method

The Rankine-Grashoff theory, which equates the deflections at the rib junctions, is an approximate analysis method commonly used for two-way ribbed slabs. Consider the ribbed-slab system shown in Figure 1 in which the rib spacings are a_1 and b_1 in the x and y directions, respectively. The deflections of the central ribs at the junction O must be the same. By equating the deflections, we have:

$$\delta = \frac{5q_1a^4}{384EI} = \frac{5q_2b^4}{384EI} \qquad (2)$$

Where q = the total load per unit area, q_1 and q_2 = the loads shared in the x and y directions, respectively, a = the shorter grid dimension, and b = the longer grid dimension. Solving Eq. 1, we have:
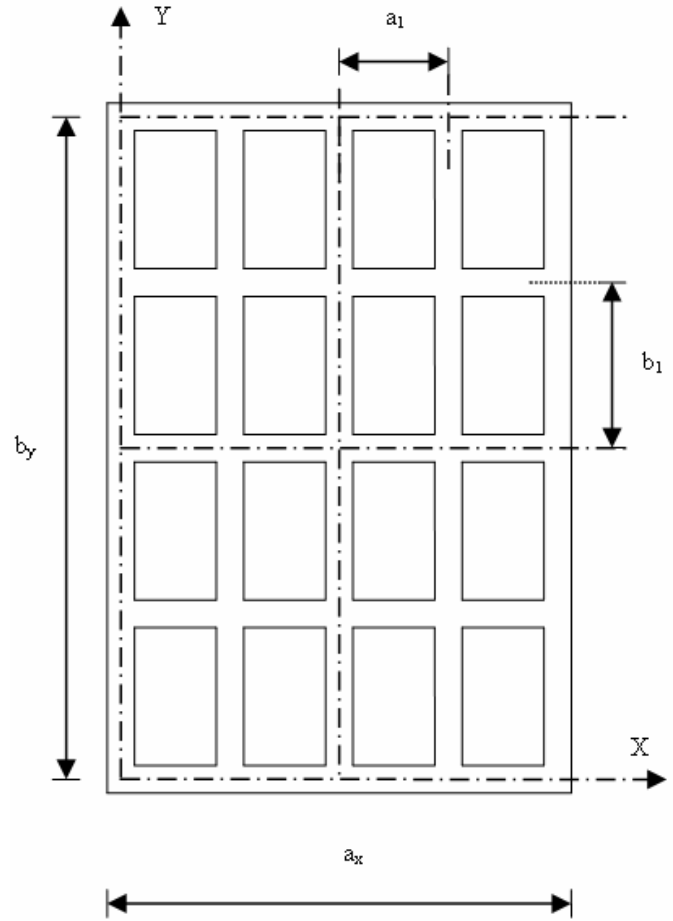
$$q_1a^4 = q_2b^4 \qquad (3)$$

Figure 1: The deflection characteristics of grid floors.

and:

$$q = q_1 + q_2 \qquad (4)$$

Solving Eqs 2 and 3, we have:

$$q_1 = q \left(\frac{b^4}{a^4 + b^4} \right) \qquad (5)$$

$$q_2 = q \left(\frac{a^4}{a^4 + b^4} \right) \qquad (6)$$

The bending moments for the central ribs are given by:

$$M_{AB} = \left(\frac{q_1 \, b_1 \, a^2}{8} \right) \qquad (7)$$

$$M_{BD} = \left(\frac{q_2 \, a_1 \, b^2}{8} \right) \qquad (8)$$

The bending moments in the other ribs can also be determined in direct proportion to their distances from the centre. The ribs are designed as flanged sections to resist the moments and shears.

However, it should be noted that the approximate methods do not yield the twisting moments in the beams and do not consider the dimensions (stiffness) of the ribs.

Plate Theory Analysis Method

The vertical deflection δ at any point of the grid shown in Figure 1 is expressed as follows:

$$\delta = \frac{16q}{\pi^6}\left[\frac{sin(\frac{\pi x}{a_x})\; sin(\frac{\pi y}{b_y})}{\frac{D_x}{a_x^4}+\frac{2H}{a_x^2 b_y^2}+\frac{D_y}{b_y^4}}\right] \qquad (9)$$

where q = the total uniformly distributed load per unit area; a_x and b_y = the plate length in x and y directions, respectively; D_x and D_y = the flexural rigidity per unit length of plate along the x and y directions, respectively, C_x and C_y = the torsional rigidity per unit length of the plate along the x and y directions.

If a_1 and b_1 are the spacings of the ribs in the x and y directions, respectively, then their relations are as follows:

$$D_x = \frac{E I_1}{b_1} \qquad\qquad C_x = \frac{C_1}{b_1}$$

$$D_y = \frac{E I_2}{a_1} \qquad\qquad C_y = \frac{C_2}{a_1} \qquad (10)$$

where EI_1, EI_2, C_1 and C_2 = the flexural and torsional rigidities of the effective section in the x and y directions, respectively.

The moments and shears are computed using the following expressions:

$$M_x = -D_x\left(\frac{\partial^2 a}{\partial x^2}\right) \qquad M_y = -D_y\left(\frac{\partial^2 a}{\partial y^2}\right)$$

$$M_{xy} = -\frac{C_1}{b_1}\left(\frac{\partial^2 a}{\partial x\,\partial y}\right) \qquad M_{yx} = -\frac{C_2}{a_1}\left(\frac{\partial^2 a}{\partial x\,\partial y}\right)$$

$$Q_x = -\frac{\partial}{\partial x}\left[D_x\left(\frac{\partial^2 a}{\partial x^2}\right)+\frac{C_2}{a_1}\left(\frac{\partial^2 a}{\partial x\,\partial y}\right)\right] \qquad (11)$$

$$Q_y = -\frac{\partial}{\partial y}\left[D_y\left(\frac{\partial^2 a}{\partial y^2}\right)+\frac{C_1}{b_1}\left(\frac{\partial^2 a}{\partial x\,\partial y}\right)\right]$$

The maximum bending moments (M_x and M_y) develop at the centre of the span while the maximum torsional moments (M_{xy} and M_{yx}) are generated at the corners of the slab. The maximum shear forces (Q_x and Q_y) develop at the mid-points of the longer side supports.

Further details on the design of two-way ribbed slabs can be found elsewhere [2-8].

USING THE *MATHCAD* PROGRAM FOR RIBBED SLAB ANALYSIS AND DESIGN

The *MathCAD* program, which has been written for the analysis and design of two-way ribbed slabs, consists of the following five computational steps.

Step 1

The first step, which is, which is summarised in Figure 2, consists of entering the input data for the *MathCAD* program.

Step 2

The second step, which is summarised in Figure 3, consists of the following computational tasks:

- Determine the position of the neutral axis of the rib cross-section;

STEP 1: READ INPUT DATA

b $\equiv$ 16	m		**Slab Long Dimension**
a $\equiv$ 12	m		**Slab Short Dimension**
b1 $\equiv$ 2	m		**Rib Spacing in y-direction**
a1 $\equiv$ 2	m		**Rib Spacing in x-direction**
q $\equiv$ 6.55·1.5	$\frac{kN}{m^2}$		**Total Load per Unit Area**
f'c $\equiv$ 20	MPa		**Concrete Compressive Strength**
fy $\equiv$ 415	MPa		**Steel Yield Strength**
E $\equiv$ 2·10^5	MPa		**Steel Elastic Modulus**
ϕs $\equiv$ 0.85			**Shear Strength Reduction Factor**
μ $\equiv$ 0.15			**Poisson Ratio**
θ $\equiv$ 2			**Creep Coefficient**

Design Data:

b3 $\equiv$ 2000	mm		**Rib Spacing**
bw $\equiv$ 200	mm		**Rib Width**
h $\equiv$ 300	mm		**Rib Depth**
h1 $\equiv$ 100	mm		**Concrete Slab Thickness**
b2 $\equiv$ 200	mm		**Rib Width**
d1 $\equiv$ 70	mm		**Concrete Cover (Tension Side)**
d' $\equiv$ 70.0	mm		**Concrete Cover (Compression Side)**
As $\equiv$ 1964	mm^2		**Tensile Steel Area**
A's $\equiv$ 982	mm^2		**Compressive Steel Area**
Mu $\equiv$ 100	kN·m		**Ultimate Bending Moment**

Figure 2: Step 1 of the *MathCAD* program.

- Compute the moment of inertia of the rib cross-section about the major axis (X-axis);
- Compute the moment of inertia of the rib cross-section about the minor axis (Y-axis).

Step 3

The third step, which is summarised in Figure 4, consists of the following computational tasks:

- Compute the deflection at the centre of the slab;
- Compute the long-term deflection of the slab;
- Compute the maximum permissible long-term deflection of the slab.

Step 4

The fourth step, which is summarised in Figure 5, consists of the following tasks:

- Compute the bending moments and shear forces using the approximate method;

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STEP 2: COMPUTE SECTION PROPERTIES
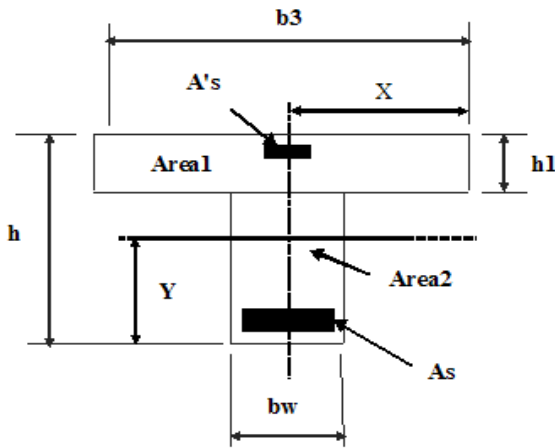
Position of Neutral Axis (Coss-Section Centroid)

$Area1 := b3 \cdot h1$

$Area2 := (h - h1) \cdot bw$

$$X := \frac{\left(Area1 \cdot \frac{b3}{2}\right) + \left[Area2 \cdot \left[\frac{bw}{2} + \left(\frac{b3}{2} - \frac{bw}{2}\right)\right]\right]}{Area1 + Area2}$$

$$Y := \frac{\left[Area1 \cdot \left(h - \frac{h1}{2}\right)\right] + \left(Area2 \cdot \frac{h - h1}{2}\right)}{Area1 + Area2}$$

Moment of Inertia about X-Axis

$$Ix1 := \left[\left[\left[\frac{b3 \cdot h1^3}{12} + \left[Area1 \cdot \left[(h - Y) - \frac{h1}{2}\right]^2\right]\right]\right]\right] \cdot 10^{-12}$$

$$Ix2 := \left[\left[\left[\frac{bw \cdot (h - h1)^3}{12} + \left[Area2 \cdot \left[Y - \left(\frac{h - h1}{2}\right)\right]^2\right]\right]\right]\right] \cdot 10^{-12}$$

$Ix := Ix1 + Ix2$

Moment of Inertia about Minor Axis (Y-Axis)

$$Iy1 := \frac{h1 \cdot b3^3}{12} + \left[Area1 \cdot \left(X - \frac{b3}{2}\right)^2\right] \cdot 10^{-12}$$

$$Iy2 := \frac{(h - h1) \cdot bw^3}{12} + \left[Area2 \cdot \left[X - \left[\frac{bw}{2} + \left(\frac{b3}{2} - \frac{bw}{2}\right)\right]\right]^2\right] \cdot 10^{-12}$$

$Iy := Iy1 + Iy2$

$Ec := 5700 \cdot \sqrt{fc} \cdot 10^3$ **Concrete Elastic Modulus**

$G := \dfrac{Ec}{2 \cdot (1 + \mu)}$ **Concrete Shear Modulus**

$Dx := \dfrac{Ix \cdot Ec}{b1}$ **Plate flexural rigidity along X-direction**

$Dy := \dfrac{Ix \cdot Ec}{a1}$ **Plate flexural rigidity along Y-direction**
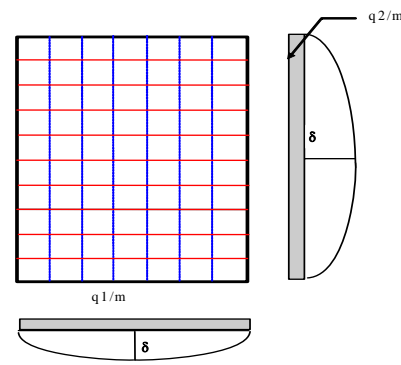
$C1 := k_1 \cdot G \cdot bw^3 \cdot h \cdot 10^{-12}$ **Torsional rigidity in the X-direction (C1)**

$C2 := k_1 \cdot G \cdot bw^3 \cdot h \cdot 10^{-12}$ **Torsional rigidity in the Y-direction (C2)**

$H := \left(\dfrac{C1}{b1} + \dfrac{C2}{a1}\right)$

Figure 3: Step 2 of the *MathCAD* program.

STEP 3: COMPUTE DEFLECTIONS

Deflection of Ribbed Slab

$$\delta C := \frac{16 \cdot q}{\pi^6} \cdot \left(\frac{1}{\frac{Dx}{a^4} + \frac{Dy}{b^4} + \frac{2H}{a^2 \cdot b^2}}\right)$$ **Center of plate deflection**

$\delta Lterm := \delta C \cdot (1 + \theta)$ **Long term deflection of the plate**

$\delta max := \dfrac{if(b > a, a, b)}{250}$ **Allowable long term deflection**

Figure 4: Step 3 of the *MathCAD* program.

- Compute the bending moments, twisting moments, and shear forces using the plate theory at every point (xi,yi) of the slab;
- Determine the maximum design moments about the major and minor axes;
- Determine the maximum design shear forces in the horizontal and vertical directions.

Step 5

The fifth step is concerned with the design based on the ACI code of the interior ribs as T-beam sections and the edge ribs as L-beam sections

TRADITIONAL VERSUS *MATHCAD* ENHANCED TEACHING

Traditional teaching methods usually involve the time-consuming task of the instructor writing detailed problem solutions on the board while students hurriedly copy the solutions into their notebooks. The learning process in the classroom is often suspended while the teacher and students occupy themselves with transcribing information. This traditional classroom activity can discourage critical thinking, and deprive both students and teachers of engaging exchanges with each other about the subject.

A *MathCAD*-enhanced teaching method can be successfully integrated into a structural design course. The program is projected directly from the instructor's computer onto a large screen in an appropriately equipped classroom. In the program, different formatting, including various fonts, colours, patterns and borders, are used. The readability of the text exceeds what instructors can produce by hand-on the classroom board. The equations look the same as they are written on a blackboard or in a reference book. In order to free students' attention from transcription, students are given a hard copy for taking additional notes.

STEP 4: COMPUTE DESIGN MOMENT AND SHEAR

Bending moment about x-axis at the point (x_i , y_i)

$$Mx_i := Dx \cdot \left(\frac{\pi}{a}\right)^2 \cdot \frac{16 \cdot q}{\pi^6} \cdot \left(\frac{\sin\left(\pi \cdot \frac{x_i}{a}\right) \cdot \sin\left(\pi \cdot \frac{y_i}{b}\right)}{\frac{Dx}{a^4} + \frac{Dy}{b^4} + \frac{2H}{a^2 \cdot b^2}}\right)$$

Bending moment about y-axis at the point (x_i , y_i)

$$My_i := Dy \cdot \left(\frac{\pi}{b}\right)^2 \cdot \frac{16 \cdot q}{\pi^6} \cdot \left(\frac{\sin\left(\pi \cdot \frac{x_i}{a}\right) \cdot \sin\left(\pi \cdot \frac{y_i}{b}\right)}{\frac{Dx}{a^4} + \frac{Dy}{b^4} + \frac{2H}{a^2 \cdot b^2}}\right)$$

Twisting moment at the point (x_i , y_i)

$$Mxy_i := -\frac{C1}{b1} \cdot \left(\frac{\pi^2}{a \cdot b}\right) \cdot \frac{16 \cdot q}{\pi^6} \cdot \left(\frac{\cos\left(\pi \cdot \frac{x_i}{a}\right) \cdot \cos\left(\pi \cdot \frac{y_i}{b}\right)}{\frac{Dx}{a^4} + \frac{Dy}{b^4} + \frac{2 \cdot H}{a^2 \cdot b^2}}\right)$$

Twisting moment at the point (x_i , y_i)

$$Myx_i := -\frac{C2}{a1} \cdot \left(\frac{\pi^2}{a \cdot b}\right) \cdot \frac{16 \cdot q}{\pi^6} \cdot \left(\frac{\cos\left(\pi \cdot \frac{x_i}{a}\right) \cdot \cos\left(\pi \cdot \frac{y_i}{b}\right)}{\frac{Dx}{a^4} + \frac{Dy}{b^4} + \frac{2 \cdot H}{a^2 \cdot b^2}}\right)$$

Shear Force in x-direction at the point (x_i , y_i)

$$Qx_i := \frac{16 \cdot q}{\pi^6} \cdot \left(\frac{\cos\left(\pi \cdot \frac{x_i}{a}\right) \cdot \sin\left(\pi \cdot \frac{y_i}{b}\right)}{\frac{Dx}{a^4} + \frac{Dy}{b^4} + \frac{2 \cdot H}{a^2 \cdot b^2}}\right) \cdot \left(Dx \cdot \frac{\pi^3}{a^3} + \frac{C2}{a1} \cdot \frac{\pi^3}{a \cdot b^2}\right)$$

Shear Force in y-direction at the point (x_i , y_i)

$$Qy_i := \frac{-16 \cdot q}{\pi^6} \cdot \left(\frac{\sin\left(\pi \cdot \frac{x_i}{a}\right) \cdot \cos\left(\pi \cdot \frac{y_i}{b}\right)}{\frac{Dx}{a^4} + \frac{Dy}{b^4} + \frac{2 \cdot H}{a^2 \cdot b^2}}\right) \cdot \left(Dy \cdot \frac{\pi^3}{b^3} + \frac{C1}{b1} \cdot \frac{\pi^3}{b \cdot a^2}\right)$$

Maximum Design Moment in X-Direction

$$MXmax := \left(\text{reverse}\,(\text{sort}\,(Mx))_0 \cdot a1\right)$$

Maximum Design Moment in Y-Direction

$$MYmax := \text{reverse}\,(\text{sort}\,(My))_0 \cdot b1$$

Maximum Design Shear in X-Direction

$$QXmax := \text{reverse}\,(\text{sort}\,(Qx))_0 \cdot a1$$

Maximum Design Shear in Y-Direction

$$QYmax := \text{reverse}\,(\text{sort}\,(Qy))_0 \cdot b1$$

Figure 5: Step 4 of the *MathCAD* program.

An electronic copy of the *MathCAD* program is also made available for students to review and practice later. The sketches are annotated with dimensions and notes. By using different drawing entities and varying their colour, pattern and line weight attributes, highly readable drawings are produced to illustrate the computations. Photographs can be easily digitised and imported into the program. Photographs and images are rich sources of visual information that can be shared among teachers and students. Images from the field or laboratory bring glimpses of the engineering world into the classroom where they can be shared by all. Existing photos and slides can be digitised using slide and film scanning processes. Digital photographs can be taken with digital cameras and downloaded directly to the computer without the use of film. Like spreadsheets, as soon as a change is made in the input data, the results are updated. Other types of charts, such as pie and histogram charts, can also be easily generated.

There are several benefits of a *MathCAD*-enhanced approach to teaching. The time saved from tedious transcription frees students and the teacher for the discussion of concepts and the exploration of alternate problem scenarios, observation of trends and an expansion of the discussion to related topics. Outside the classroom, the instructor uses the same program to quickly generate test questions and solution keys. Trial and error solutions are cycled through rapidly. Students can review the classroom materials by changing input variables and observing results. Homework assignments can be developed to encourage students to use the program.

Making the program available to students, encourages them to learn by exploring on their own. Visual changes of the interaction diagram give students a good control of the design. The time spent using the program to explore problem scenarios posed by the instructor can lead students to a better understanding of the concepts involved in the problems. Students can learn to write *MathCAD* programs using their own method of problem solving.

Structural design problems usually have a number of solutions that lie within a design space. The traditional teaching of structural design usually focuses on a single solution through a number crunching exercise, following the rules set in a code of practice. Students are often unaware of a design space in traditional teaching. *MathCAD* allows students to undertake studies into numerous structural designs. More importantly, it provides a good graphical user interface, enabling students to see various design scenarios. *MathCAD* also provides good graphical output rather than pages and pages of script.

MathCAD develops in students a better understanding of structural design by encouraging deep learning rather than surface learning. Marton and Saljo emphasise the importance of deep learning as an effective learning paradigm in engineering [9]. *MathCAD* also helps students to develop a better understanding of structural design by encouraging case studies-based learning. Hills and Tedford emphasise the importance of case studies-based learning in engineering as the only way of effective learning and describes this as *the new learning paradigm* [10]. This type of learning is an effective and satisfying method of acquiring knowledge, as well as the intellectual and other skills associated with it. It invariably involves teamwork, project work, laboratory exercises and analytical reflection. Because many aspects of case studies are open ended, they invite discussion and judgemental conclusions. This engages the student's interests and is highly motivating.

CASE STUDY

In the following case study, the effects of rib spacing and dimension on the behaviour of two-way ribbed slabs have been studied. It is well known that rib spacing and depth is the most important parameter that affects the behaviour of two-way ribbed slabs as a whole. In the study, the rib spacing has been

changed from 0.5 metre to 2.0 metres while the rib depths have been changed from 300 mm to 1,300 mm. Figure 3 shows the input data of the two-way ribbed slab selected for the study.

The *MathCAD* program was utilised in order to determine the design bending moments and shear forces based on the approximate analysis method. Figure 6 presents the variation of the design bending moments MX_{max} and MY_{max} due to changes in the rib spacing.

The *MathCAD* program was also used to determine the design bending moments and shear forces based on the plate theory analysis method. Figures 7 and 8 present the variation due to changes in rib spacing and depth of the design bending moments MX_{max} and MY_{max}, respectively. Tables 1 and 2 summarise the design bending moments MX_{max} and MY_{max} obtained using the approximate and plate theory analysis methods.

Table 1: Design bending moments MX.

Analysis Method	Rib Depth (mm)	Rib Spacing			
		2.00 m	1.00 m	0.75 m	0.50 m
Approximate		269	134	125	84
Plate theory	300	265	132	99	66
	350	279	139	104	70
	400	289	145	108	72
	450	299	149	112	75
	500	306	153	115	76
	550	312	156	117	78
	600	317	159	119	79
	700	325	162	122	81
	800	330	165	124	82
	900	334	167	125	83
	1,000	337	168	126	84
	1,100	339	170	127	85
	1,200	341	171	128	85
	1,300	343	171	128	86
	1,400	344	172	129	86

Table 2: Design bending moments MY.

Analysis Method	Rib Depth (mm)	Rib Spacing			
		2.00 m	1.00 m	0.75 m	0.50 m
Approximate		151	76	70	47
Plate theory	300	149	74	56	37
	350	157	78	59	39
	400	163	81	61	41
	450	168	84	63	42
	500	172	86	65	43
	550	176	88	66	44
	600	178	89	67	45
	700	183	91	68	46
	800	186	93	70	46
	900	188	94	70	47
	1,000	189	95	71	47
	1,100	191	95	72	48
	1,200	192	96	72	48
	1,300	193	96	72	48
	1,400	193	97	73	48

Without the use of *MathCAD* program and its user interface, the potential to obtain this knowledge and full understanding of the behaviour of two-way ribbed slab is likely to have been masked by a *number crunching* exercise. From the results shown in Tables 1 and 2 and the bending moment plots in Figures 6, 7

and 8, it is clear that the approximate method analysis results are only valid when the rib has the following features:

- A depth of around 300-350 mm for rib spacing of 1 metre and 2 metres;
- A depth of around 900-1,000 mm for rib spacing of 0.5 metre and 0.75 metre.

Unfortunately, the approximate analysis method does not allow for variation in rib depth (stiffness). Engineers generally use the approximate analysis for two-way ribbed slabs regardless of the rib depth. It is clear that if engineers use the approximate analysis method, without questioning their validity and limitations, then there is a danger of reaching a wrong decision that may result in an unsafe design. The interactive use of the *MathCAD* program, such as that used in this case study, provides the potential for undergraduates to explore the problem solution space and to gain a better understanding of structural behaviour.

CONCLUSIONS

MathCAD contains tools that can enhance and supplement traditional methods of teaching and learning. The versatility, accessibility and ease of use make *MathCAD* a platform for creating learning modules for technically-based courses. *MathCAD* contains the capabilities for traditional classroom computation, but with a greater degree of accuracy, reliability and presentation quality. In addition, its speed at repetitive tasks, as well as its programmability, make new learning strategies possible. *MathCAD* programs take time for an instructor to develop, but have many benefits in return. By freeing the instructor and students from tedious computation and transcription, *MathCAD* programs create opportunities for meaningful understanding of technical materials. A well-designed *MathCAD* program can engage both students and teacher, inviting their exploration and discovery of the subject, thereby drawing them deeper into the secrets that it holds.

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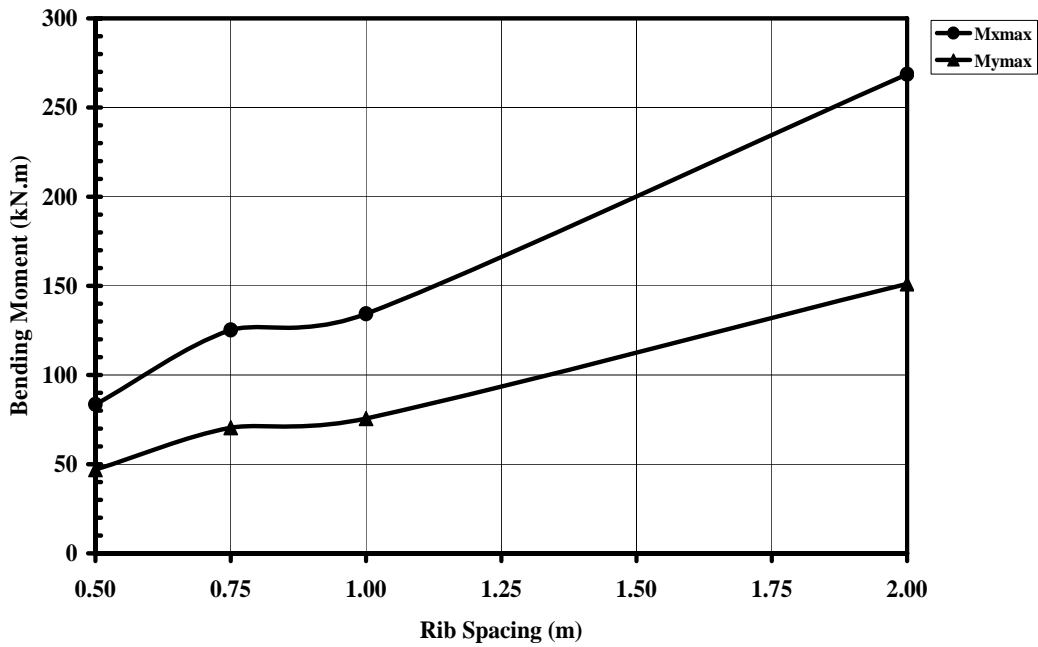
Figure 6: Slab design bending moments (approximate method).
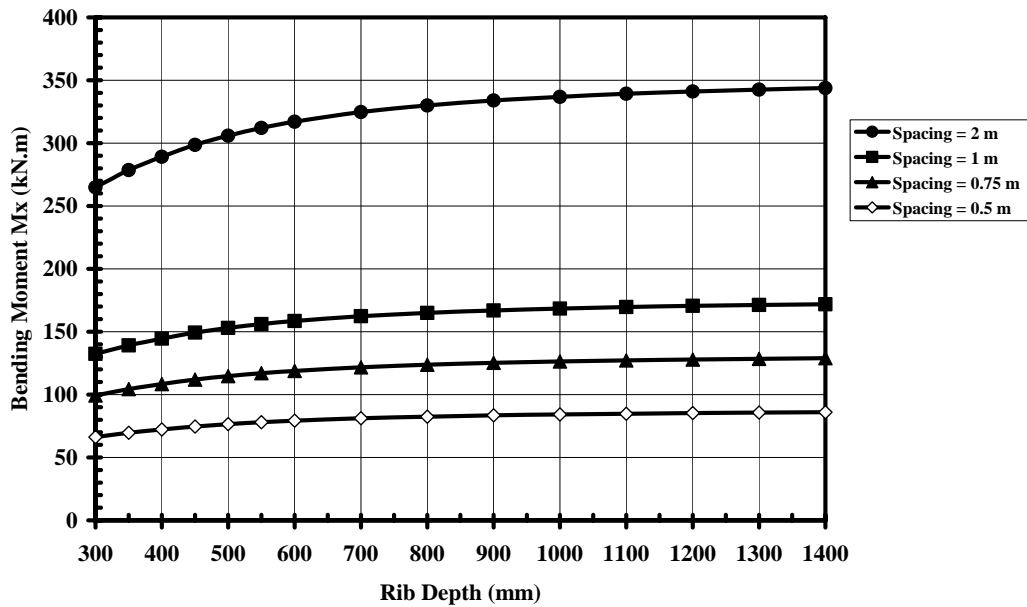
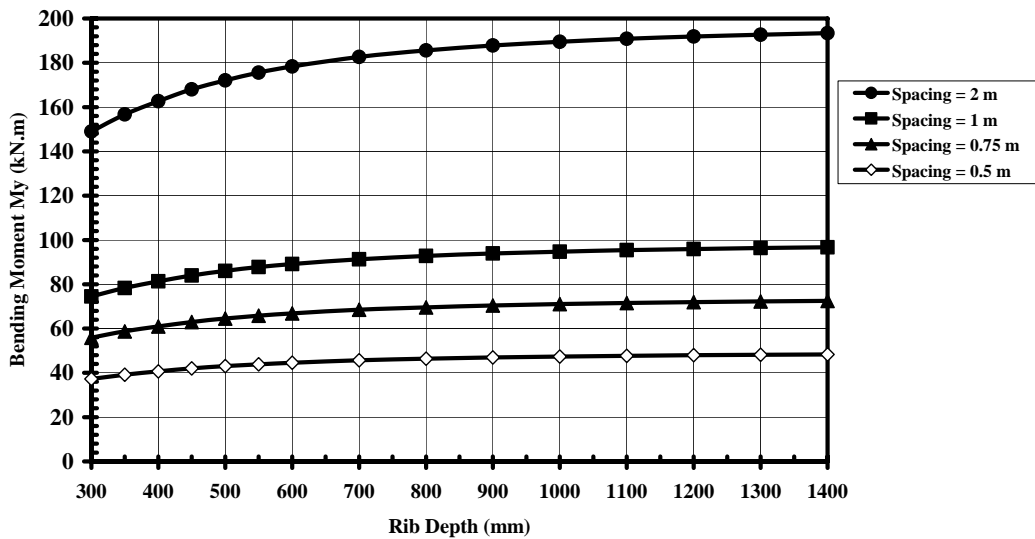

Figure 7: Slab design bending moments Mx (plate theory method).

Figure 8: Slab design bending moment My (plate theory method).