ISSN: 0128-7680
Pertanika J. Sci. & Technol. **17 (1)**: 69 – 85 (2009)

Software Development for Optimal Design of Different Precast Slabs

J. Noorzaei*, J.N. Wong, W.A. Thanoon and M.S. Jaafar
Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
**E-mail: jamal@eng.upm.edu.my*

ABSTRACT

Precast concrete technology forms an important part in the drive towards a full implementation of the Industrialized Building System (IBS). The IBS requires building components and their dimensions to be standardized, and preferably cast off site. Slabs are major structural elements in buildings, other than beams and columns. Standardized and optimized slabs can significantly enhance the building industries in achieving the full implementation of the IBS. Nevertheless, this requires computer techniques to achieve standardized and optimized slabs which can satisfy all building design requirements, including the standards of architectural and structural design standards. This study proposed a computer technique which analysed and designed five different types of slabs which will satisfy all the requirements in design. The most commonly used slabs included in this study were the solid one way, solid two way, ribbed, voided and composite slabs. The computer techniques enable the design of the most optimized sections for any of the slab types under any loading and span conditions. The computer technique also provides details for the reinforcements required for the slabs.

Keywords: Precast slabs, Industrialized Building System, optimized sections, building design

INTRODUCTION

For the past half century, the precast concrete components have been marketed on the basis of savings in materials and improved quality of products and workmanship, as well as the ease of construction. According to Yee (2001), the precast concrete technology has taken an important perspective in terms of its impact on both social and environment.

Architects and engineers have long hailed precast concrete for its high quality architectural and structural products. Precast concrete products can be fabricated in a large variety of shapes and sizes, while the use of prestressing provides for much longer spans than can be achieved using conventional insitu methods of construction (Yee, 2001).

Mixed construction techniques are now being used in more than 50 per cent of new multi-storey buildings in the western world, whereby the increased use of precast concrete over the past 10-15 years is due to the move towards greater offsite prefabrication of structural elements (Elliot, 2002). Some of the limitations found in precast concrete have inevitably led to it being used with other materials in a cost effective manner. Structurally, different components may either work together or independently, but they can provide many advantages over the use of a single material when used together.

Similar to the design of other structural elements, the aim of the design of a slab system is the attainment of acceptable probabilities which will not become unfit for their specified use during some defined life. Therefore, slabs should be designed to sustain, with an

Received: 10 September 2008
Accepted: 29 October 2008
*Corresponding Author

appropriate degree of safety, all loads and deformations liable to occur during construction and in service, so as to adequately perform their intended functions, and to possess an appropriate factor of safety against failure. Significant improvements in the efficiency of the overall building system can be gained by improving precast structural floor system to reduce weight, depth, and cost to better accommodate service systems (Pessiki *et al.*, 1995).

Comprehensive design formulations and procedures, for solid (one-way and two-way), ribbed, hollow core and composite slabs, are available in reinforced concrete books and British Standards (BS8110: Part 1: 1997, Allen, 1988; Kong and Evans, 1987; MacGinley and Choo, 1990; Mosley and Bungey, 1993). In order to achieve effective design of different precast slab systems and optimize the sections which consider all design requirements, a computer technique is therefore required. The objective of this study was to propose a comprehensive design using a computer technique for the most commonly used slabs in building construction, i.e. solid one-way, solid two-way, ribbed, voided and composite slabs. A computer program written in FORTRAN was developed for the purpose of achieving an optimum slab design which will fulfil all the BS8110 design requirements.

DEVELOPMENT OF COMPUTER CODE AND COMPUTATION ASPECT

A general computer code has been written in the FORTRAN language. The computer coding is done in two stages. In Stage I, individual type of slab system is programmed and validated with manual computation. Meanwhile in Stage II, all the individual programs are combined in the form of sub-routines and works under a master program. Each type of the slab systems is identified by a predefined code as:

i) NTYPE 1: Solid one-way
ii) NTYPE 2: Solid two-way
iii) NTYPE 3: Ribbed
iv) NTYPE 4: Voided (hollow core)
v) NTYPE 5: Composite (half slab)

Therefore, by merely inputting the respective code, the complete analysis, design and drafting of each slab type is carried out automatically. The design of every floor slab is started using loading and trial dimension as input. The depth of the slab is fixed based on satisfying BS8110 requirement for bending moment, shear force and deflections. *Fig. 1* shows the computational flowchart implemented for the solid one-way slab, solid two-way slab, ribbed slab, hollow core slab and composite slab, respectively. The analysis and design of the floor slabs were implemented in such a way that nine independent blocks were formed to obtain the load, moment, reinforcement, shear check, deflection check and result. All these blocks were controlled by the sub-routine MAIN. Other than these nine independent blocks, there were also five secondary sub-routines, identified as BARSIZE, INCREASEHEIGHT, DRAWLINES, DRAWSHAPES and TEXT. The function of each subroutine is explained in the Appendix.

APPLICATION AND VALIDATION OF THE COMPUTER CODE

Numerical Example 1: One-way Solid Slab

The chosen cross-section and the material properties of the slab are shown in *Fig.2.* The slab was designed to carry a selected live load of 1.5 kN/m^2, plus floor finishes and finishing load of 1.5 kN/m^2.

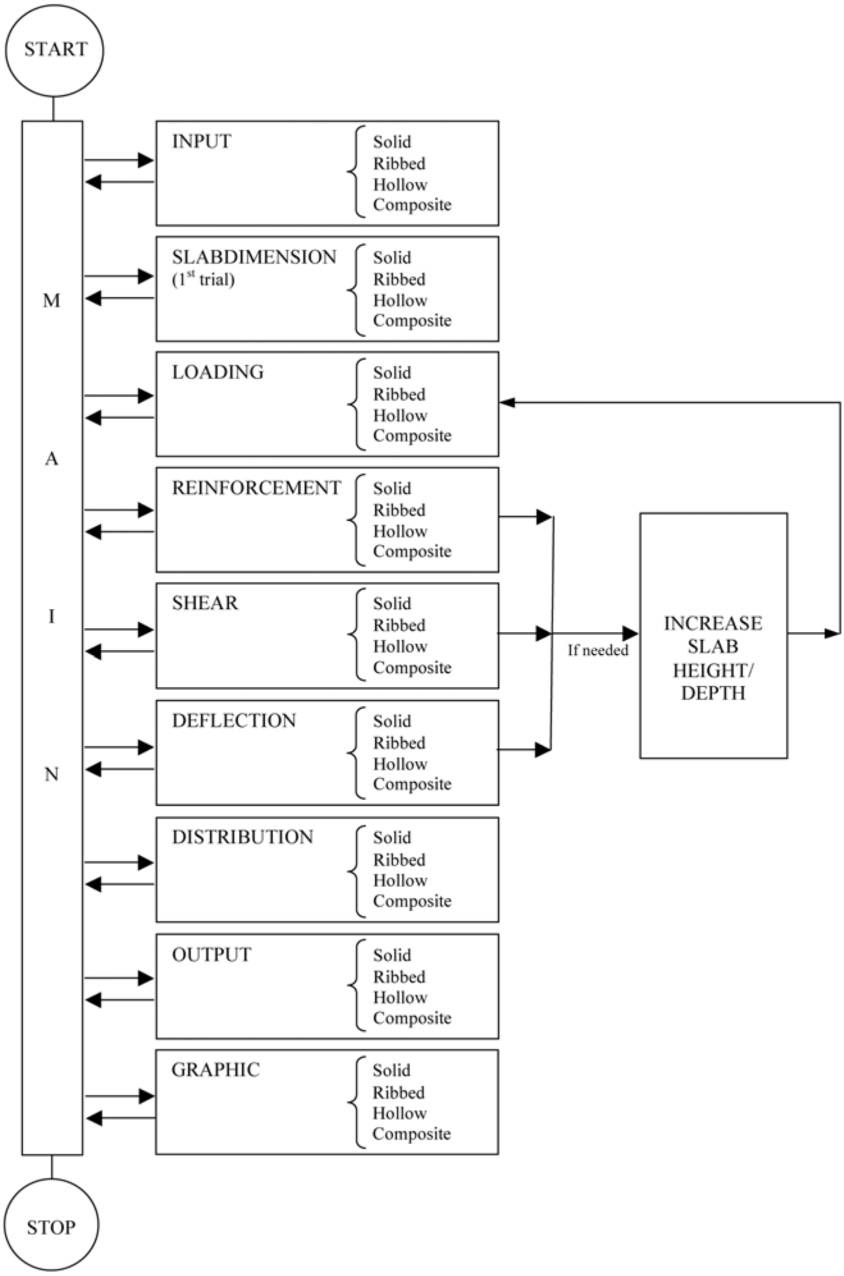

Fig. 1: Generalized flowchart for the design of different flooring

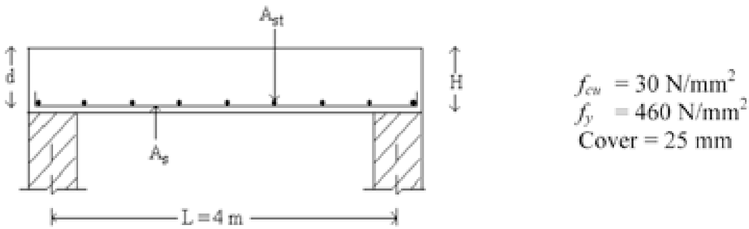

Fig. 2: Solid one-way slab for example 1

The output cross-section details evaluated through the program are shown in Table 1. Initially, the trial depth was assumed to be 80 mm. This depth represented the minimum depth which fulfilled the moment requirement (Eqn. 1, see Appendix). The program fixed the optimal depth after 19 iterations, i.e. 170 mm. This slab was designed manually and the comparisons of the various items are illustrated in Table 2. It is evident from this table that there is an excellent agreement between the results.

After deciding the final cross-section details of the floor slab, the graphic sub-routines were called and the structural members were drawn and viewed on the computer terminal. Since the FORTRAN 90 Power Station is equipped with graphic libraries, the various cross-sections can be drawn using these libraries; this is useful to the structural engineer. *Fig. 3* shows the graphical representation of the cross-section for numerical example 1.

TABLE 1
Cross-section details

Item	Value
Initial Height (mm)	80
No. of Iteration	19
Slab depth, *H* (mm)	170

Numerical Example 2: Two-way Solid Slab

A selected slab measuring 4.5 m x 7.0 m is simply supported at the edges with no provision to resist torsion at the corners or to hold the corners down (see *Fig. 4*). The characteristic dead load including finishes and the partition for this example is 1.5 kN/m^2, and the characteristic live load is 1.5 kN/m^2.

The cross-section details, evaluated through the program, are shown in Table 3. Using this cross-section, the analysis and design proceed are as shown in Table 4. Initially, the trial depth was assumed to be 85 mm. This depth represented the minimum depth which fulfilled the moment requirement. The program fixed the optimal depth after 21 iterations, i.e. 185 mm. *Fig. 5* shows the graphical representation of the cross-section for numerical example 2.

TABLE 2
Comparison of analysis and design for one-way solid slab

Item	Manual	Computer Output	Item	Manual	Computer Output
Loading & Moment			**Shear Check**		
Ultimate load, w (kN/m^2)	10.212	10.212	Shear Force, V (kN)	20.424	20.424
Ultimate moment, M_u (kNm)	20.424	20.424	Shear Stress, v (N/mm^2)	0.145	0.145
$A_{S(req)}$ (mm^2/m)	348.913	348.913	$v < 0.8\sqrt{f_{cu}}$ or 5N/mm^2	OK	OK
$A_{S(pro)}$ (mm^2/m)	402.000	402.000	Shear Capacity,		
v_c (N/mm^2)	0.574	0.574			
Use	Y8 @125 c/c	Y8 @ 125 c/c	$v < v_c$	OK	OK
Transverse Reinforcement			**Deflection Check**		
$A_{St(req)}$ (mm^2)	221	221	Modification Factor, *MF*	1.462	1.462
$A_{St\ (pro)}$ (mm^2)	226	226	L/d (allowable)	29.240	29.232
Use	Y6 @125 c/c	Y6 @ 125 c/c	L/d (actual)	28.369	28.369
			Actual < Allowable	OK	OK

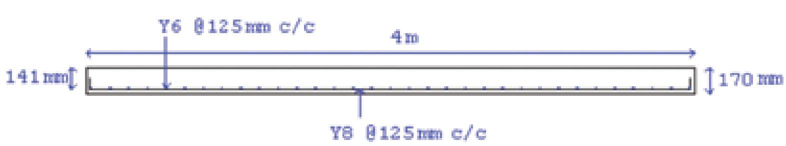

Fig. 3: Graphical representation of the solid one-way slab

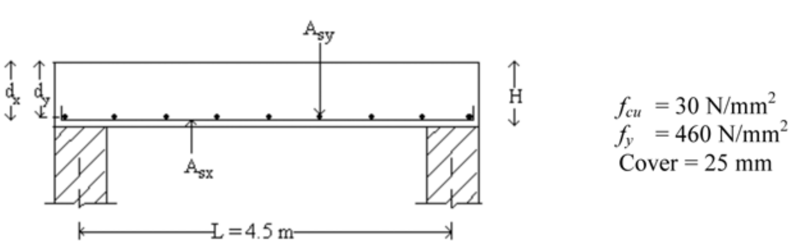

Fig. 4: Solid two-way slab for example 2

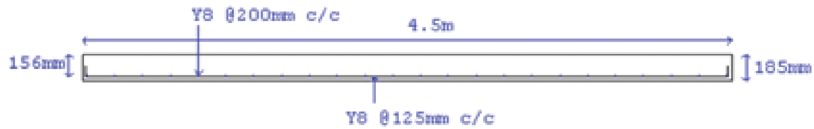

Fig. 5: Graphical representation of solid two-way slab

TABLE 3
Cross-section details

Item	Value
Initial Height (mm)	85
No. of Iteration	21
Slab depth, H (mm)	185

TABLE 4
Comparison of analysis and design for two-way solid slab

Item	Manual	Computer Output	Item	Manual	Computer Output
Loading & Moment			**Shear Check**		
Ultimate load, w (kN/m^2)	10.716	10.716	Shear Force, V (kN)	24.111	24.111
Ultimate moment, M_{sx} (kNm)	23.219	23.168	Shear Stress, v (N/mm^2)	0.163	0.163
Ultimate moment, M_{sy} (kNm)	9.548	9.575	$v < 0.8$ or 5N/mm^2	OK	OK
Reinforcement-Short Span			Shear Capacity, v_c (N/mm^2)	0.477	0.477
$A_{SX(req)}$ (mm^2/m)	358.520	357.734	$v < v_c$	OK	OK
$A_{SX(pro)}$ (mm^2/m)	402.000	402.000	**Deflection Check**		
Use	Y8 @125 c/c	Y8 @125 c/c	Basic *Span/Depth*	20.000	20.000
Reinforcement-Long Span			Modification Factor, *MF*	1.465	1.468
$A_{SY(req)}$ (mm^2/m)	240.500	240.500	L/d (allowable)	29.300	29.368
$A_{SY(pro)}$ (mm^2/m)	251.000	251.000	L/d (actual)	28.846	28.846
Use (No. & bar diameter)	Y8 @200 c/c	Y8 @ 200 c/c	Actual < Allowable	OK	OK

Numerical Example 3: Ribbed Slab

A sample precast floor slab, consists of several units of ribbed slab, is simply supported at the ends, as shown in *Fig. 6*. The effective span is 5.0 m, while the chosen characteristic dead load includes finishes and partition is 1.5 kN/m² and the characteristic live load is 2.0 kN/m². The distance of the centre to the centre of the ribs is 300 mm.

The final cross-sections evaluated through the program are shown in Table 5. Using this cross-section, the analysis and design was proceeded, as shown in Table 6. Initially, the trial depth was assumed to be 110 mm. This depth represented the minimum depth which satisfied the moment requirement. The program fixed the optimal depth, after 21 iterations, which was 210 mm. *Fig. 7* shows the graphical representation of the cross-section for numerical example 3.

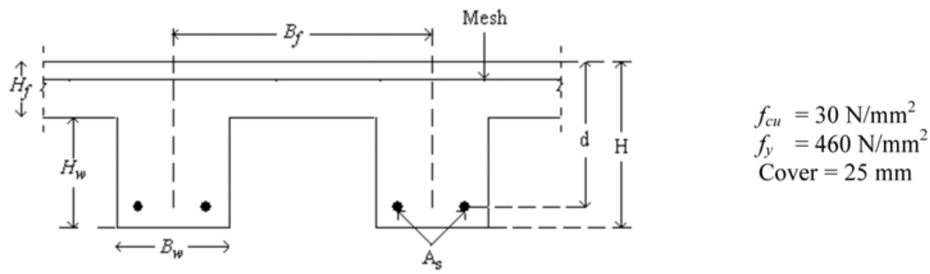

Fig. 6: Cross-section of the ribbed slab

TABLE 5
Cross section details

Item	Computation
Initial Height (mm)	110
No. of Iteration	21
Sla depth b, H (mm)	210
Flange width, B_f (mm)	300
Topping, H_f (mm)	60
Web width, B_w (mm)	125
Web height, H_w (mm)	150

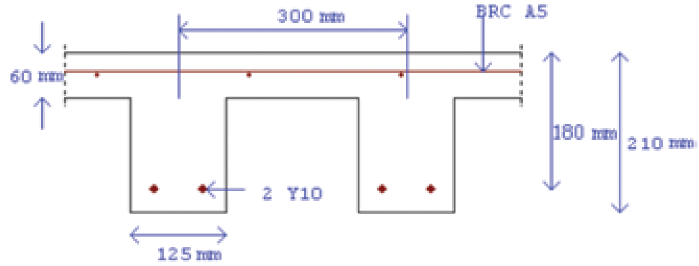

Fig. 7: Graphical representation of the ribbed slab

TABLE 6
The comparison of the analysis and design for the ribbed slab

Item	Manual	Computer Output	Item	Manual	Computer Output
Loading & Moment			Shear Check		
Ultimate load, w (kN/m^2)	2.825	2.825	Shear Force, V (kN)	7.063	7.062
Ultimate moment, M_u (kNm)	8.828	8.828	Shear Stress, v (N/mm^2)	0.314	0.314
Moment resistance, M_{RC} (kNm)	36.450	36.450	$v < 0.8\sqrt{f_{cu}}$ or 5N/mm^2	OK	OK
Reinforcement			Shear Capacity, v_c (N/mm^2)	0.727	0.727
$A_{S(req)}$ (mm^2)	118.137	118.130	$v < v_c$	OK	OK
$A_{S(pro)}$ (mm^2)	157.000	157.000	**Deflection Check**		
Use (No. & bar diameter)	2Y10	2Y10	Basic Span/ Depth	16.667	16.667
Topping Reinforcement			Modification Factor, *MF*	1.685	1.685
$A_{St(req)}$ (mm^2)	72	72	*Ld/* (allowable)	28.084	28.082
Use (Type of mesh)	A98	A98	*L/d* (actual)	27.778	27.778
$A_{St\ (pro)}$ (mm^2)	98	98	Actual < Allowable	OK	OK

Numerical Example 4: Hollow Core Slab

A sample precast floor slab, consisting of several units of hollow core slab, is simply supported at the ends, as shown in *Fig. 8.* The characteristic dead load, including finishes and partition, is 1.0 kN/m^2 and the characteristic live load is 1.5 kN/m^2. The distance of the centre to the centre of the core is 300 mm.

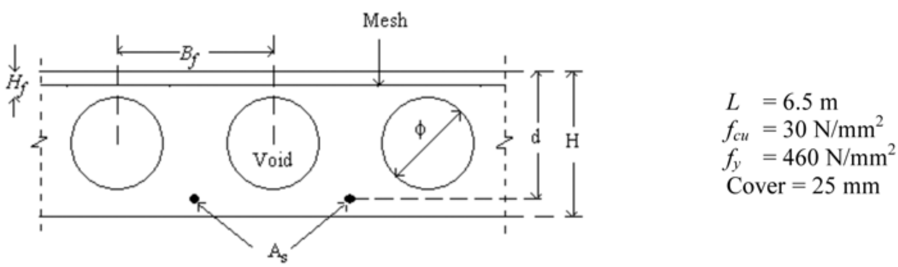

Fig.8: Cross section of hollow core slab

The cross-section details evaluated through the program are shown in Table 7. Using this cross-section, the analysis and design proceed, are as shown in Table 8. Initially, the trial depth was assumed to be 130mm. This depth represented the minimum depth which satisfied the moment requirement. The program fixed the optimal depth after 29 iterations, i.e. 270 mm. *Fig. 9* shows the graphical representation of the cross-section for numerical example 4.

TABLE 7
Cross-section details

Item	Value
Initial depth (mm)	130
No. of Iteration	29
Slab depth, H (mm)	270
Core c/c, B_f (mm)	300
Topping, H_f (mm)	50
Core Diameter., ϕ (mm)	170

TABLE 8
Comparison of analysis and design for hollow core slab

Item	Manual	Computer Output	Item	Manual	Computer Output
Loading & Moment			**Shear Check**		
Ultimate load, w (kN/m^2)	3.099	3.099	Shear Force, V (kN)	10.072	10.072
Ultimate moment, M_u (kNm)	16.367	16.366	Shear Stress, v (N/mm^2)	0.216	0.216
Moment resistance, M_{RC} (kNm)	42.930	42.930	$v < 0.8\sqrt{f_{cu}}$ or 5N/mm^2	OK	OK
Reinforcement			Shear Capacity, v_c (N/mm^2)	0.578	0.578
$A_{S(req)}$ (mm^2)	166.347	166.340	$V < v_c$	OK	OK
$A_{S(prov)}$ (mm^2)	201.000	201.000	**Deflection Check**		
Use (No. & bar diameter)	1Y16	1Y16	Basic Span/ Depth	18.035	18.035
Topping Reinforcement			Modification Factor, MF	1.544	1.544
$A_{St(req)}$ (mm^2)	60.000	60.000	$L/$ (allowable)	27.846	27.847
Use (Type of mesh)	BRC A4	BRC A4	L/d (actual)	27.426	27.426
$A_{St\ (prov)}$ (mm^2)	63.000	63.000	Actual < Allowable	OK	OK

As stated, the initial trial depth of 130 mm was used in the analysis and design of the voided slab following BS8110 Code. In deflection check, the slab depth does not satisfy the requirement for allowable span/depth ratio (the span/depth ratio is greater than allowable span/depth). Thus, the slab depth was increased to 135 mm and the calculations of loading, moment, reinforcement, shear check and deflection check were performed. The procedure was repeated until all the BS8110 requirements were satisfied. The optimal slab height was obtained after 29 iterations, and the final slab depth was found to be 270 mm. The comparison of analysis and design, obtained in the present study with the ones which were manually calculated, is presented in Table 8. This table clearly shows there is a good agreement between the results obtained.

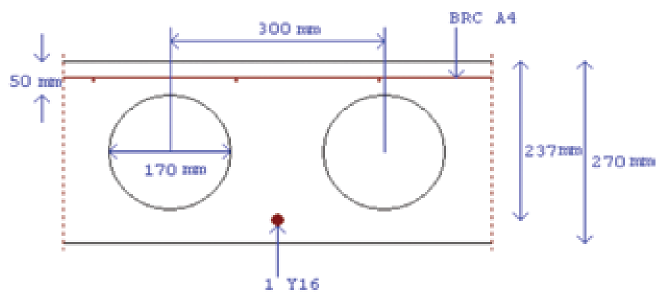

Fig. 9: Graphical representation of the computer output for hollow core slab example

Furthermore, the effects of the imposed load on the optimal void sizes and slab depth have been studied using the developed computer code to minimise the self weight, and hence, the overall cost. The correlations, between the void size and the self weight of the slab for 1 m width, are shown in *Figs. 10* to *12* for different imposed loads and floor spans. In general, when the void size increased, the self weight of the slab also decreased. All curves show similar correlations.

Table 9 presents the economical and practical design cases for the voided hollow precast slab. This includes the different span lengths of 5 m, 5.5 m and 6 m for three different imposed loads of 1.5, 2.0 and 2.5 kN/m^2.

TABLE 9
Optimal design

Span (m)	Imposed Load (kN/m^2)	depth (mm)	Void Diameter (mm)
	1.5	210	110
5.0	2.0	215	115
	2.5	225	125
	1.5	235	135
5.5	2.0	245	145
	2.5	250	150
	1.5	265	160
6.0	2.0	270	170
	2.5	275	170

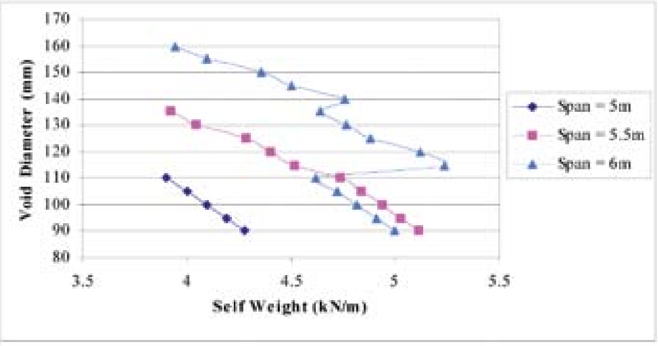

Fig. 10: Variation of self weight using IL = 1.5 kN/m² and DL = 1.5 kN/m²

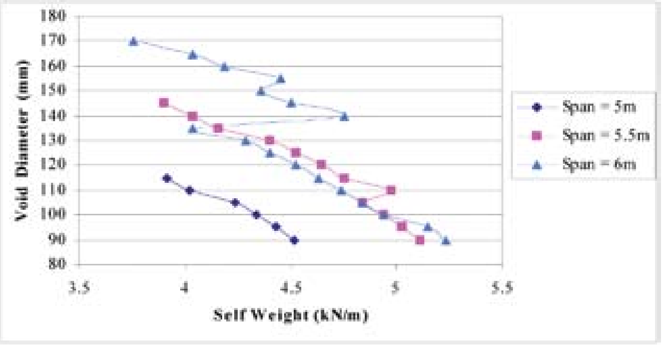

Fig. 11: Variation of self weight using IL = 2.0 kN/m² and DL = 1.5 kN/m²

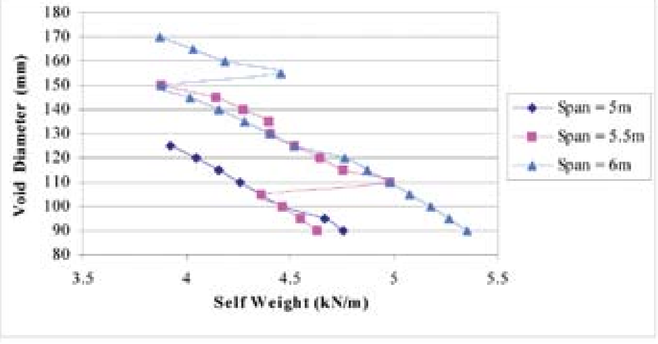

Fig. 12: Variation of self weight using IL = 2.5 kN/m² and DL = 1.5 kN/m²

Numerical Example 5: Half (Composite) Slab

The composite floor slab *(Fig. 13)* was simply supported over an effective span of 3.5 m. The characteristic dead load, including the finishes and partition, is 1.5 kN/m², while the characteristic live load is 2.5 kN/m². The allowance for the construction load = 0.75 kN/m².

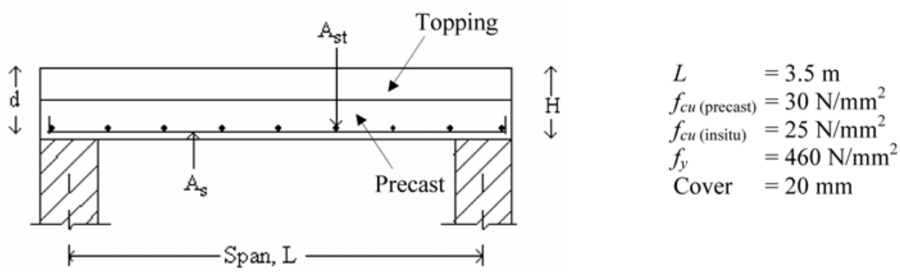

Fig. 13: The cross-section of the composite slab

The cross-section details, evaluated through the program, are shown in Table 10. Using this cross-section, the analysis and design proceed, are as shown in Table 11. Initially, the trial depth was assumed to be 75 mm. This depth represented the minimum depth which satisfied the moment requirement. The program fixed the optimal depth after 16 iterations, i.e. 150 mm. *Fig. 14* shows the graphical representation of the cross-section for numerical example 5.

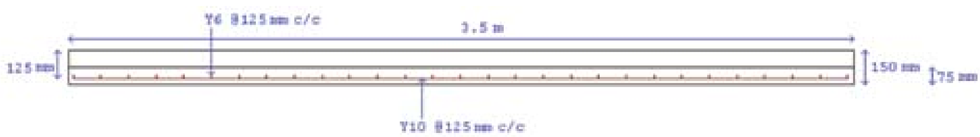

Fig. 14: Graphical representation of the composite slab

TABLE 10
Cross-section details

Item	Value
Initial depth (mm)	75
No. of Iteration	16
Slab depth, *H* (mm)	150
Precast depth (mm)	75
Insitu topping (mm)	75

TABLE 11
The comparison of analysis and design for the composite slab

Item		Manual	Computer Output	Item		Manual	Computer Output
Loading & Moment				Shear Check			
Precast	Ultimate load, w (kN/m^2)	6.240	6.240	Precast	Shear Force, V (kN)	10.920	10.920
	Ultimate moment, M_u (kNm)	9.555	9.555		Shear Stress, v (N/mm^2)	0.218	0.218
Composite	Ultimate load, w (kN/m^2)	11.140	11.140		$v < 0.8 \sqrt{f_{cu}}$ or 5N/mm^2	OK	OK
	Ultimate moment, M_u (kNm)	17.058	17.058		Shear Capacity, v_c (N/mm^2)	1.219	1.219
Reinforcement					$v < v_c$	OK	OK
Precast	$A_{S(req)}$ (mm^2)	520.607	527.306	Composite	Shear Force, V (kN)	19.495	19.495
					Shear Stress, v (N/mm^2)	0.156	0.156
Composite	$A_{S(req)}$ (mm^2)	329.245	329.106		$v < 0.8 \sqrt{f_{cu}}$ or 5N/mm^2	OK	OK
					Shear Capacity, v_c (N/mm^2)	0.672	0.672
$A_{S(req)}$ (mm^2) (Choose greater value)		520.607	527.306		$v < v_c$	OK	OK
$A_{S(prov)}$ (mm^2)		628.00	628.000	**Deflection Check**			
Use		Y10 @ 125 c/c	Y10 @ 125 c/c	Precast	a	9.814	9.814
Topping Reinforcement					Span/250	14.000	14.000
$A_{St(req)}$ (mm^2)		195.000	195.000		$a <$ *Span/250*	OK	OK

CONCLUSIONS

The analysis, design and graphical features of the different types of precast industrialized slab systems have been presented in the form of a generalized computer code. The programme is written in FORTRAN 90 Power Station environment and can run on any small PC. The computer code is a user-friendly programme, with several options, covering different types of slab systems. The program always starts with the minimum dimension of the slabs (as defined by the code) and evaluates the most optimum sections, based on the least weight section which is represented by the sections with the smallest depth. After deciding on the details of the final cross-section of the floor slab, this software equipped with graphic facilities can draw the structural members to be viewed on the computer terminal. The illustrated examples show that the results obtained using the developed computer code and from the manual calculation are in excellent agreement. Furthermore, the application of the programme, on the voided slab, indicates that the programme can select the optimal dimension of the slab and voids for minimum weight and, thus minimum cost of the slabs.

REFERENCES

Allen A.H. (1988). *Reinforced Concrete Design To BS8110 Simply Explained.* E. & F.N. Spon.

BS 8110 Part 1. (1997). Structural use of concrete. British Standard Institution, London.

Elliot K.S. (1996). *Multi-Storey Precast Concrete Frame Structures.* Blackwell Science Ltd.

Elliot K.S. (2002). *Precast Concrete Structures.* Butterworth-Heinemann.

Fortran Power Station Programmer's Guide.

Kong, F.K. and Evans, R.H. (1987). *Reinforced and Prestressed Concrete* (3rd edition). Chapman & Hall.

MacGinley, T.J. and Choo, B.S. (1990). *Reinforced Concrete Design Theory and Examples* (2nd edition). E. & F.N. Spon.

Mosley, W.H. and. Bungey, J.H. (1993). *Reinforced Concrete Design* (4th edition). MacMillan.

Pessiki, S., Prior, R., Sause, R. and Slaughter, S. (1995). Review of existing concrete gravity load framing systems. *PCI Journal, 40*(2), 52-67.

Yee A.A. (2001). Social and environmental benefits of precast concrete technology. *PCI Journal, 46*(3), 14-19.

Yee A.A. (2001). Structural and economic benefits of precast/prestressed concrete construction. *PCI Journal, 46*(4), 34-42.

Appendix: Function of each sub-routine

Subroutine	Function
MAIN	NTYPE of slab is selected corresponding to 1. Solid slab 2. Ribbed slab 3. Hollow slab 4. Composite slab If solid slab is selected, JTYPE of slab is selected according to 1. One-way slab 2. Two-way slab
INPUT	This read the geometric data, material properties and loads. Input data for: 1. Solid slab: L, L_y (for two way slab only), cover, f_{cu}, f_y, DL, LL and % redistribution. 2. Ribbed: L, B_{flange}, cover, f_{cu}, f_y, DL, LL and % redistribution. 3. Hollow: L, centre of core distance, cover, f_{cu}, f_y, DL, LL and % redistribution. 4. Composite: L, cover, f_{cu} (precast & topping), f_y, DL, LL, construction load and % redistribution.
SLABDIMENSION	This sub-routine creates the trial dimension of the slab (including effective depth, height, web width, flange height, etc., according to the types of slabs) which satisfy the moment requirement. The trial cross-section is of a minimum value, which will be changed whenever the limiting condition is not being satisfied. $minimum\ effective\ depth = \sqrt{\frac{M}{0.156 f_{cu} b}}$ (1) $Trial\ height = minimum\ effective\ depth + cover + \phi_{bar}/2$ (2)
LOADING	The calculation of the self weight, design ultimate load, design ultimate moment and moment of resistance (for the ribbed and hollow slabs only) is carried out in this sub-routine. Ultimate load, $\omega = 1.4G_k + 1.6Q_k$ (3) Ultimate moment; (a) One-way slab, ribbed, hollow and composite: $M \frac{\omega l^2}{8}$ (4) (b) Two-way slab $m_{sx} = \alpha_{sx} n l_x^2$ in direction of span l_x (5)

$$m_{sy} = \alpha_{sy} n l_x^2 \text{ in direction of span } l_y \tag{6}$$

Moment of resistance, $$M_{RC} = 0.45 f_{cu} b_f h_f \left(d - \frac{h_f}{2}\right) \tag{7}$$

REINFORCEMENT

This sub-routine calculates the area of the tensile steel rquired, As_{req}.

$$As_{req} = \frac{M}{0.95 f_y z} \tag{8}$$

After obtaining As_{req}, this sub-routine calls upon the sub-routine BARSIZE to select the suitable bar size and bar spacing.

SHEAR

Checking of design shear stress, v and design shear capacity, v_c is done in this subroutine.

$$v = \frac{V}{bd} \tag{9}$$

$$v_c = 0.79\{100A_s/(b_v d)\}^{1/3}\,(400/d)^{1/4}\,(f_{cu}/25)^{1/3}/\gamma_m \tag{10}$$

DEFLECTION

To carry the task on deflection checking. Check *actual span/depth* should not be greater than *allowable span/depth* so that the deflection of a slab will not be excessive.

$$\textit{Allowable span / effective depth} = \textit{basic span/effective depth ratio} \times \textit{M.F.} \tag{11}$$

$$\text{where } M.F. = 0.55 + \frac{(477 f_s)}{120\left(0.9 + \dfrac{M}{bd^2}\right)} \tag{12}$$

$$\textit{Actual span / effective depth} = \frac{l}{d} \tag{13}$$

DISTRIBUTION

This sub-routine calculates the distribution, which is also known as the transverse reinforcement required, Ast_{req} for the solid and composite slabs. Meanwhile, for the ribbed and hollow slabs, this sub-routine calculates the topping reinforcement required. Suitable bar size and spacing will be selected.

(a) For solid and composite slabs:

$$Ast_{req} = 0.13\%\ bh \text{ for high-yield steel} \tag{14}$$

$$Ast_{req} = 0.24\%\ bh \text{ for mild steel} \tag{15}$$

(b) For ribbed and hollow slabs:

$$A_{mesh} = 0.12\% \text{ of the topping cross sectional area} \tag{16}$$

	After obtaining Ast_{req}, this sub-routine calls upon subroutine BARSIZE to select the suitable bar size and bar spacing. In the case of the ribbed and hollow slabs, a suitable mesh is selected within the DISTRIBUTION sub-routine.
OUTPUT	All the results and values of the calculation will be presented in this sub-routine.
GRAPHICMODE	To draw the cross-section of the optimal slab dimension. This sub-routine will call upon the sub-routine DRAWLINES (), DRAWSHAPES (), and TEXT ().
BARSIZE	This sub-routine selects the bar diameter, spacing and the number of bars which satisfy the required reinforcement. The area of reinforcement provided will be calculated.
INCREASEHEIGHT	This subroutine is called whenever the limiting condition in the sub-routine REINFORCEMENT, SHEAR and DEFLECTION is not being satisfied. Examples of the limiting conditions are: *i)* $K > K'$ (subroutine REINFORCEMENT) *ii)* $v >$ lesser of $0.8\sqrt{f_{cu}}$ or $5N/mm^2\}$ (Subroutine SHEAR) *iii)* $v > v_c$ *iv)* Actual l/d > Allowable l/d (subroutine DEFLECTION) The slab height will be increased by 5mm each time this sub-routine is being called. Whenever the slab dimension is changed, the recalculation of all the parameters has to be carried out starting from the sub-routine LOADING and so on.
DRAWLINES	To draw straight lines for the slab cross-section, reinforcement and dimension lines.
DRAWSHAPES	To draw rectangular and circle shapes for the appropriate slabs.
TEXT	To write the text for the slab dimension and the type of reinforcements.