CORK INSTITUTE OF TECHNOLOGY
INSTITIÚID TEICNEOLAÍOCHTA CHORCAÍ

Semester 1 Examinations 2008/09

Module Title: Advanced Structural Design

Module Code: **CIVL 8001**

School: Building & Civil Engineering

Programme Title: Bachelor of Engineering (Honours) in Structural Engineering - Award

Programme Code: **CSTRU_8_Y4**

External Examiner(s): Mr P Anthony; Prof P O'Donoghue
Internal Examiner(s): Mr M P Mannion; Mr L O'Driscoll

Instructions:
1. Paper contains **four** questions.
2. Attempt **all four** questions
3. All questions carry **equal** marks.
4. Use **separate** Answer books for each Section.
5. Candidates may refer to: BSI-PP7312: - *Extracts from British Standards for students of Structural Design* and *Approved design aids.*

Duration: 2 Hours

Sitting: Winter 2008

Requirements for this examination: 2 desks per candidate – one for calculations, etc., and a second as a layoff table.

Note to Candidates: Please check the Programme Title and the Module Title to ensure that you have received the correct examination paper.
If in doubt please contact an Invigilator.

Section A

QA1. A trial cross–section of a ribbed slab floor is shown in Fig. QA1. The floor is constructed of reinforced concrete, permanent 300 mm x 300 mm x 250 mm structural-type hollow clay blocks, of wall thickness 20 mm, and a 12 mm-plaster ceiling. The floor is continuous over several equal spans of 6.5 m, but may be treated as single span simply supported for analysis and fire resistance purposes. Check the effectiveness of the trial section; design the floor for flexure; check if deflection criteria are satisfied. Omit calculations for shear and anchorage. Take the effective depth, d = 260 mm.

Characteristic loads:	self weight	=	3.51 kN/m^2
	plaster	=	0.25 kN/m^2
	imposed	=	4.00 kN/m^2
	Exposure:		mild
	Fire resistance:		1 hour
	Concrete:		Grade C35
	Reinforcement:		Grade 460 Type 2 deformed 20 mm diam. bars

(Attached: BS 8110/1 Cl 3.6; BS 8110/2 Cl 4.2)

QA2. The stiffened steel plate girder of Fig. QA2 is fully restrained throughout its length. Using grade S275 steel and the requirements of BS 5950, check the moment capacity of the section (ignore the web). Assuming the end panels are the most critical, check the shear capacity of the girder. No checks are required on the end posts or stiffeners.

The **design** loading for the ultimate limit state is given in the Fig., with the point loads being transferred via UBs.

QA3. Fig. QA3 gives details of the trial section for a fin wall of a warehouse building. The wall is 8 m high from d.p.c to the supported flat roof level, and the fins project on the external face. Check the flexural adequacy of the trial section under a characteristic wind pressure of 0.8 kN/m^2.

The wall is constructed from 15 N, 215 mm x 102.5 mm x 65 mm clay bricks, having a water absorption of 7 to 12%. The bricks are set in a grade (iii) mortar with special/normal control on manufacturing/construction.

$W_{brickwork}$ = 20 kN/m^3; I = 157 x 10^{-4} m^4

(Attached information:- BS 5628:Part1, Fig. 10)

Cork Institute of Technology - BEng in Structural Engineering - Stage 4

Semester 1 Examinations 2008-'09 - ***Advanced Structural Design - Section A***

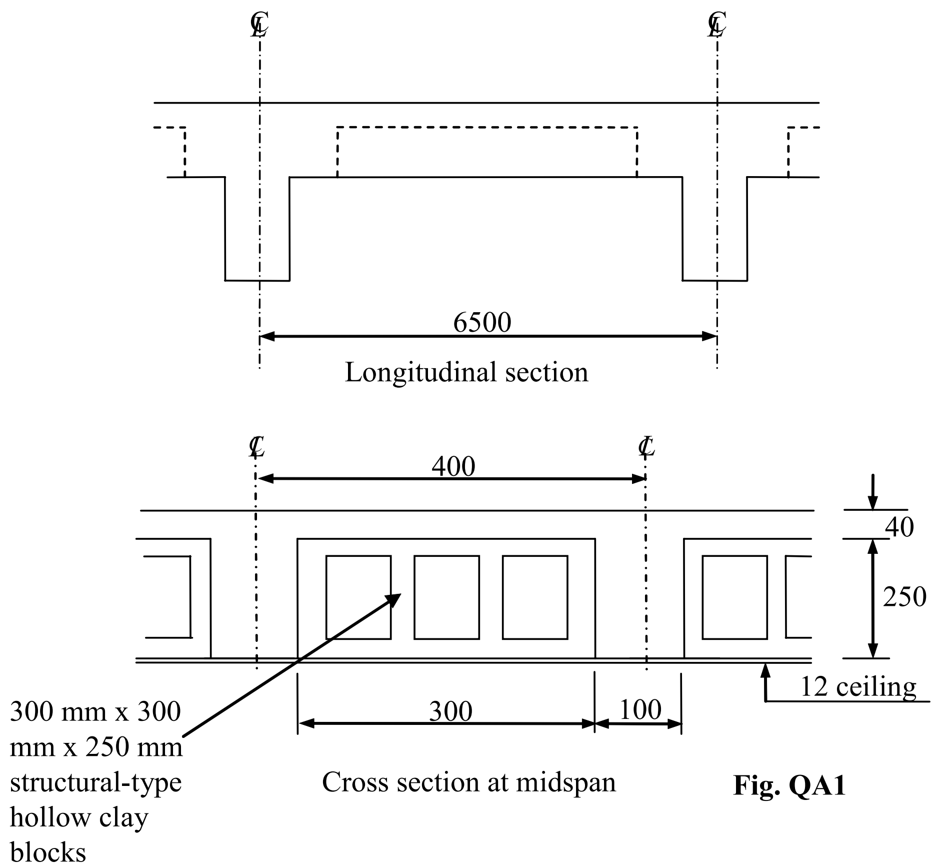

Fig. QA1

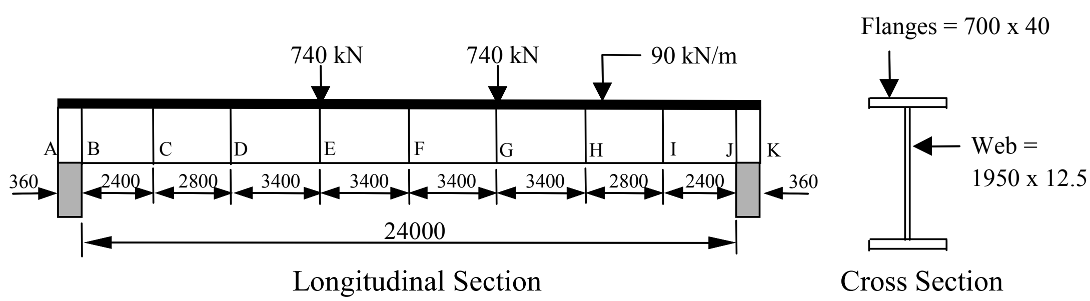

Fig. QA2

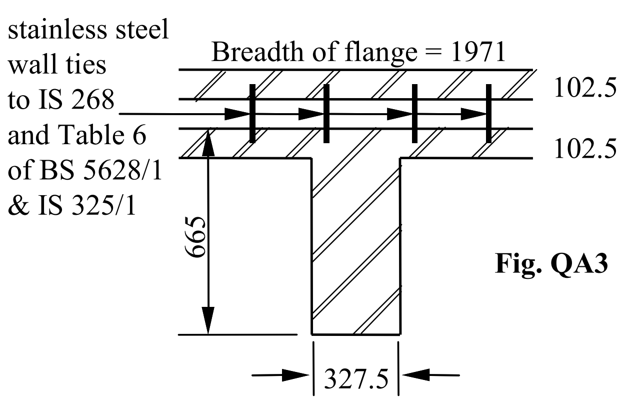

Fig. QA3

All dimensions in mm

DO NOT SCALE

Section A Attachments

3.5.5.2 ***Shear stresses***

The design shear stress v at any cross-section should be calculated from equation 21:

$$v = \frac{V}{bd} \qquad \text{equation 21}$$

In no case should v exceed $0.8\sqrt{f_{cu}}$ or 5 N/mm², whichever is the lesser, whatever shear reinforcement is provided.

3.5.5.3 ***Shear reinforcement***

Recommendations for shear reinforcement in solid slabs are given in Table 3.16.

3.5.6 Shear in solid slabs under concentrated loads

The provisions of **3.7.7** may be applied.

3.5.7 Deflection

Deflections may be calculated and compared with the serviceability requirements given in Section 3 of BS 8110-2:1985 but, in all normal cases, it will be sufficient to restrict the span/effective depth ratio. The appropriate ratio may be obtained from Table 3.9 and modified by Table 3.10. Only the conditions at the centre of the span in the width of slab under consideration should be considered to influence deflection.

The ratio for a two-way spanning slab should be based on the shorter span.

3.5.8 Crack control

In general the reinforcement spacing rules given in **3.12.11** will be the best means of controlling flexural cracking in slabs, but, in certain cases, advantage may be gained by calculating crack widths (see Section 3 of BS 8110-2:1985).

3.6 Ribbed slabs (with solid or hollow blocks or voids)

3.6.1 General

3.6.1.1 ***Introduction***

The term "ribbed slab" in this sub-clause refers to in-situ slabs constructed in one of the following ways.

a) *Where topping is considered to contribute to structural strength* (see Table 3.17 for minimum thickness):

1) as a series of concrete ribs cast in-situ between blocks which remain part of the completed structure; the tops of the ribs are connected by a topping of concrete of the same strength as that used in the ribs;

2) as a series of concrete ribs with topping cast on forms which may be removed after the concrete has set;

3) with a continuous top and bottom face but containing voids of rectangular, oval or other shape.

b) *Where topping is not considered to contribute to structural strength:* as a series of concrete ribs cast in-situ between blocks which remain part of the completed structure; the tops of the ribs may be connected by a topping of concrete (not necessarily of the same strength as that used in the ribs).

3.6.1.2 ***Hollow or solid blocks and formers***

Hollow or solid blocks and formers may be of any suitable material but, when required to contribute to the structural strength of a slab, they should:

a) be made of concrete or burnt clay;

b) have a characteristic strength of at least 14 N/mm², measured on the net section, when axially loaded in the direction of compressive stress in the slab;

c) when made of fired brickearth, clay or shale, conform to BS 3921.

3.6.1.3 ***Spacing and size of ribs***

In-situ ribs should be spaced at centres not exceeding 1.5 m and their depth, excluding any topping, should not exceed four times their width. The minimum width of rib will be determined by considerations of cover, bar spacing and fire.

3.6.1.4 ***Non-structural side support***

Where the side of a slab is built into a wall or rests on a beam parallel to the ribs, that side should be strengthened by the formation of a rib of width equal to that of the bearing.

3.6.1.5 ***Thickness of topping used to contribute to structural strength***

The thickness after any necessary allowance has been made for wear, should be not less than those of Table 3.17.

3.6.1.6 ***Hollow block slabs where topping is not used to contribute to structural strength***

When a slab is constructed to b) of Table 3.17 the blocks should conform to **3.6.1.2**. In addition the thickness of the block material above its void should be not less than 20 mm nor less than one-tenth of the dimension of the void measured transversely to the ribs. The overall thickness of the block and topping (if any) should be not less than one-fifth of the distance between ribs.

Table 3.17 — Minimum thickness of structural toppings

Type of slab	Minimum thickness of topping mm
Slabs with permanent blocks	
As described in **3.6.1.1** a) 1) and **3.6.1.2**	
a) Clear distance between ribs not more than 500 mm jointed in cement: sand mortar not weaker than 1:3 or 11 N/mm²	25
b) Clear distance between ribs not more than 500 mm, not jointed in cement: sand mortar	30
c) All other slabs with permanent blocks	40 or one-tenth of clear distance between ribs, whichever is greater
All slabs without permanent blocks	
As described in **3.6.1.1** a) 2) and 3)	50 or one-tenth of clear distance between ribs, whichever is greater

3.6.2 Analysis of structure

The moments and forces due to design ultimate loads on continuous slabs may be obtained by any of the methods given in **3.5.2** for solid slabs. Where the slabs are ribbed in two directions, they may be designed as two-way spanning in accordance with **3.5.3** or as flat slabs in accordance with **3.7**, whichever is the more appropriate.

Alternatively, if it is impracticable to provide sufficient reinforcement to develop the full design support moment, the slabs may be designed as a series of simply-supported spans. If this is done, sufficient reinforcement should be provided over the support to control cracking. It is recommended that such reinforcement should have an area of not less than 25 % of that in the middle of the adjoining spans and should extend at least 15 % of the spans into the adjoining spans.

3.6.3 Design resistance moments

The provisions given in **3.4.4** for determining the design ultimate resistance moment of beams may be used. In the analysis of sections the stresses in burnt clay blocks or solid blocks in the compression zone may be taken as 0.25 times the strength determined in **3.6.1.2b)**; however, when evidence is available to show that not more than 5 % of the blocks have strength below a specified crushing strength, the stress may be taken as 0.3 times that strength.

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3.6.4 Shear

3.6.4.1 ***Flat slab construction***

If the design assumes this method **3.7.6** should be used. Where a perimeter (see **1.3.3.1**) cuts any ribs, they should each be designed to resist an equal proportion of the applied effective design shear force. Shear links in the ribs should continue for a distance of at least d into the solid area.

3.6.4.2 ***One- or two-way spanning slabs***

The design shear stress v should be calculated from equation 22:

$$v = \frac{V}{b_v d} \qquad \text{equation 22}$$

where

- V is the design shear force due to design ultimate loads on a width of slab equal to the centre distance between ribs;
- b_v is the average width of the rib;
- d is the effective depth.

3.6.4.3 ***Shear contribution by hollow blocks***

In equation 22, b_v may be increased by the wall thickness of the block on one side of the rib.

3.6.4.4 ***Shear contribution from solid blocks***

Where blocks satisfy **3.6.1.2**, b_v in equation 22 may be increased by one-half of the rib depth on each side of the rib.

3.6.4.5 ***Shear contribution by joints between narrow precast units***

In equation 22, b_v may be increased by the width of mortar or concrete joint.

3.6.4.6 ***Maximum design shear stress***

In no case should v exceed $0.8\sqrt{f_{cu}}$ or 5 N/mm², whichever is the lesser (this includes an allowance for γ_m of 1.25).

3.6.4.7 ***Area of shear reinforcement in ribbed hollow block or voided slabs***

No shear reinforcement is required when v is less than v_c (where v_c is obtained from Table 3.8). When v equals or exceeds v_c reinforcement conforming to Table 3.16 should be provided.

3.6.5 Deflection in ribbed, hollow block or voided construction generally

3.6.5.1 ***General***

For one-way spanning floors, the span/effective depth ratios should be checked in accordance with **3.4.6** except that the rib width may include the walls of the blocks on both sides of the rib. For slabs spanning in two directions on to walls or beams, the check should be carried out for the shorter span. Where the slab is designed as a flat slab, the provisions of **3.7.8** apply.

3.6.5.2 ***Rib width of voided slabs or slabs of box or I-section units***

In deriving the basic ratio from Table 3.9, b_v may be calculated assuming all material below the upper flange of the unit to be concentrated in a rectangular rib having the same cross-sectional area and depth.

3.6.6 Arrangement of reinforcement

3.6.6.1 ***Curtailment of bars***

The reinforcement should be curtailed in accordance with **3.12.9**. However, where appropriate, the simplified rules given in **3.12.10** may be used.

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3.6.6.2 ***Reinforcement in topping for ribbed or hollow block slabs***

Consideration should be given to providing a single layer of welded steel fabric, having a cross-sectional area of not less than 0.12 % of the topping, in each direction; the spacing between wires should not be greater than half the centre-to-centre distance between ribs.

3.6.6.3 ***Links in ribs***

Provided the geometry satisfies **3.6.1.3** ribs reinforced with a single bar or ribs in waffle slabs do not require links unless shear or fire resistance requirements so dictate. However consideration should be given to the use of purpose made spacers occupying the full width of the rib to ensure correct cover to the bar.

Where two or more bars are used in a rib, the use of link reinforcement in addition to normal spacers is recommended except in waffle slabs, to ensure correct cover to reinforcement. The spacing of the links can generally be of the order of 1 m to 1.5 m depending on the size of the main bars

The cover of the link reinforcement should satisfy the durability requirement of Table 3.4 but need not satisfy the requirements for fire resistance in Table 3.5 provided the cover to the main bars does so.

3.7 Flat slabs

NOTE See **1.3.2** for definitions specific to flat slabs.

3.7.1 General

3.7.1.1 ***Symbols***

For the purposes of **3.7** the following symbols apply.

a_v	distance from the edge of the loaded area to the perimeter considered.
A_{sv}	area of shear reinforcement.
b_e	breadth of effective moment transfer strip (see Figure 3.13).
C_x C_y	plan dimensions of column (see Figure 3.13).
d_h	depth of the head.
F	total design ultimate load on the full width of panel between adjacent bay centre lines ($= 1.4G_k + 1.6Q_k$).
f_{yv}	characteristic strength of shear reinforcement.
h_c	effective diameter of a column or column head.
l	given in Table 3.12 should be taken as the full panel length in the direction of span.
l_1	panel length parallel to span, measured from centres of columns.
l_2	panel width, measured from centres of columns l_h.
l_c	dimensions of the column measured in the same direction as l_h.
l_h	effective dimension of a head.
l_x	shorter span of flat slab panel.
l_y	longer span of flat slab panel.
M_t	design moment transferred between slab and column.
n	design ultimate load per unit area ($= 1.4g_k + 1.6q_k$).
u	effective length of the outer perimeter of the zone.
u_o	effective length of the perimeter which touches a loaded area.
v	design shear stress.
v_c	design concrete shear stress.
V	design ultimate value of the concentrated load.
V_t	design shear transferred to column.
V_{eff}	design effective shear including allowance for moment transfer.
x	dimension of a shear perimeter parallel to axis of bending.
α	angle between the shear reinforcement and the plane of the slab.

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4.1.6 Spalling of concrete at elevated temperatures

Rapid rates of heating, large compressive stresses or high moisture contents (over 5 % by volume or 2 % to 3 % by mass of dense concrete) can lead to spalling of concrete cover at elevated temperatures, particularly for thicknesses exceeding 40 mm to 50 mm. Such spalling may impair performance by exposing the reinforcement or tendons to the fire or by reducing the cross-sectional area of concrete. Concretes made from limestone aggregates are less susceptible to spalling than concretes made from aggregates containing a higher proportion of silica, e.g. flint, quartzites and granites. Concrete made from manufactured lightweight aggregates rarely spalls.

It may be possible to show that a particular form of construction has given the required performance in a fire resistance test without any measures to avoid spalling. Alternatively, the designer may be able to demonstrate by fire engineering principles that the particular performance can be provided, even with spalling of concrete cover to the main tensile reinforcement.

4.1.7 Protection against spalling

In any method of determining fire resistance where loss of cover can endanger the structural element, measures should be taken to avoid its occurrence. Acceptable measures are:

a) an applied finish by hand or spray of plaster, vermiculite, etc.;

b) the provision of a false ceiling as a fire barrier;

c) the use of lightweight aggregates;

d) the use of sacrificial tensile steel.

NOTE An applied finish or false ceiling may increase the fire resistance of an element as described in **4.2.4**.

Welded steel fabric as supplementary reinforcement is sometimes used to prevent spalling; it is then placed within the cover at 20 mm from the concrete face. There are practical difficulties in keeping the fabric in place and in compacting the concrete; in certain circumstances there would also be a conflict with the durability recommendations of this standard.

4.1.8 Detailing

The detailing of the structure for any of the three methods of design should be such as to implement the design assumptions for the changes during a fire in the distribution of load and the characteristic strengths of the materials. In particular, the reinforcement detailing should reflect the changing pattern of the structural action and ensure that both individual elements and the structure as a whole contain adequate supports, ties, bonds and anchorages for the required fire resistance.

4.2 Factors to be considered in determining fire resistance

4.2.1 General

The factors given in **4.2.2**, **4.2.3**, **4.2.4**, **4.2.5**, **4.2.6**, **4.2.7**, **4.2.8**, **4.2.9** and **4.2.10** should be considered for the determination of the fire resistance of any element by any method.

4.2.2 Aggregates

Table 4.1, Table 4.2, Table 4.3, Table 4.4, Table 4.5 and Table 4.6 in method 1 refer to two types of concrete:

a)	dense concrete:	calcareous aggregates and aggregates siliceous in character, e.g. flints, quartzites and granites;
b)	lightweight concrete: ($\leqslant$ 2 000 kg/m^3)	aggregates made from sintered p.f.a., expanded clays and shales, etc.

In general, calcareous aggregates, i.e. limestone, give superior performance in fire compared with siliceous aggregates. However, insufficient data are available to provide comprehensive tables, except for columns. Therefore, where calcareous aggregates are used in method 1, the dimensions used should be those for dense concrete.

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4.2.3 Cover to main reinforcement

Cover has to provide lasting protection to the reinforcement from both fire and environmental attack. Choice of thickness should be on the basis of the more onerous. In this section "cover" is the distance between the nearest heated face of the concrete and the surface of the main reinforcement or an average value determined as shown below.

NOTE 1 This definition differs from that of "nominal cover" used in BS 8110-1; for practical purposes cover is stated as nominal cover to all steel reinforcement.

a) *Floor slabs.* Cover is the average distance from the soffit or the heated face. With one-way spanning single layer reinforcement the actual distance is used, i.e. C_1. With two-way spanning floor slabs the average distance is calculated taking into account reinforcement in both directions as multi-layer reinforcement. With one-way spanning floor slabs only multi-layer reinforcement in the same direction should be used to determine the average distance. The average distance C_{ave} is calculated as follows:

$$C_{ave} = \frac{A_1C_1 + A_2C_2 + A_3C_3 + \dots A_nC_n}{A_1 + A_2 + A_3 + \dots A_n} = \frac{\Sigma AC}{\Sigma A} \qquad \text{equation 15}$$

where

- A is the area of tensile reinforcement/tendons;
- C is the distance between the nearest exposed surface and the main reinforcement.

b) *Rectangular beams.* The effective cover C_{ave} for the assembly of main reinforcement is determined as in a). Examples of calculation of average cover are given in Figure 4.1.

NOTE 2 *Method 3.* Where C_1 (floor slabs) or C_1 or C_3 to individual corner bars (rectangular beams) is less than half C_{ave} then that reinforcement should be disregarded in the calculation of the ultimate resistance at high temperature.

c) *I-section beams.* The effective cover $C_{ave,}$ after determination as in b) is adjusted by multiplying it by 0.6 to allow for the additional heat transfer through the upper flange face.

4.2.4 Additional protection

Where plaster, except Gypsum, or sprayed fibre is used as an applied finish to other elements, it may be assumed that the thermal insulation provided is at least equivalent to the same thickness of concrete. Such finishes can therefore be used to remedy deficiencies in cover thickness. For selected materials and, subject to riders existent in BRE Guidelines, the following guidance can be given with respect to the allowance of the use of additional protection not exceeding 25 mm in thickness as a means of providing effective cover to steel reinforcing or prestressing elements. In each case the equivalent thickness of concrete may be replaced by the named protection.

Mortar Gypsum plaster	≡ 0.6 × concrete thickness
Lightweight plaster Sprayed lightweight insulation	≡ 1.0 × concrete thickness up to 2 h 2.0 × concrete thickness > 2 h
Vermiculite slabs	≡ 1.0 × concrete thickness up to 2 h ≡ 1.5 × concrete thickness > 2 h

4.2.5 Floor thickness

For all methods the thickness of floors is governed by the dimensions of slabs. In the case of solid slabs the thickness to consider is the actual thickness of the slab plus any non-combustible finish on top. With hollow slabs (or beams with filler blocks) the effective thickness t_e should be obtained by considering the total solid per unit width as follows:

$$t_e = h \times \sqrt{\xi} + t_f \qquad \text{equation 16}$$

where

- h is the actual thickness of slab;
- ξ is the proportion of solid material per unit width of slab;
- t_f is the thickness of non-combustible finish.

For ribbed slabs the thickness may include any non-combustible finish on top.

4.2.6 Width of beams

For all beams, the width for the purpose of satisfying tabular data is the width determined at the level of the lowest reinforcement. For I-section beams the web thickness b_w of fully exposed I-section beams should be not less than 0.5 of the minimum width stated in the table for beams for various fire resistance periods.

4.2.7 Distinction between ribs and beams

Where failure of a rib does not critically affect the stability and integrity of a floor, the rib spacing is at the choice of the designer; otherwise ribs should be spaced at a maximum of 1.5 m centres or be treated as beams.

4.2.8 Beams and floors

Table 4.3 to Table 4.5 relating to beams and floors give minimum dimensions for widths, thicknesses and covers. Examples of such constructions are shown in Figure 4.2.

4.2.9 Columns

Table 4.2 relating to reinforced concrete columns gives minimum dimensions for width and actual cover (i.e. not C_{ave}). Examples are shown in Figure 4.3.

4.3 Tabulated data (method 1)

4.3.1 Method by design from BRE guidelines

This method employs information and tabular data contained in a Building Research Establishment Report published by the Department of the Environment [4] and also takes into account international test data given in Table 4.2, Table 4.3, Table 4.4, Table 4.5 and Table 4.6 reproduce BRE tabular data but are updated by information received between the publication dates of the BRE report 1980 and this code. The method may be used when no relevant test result is available from a laboratory that has carried out a test in accordance with BS 476-8:1972.

4.3.2 Support conditions: simply supported and continuous

The data set out in the following tables distinguishes between simply supported and continuous constructions for flexural members, i.e. beams and slabs for both reinforced concrete and prestressed concrete. In practice the majority of constructions will be continuous and benefits can be derived from the permissible reductions in cover and other dimensions, where the designer has made provision for fixity in the resistance to normal loads by the provision of reinforcement properly detailed and adequately tied to adjacent members. In the case of precast construction or a mixture of precast and in situ construction, it will be necessary for adequate provision to be made for continuity and restraint to end rotation.

4.3.3 Use of tabular data

All tabular data should be read in conjunction with 4.2. The tables are based on the assumption that the elements considered are supporting the full design load.

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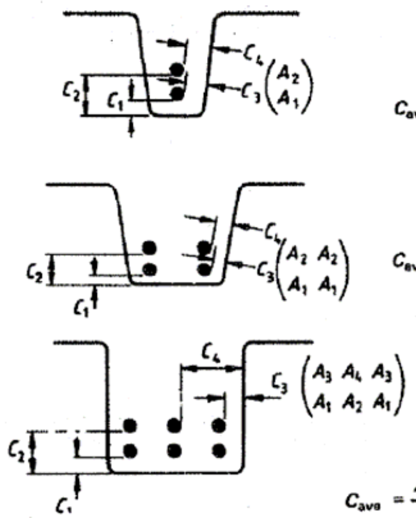

$$C_{avg} = \frac{A_1 \times \begin{pmatrix}\text{lesser of}\\ C_1 \text{ or } C_3\end{pmatrix} + A_2 \times \begin{pmatrix}\text{lesser of}\\ C_2 \text{ or } C_4\end{pmatrix}}{A_1 + A_2}$$

$$C_{avg} = \frac{2A_1 \times \begin{pmatrix}\text{lesser of}\\ C_1 \text{ or } C_3\end{pmatrix} + 2A_2 \times \begin{pmatrix}\text{lesser of}\\ C_2 \text{ or } C_4\end{pmatrix}}{2A_1 + 2A_2}$$

$$C_{avg} = \frac{A_2C_1 + 2A_1 \begin{pmatrix}\text{lesser of}\\ C_1 \text{ or } C_3\end{pmatrix} + 2A_3 \begin{pmatrix}\text{lesser of}\\ C_2 \text{ or } C_3\end{pmatrix} + A_4 \begin{pmatrix}\text{lesser of}\\ C_2 \text{ or } C_4\end{pmatrix}}{2(A_1 + A_3) + A_2 + A_4}$$

Figure 4.1 — Calculation of average cover

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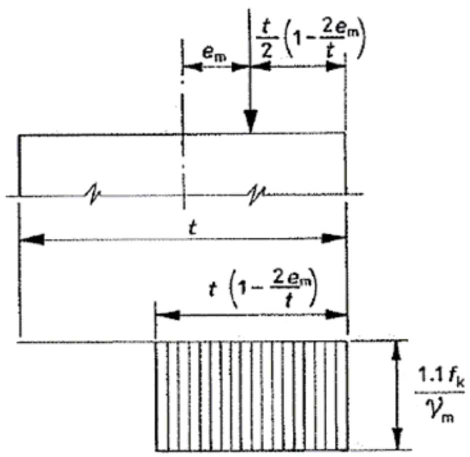

Figure 10 — Stress block under ultimate conditions

B.3 Alternative assumptions for design of single-leaf walls with hollow concrete blocks

Single-leaf walls with hollow concrete blocks may be designed on the assumption of a stress block acting on the net area using a characteristic strength enhanced in the ratio of gross area to net area. It is conservative, however, to assume for design purposes that the units are solid, using the characteristic strength based on the gross unit area, and this is why no distinction is drawn in clause **32**.

B.4 Alternative assumptions for design of single-leaf walls of shell bedded blocks or hollow clay masonry with divided bed joints

A stress block approach may also be used for single-leaf walls of shell bedded blocks or hollow clay masonry with divided bed joints as indicated in **B.3** but it is sufficient and conservative to treat them as solid walls, provided the strength is derived as described in clause **32**.

Appendix C
Connections to floors and roofs by means of metal anchors and joist hangers capable of resisting lateral movement

Figure 11 to Figure 25 illustrate connections which may be used to provide lateral restraint in accordance with **28.2.2**. In the illustrations, floors are generally shown; however, the same details are applicable to roofs. The effective cross-section of anchors and of their fixings should be capable of resisting the loads as specified in **28.2.1**, assuming a stress equal to the characteristic yield strength (or its equivalent) as laid down in the appropriate British Standard divided by $\gamma_m = 1.15$. Anchors should be provided at intervals of not more than 2 m in houses of not more than three storeys and not more than 1.25 m for all storeys in all other buildings. Galvanized mild steel anchors having a cross-section of 30 mm × 5 mm may be assumed to have adequate strength in buildings of up to six storeys in height.

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Section B

B1(a) A covered underground reinforced concrete wastewater storage tank is required as shown in Figure C1. The tank shall have internal plan dimensions as shown. All walls are 450mm thick. The cover comprises of precast concrete slabs, with a thickness of 200mm.

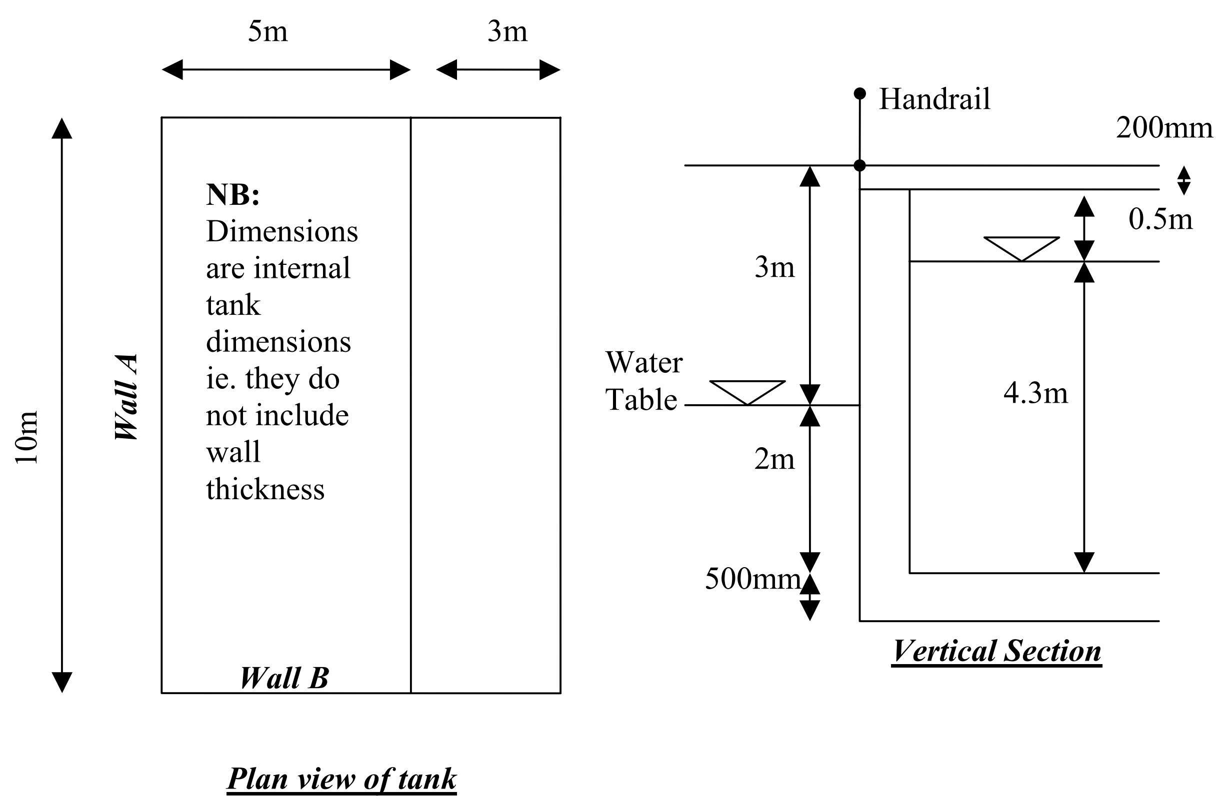


Figure C1

Complete the following design checks:

(i) Calculate the maximum vertical moment at the base of Wall A for serviceability limit states, for tank empty, and full backfill, including maximum water table. **(7 marks)**

(ii) Calculate the maximum vertical moment in the Wall B for serviceability limit states, for tank full, and no backfill. **(5 marks)**

(iii) Calculate minimum thermal steel requirements (horizontal steel) for Wall A. **(5 marks)**

(iv) Using the "Deemed to satisfy" requirements in BS 8007, calculate the vertical steel required on the outside face of Wall A. **(8 marks)**

Design information:

f_{cu} = 35 N/mm^2 f_y = 460 N/mm^2

α_{conc} = 12 x 10^{-6} / ^{0} C (coefficient of thermal expansion of mature concrete)

ΔT = 30^{0}C = Temperature change

Assume soil bearing capacity is adequate. Maximum design crack width = 0.2mm. The surcharge load on surrounding ground is 10 KN / m^2.

Soil Properties

Granular soil density = 18 KN/m^3. Angle of repose (ϕ) = 30^0

Clearly state any design assumptions made.

The structure should not include movement joints.

Additional Information

ASSESSMENT OF CRACK WIDTHS IN FLEXURE

Depth to Neutral Axis, x (elastic theory)

$x = \alpha_e \rho \left(\left(1 + 2/ \alpha_e \rho \right)^{0.5} - 1 \right) d$ (Assume $\alpha_e = 15$)

$z = d - x/3$

Steel stress $f_s = M/z.A_s$

$\varepsilon_1 = (h - x) f_s / (d - x) E_s$

$\varepsilon_2 = b (h - x)^2 / 3 E_s A_s (d - x)$ (For a limiting design surface crack of 0.2mm)

$\varepsilon_m = \varepsilon_1 - \varepsilon_2$

$w = 3 a_{cr} \varepsilon_m / \{1 + \{2 (a_{cr} - c_{min}) / (h - x)\}\}$ ***BS 8007:Appendix B:Section B.2***

THERMAL AND MOISTURE CRACKING

$\rho_{crit} = 0.0035$ for high yield steel *BS 8007: Table A.1*

$s_{max} = (f_{ct} / f_{cb}) \times (\phi / 2 \rho)$

where:

$f_{ct} / f_b = 2/3$

s_{max} = maximum crack spacing

ρ = Steel ratio

ϕ = Size of each reinforcing bar

$w_{max} = s_{max} (\alpha / 2) \Delta T$ ***BS 8007:Appendix A*** : Section A.3

Design Crack Width (mm)	**Plain bars**	**Deformed bars**
mm	N/mm^2	N/mm^2
0.1mm	85	100
0.2mm	115	130

BS 8007: Section Three: Table 3.1
Allowable steel stresses in direct of flexural tension for serviceability limit states

Section B Attachments

Table A2–1 Areas of groups of reinforcement bars (mm²)

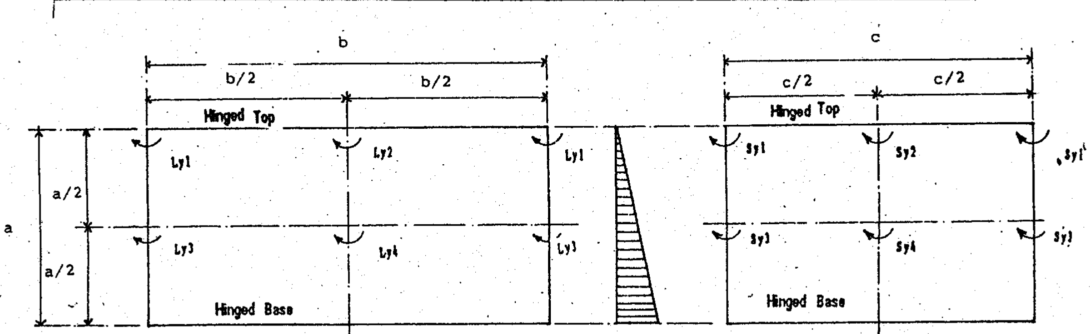
Bar size (mm)	*Number of bars*									
	1	2	3	4	5	6	7	8	9	10
8	50	101	151	201	251	302	352	402	452	503
10	79	157	236	314	393	471	550	628	707	785
12	113	226	339	452	565	679	792	905	1017	1131
16	201	402	603	804	1005	1206	1407	1608	1809	2011
20	314	628	942	1257	1571	1885	2199	2513	2827	3142
25	491	982	1473	1963	2454	2945	3436	3927	4418	4909
32	804	1608	2412	3216	4021	4825	5629	6433	7237	8042
40	1256	2513	3769	5026	6283	7539	8796	10050	11310	12570

Table A2–2 Reinforcement-bar areas (mm²) per metre width for various bar spacings

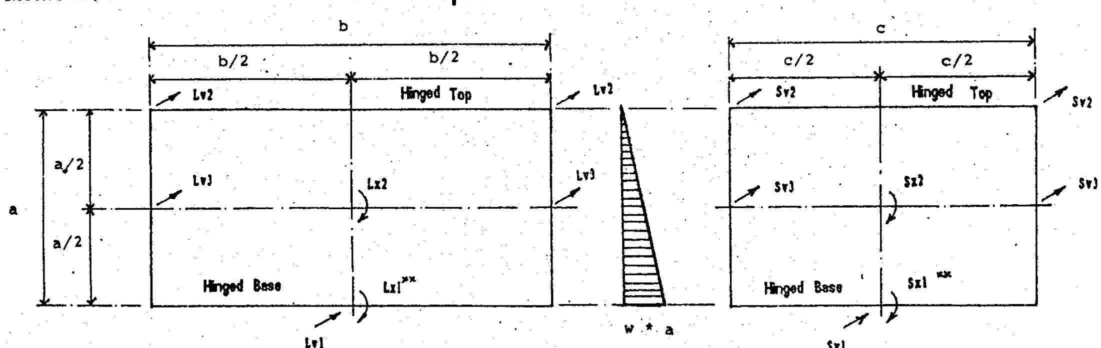
Bar size (mm)	*Bar spacing* (mm)									
	75	100	125	150	175	200	225	250	275	300
8	671	503	402	335	287	252	223	201	183	168
10	1047	785	628	523	449	393	349	314	286	262
12	1508	1131	905	754	646	566	503	452	411	377
16	2681	2011	1608	1340	1149	1005	894	804	731	670
20	4189	3142	2513	2094	1795	1571	1396	1257	1142	1047
25	6545	4909	3927	3272	2805	2454	2182	1963	1785	1636
32	—	8042	6434	5362	4596	4021	3574	3217	2925	2681
40	—	—	10050	8378	7181	6283	5585	5027	4570	4189

Table 9.21 Moment and shear force coefficients for walls subjected to hydrostatic pressure in a three-dimensional rectangular tank, assuming a hinged base, hinged top and continuous sides (adapted from PCA tables)

		LONG WALL VERTICAL MOMENTS**		LONG WALL HORIZONTAL MOMENTS				SHORT WALL VERTICAL MOMENTS**		SHORT WALL HORIZONTAL MOMENTS				LONG WALL SHEAR FORCES			SHORT WALL SHEAR FORCES		
b/a	c/a	Lx1**	Lx2	Ly1	Ly2	Ly3	Ly4	Sx1**	Sx2	Sy1	Sy2	Sy3	Sy4	Lv1	Lv2	Lv3	Sv1	Sv2	Sv3
2.0	2.0	-60.	42.	0.	0.	59.	20.	-60.	42.	0.	0.	-59.	20.	33.	0.	36.	30.	0.	38.
2.0	1.5	-60.	43.	0.	0.	-56.	20.	-51.	27.	0.	0.	-56.	21.	33.	0.	36.	30.	0.	34.
2.0	1.0	-60.	44.	0.	0.	-46.	20.	-32.	7.	0.	0.	-46.	14.	33.	0.	36.	24.	0.	26.
2.0	0.5	-60.	46.	0.	0.	-34.	20.	-11.	-6.	0.	0.	-34.	-9.	33.	0.	36.	14.	0.	13.
1.5	1.5	-51.	28.	0.	0.	-52.	21.	-51.	28.	0.	0.	-52.	21.	30.	0.	34.	32.	0.	34.
1.5	1.0	-51.	30.	0.	0.	-43.	21.	-32.	8.	0.	0.	-43.	14.	30.	0.	34.	24.	0.	26.
1.5	0.5	-51.	35.	0.	0.	-31.	24.	-11.	-5.	0.	0.	31.	-7.	30.	0.	34.	14.	0.	13.
1.0	1.0	-32.	11.	0.	0.	-35.	16.	-32.	11.	0.	0.	-35.	16.	24.	0.	26.	24.	0.	26.
1.0	0.5	-32.	15.	0.	0.	-21.	8.	-11.	-3.	0.	0.	-21.	-2.	24.	0.	26.	14.	0.	13.
0.5	0.5	-11.	2.	0.	0.	-10.	1.	-11.	1.	0.	0.	-10.	1.	14.	0.	13.	14.	0.	13.
MOMENT		$\frac{COEF*wa^3}{1000}$		$\frac{COEF*wa^3}{1000}$				$\frac{COEF*w*a^3}{1000}$		$\frac{COEF*wa^3}{1000}$				—			—		
SHEAR FORCE		—		—				—		—				$\frac{COEF*wa^2}{100}$			$\frac{COEF*wa^2}{100}$		



Moment Coefficients — Horizontal Span



Moment Coefficients — Vertical Span

Shear Coefficients ** (Lx1 and Sx1 coefficients only to be used where a fixed base alternative is being considered)

DSE4 Advanced Structural Design - Section B – Attachment B3 - Limiting moments (KNm)

TABLE B25

REINFORCEMENT		SLAB	200		225		250		275		300		350		400		450		500		600		750		900	
DIA.	c/c	As	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult
10	100	785	28	46	34	53	41	61	48	69	56	76	72	91	89	106										
10	125	628	23	37	29	43	35	49	40	55	47	61	61	73												
10	150	524	21	31	25	36	30	41	36	46																
10	175	449	18	26	23	31	27	35																		
10	200	393	17	23																						
12	100	1131	35	63	44	74	52	86	61	97	70	108	89	131	109	152	131	174	154	195	205	238				
12	125	905	29	52	36	61	43	70	50	79	57	87	73	105	90	122	109	139	129	156						
12	150	754	25	44	31	51	37	58	43	66	49	73	63	87	78	101										
12	175	646	22	38	27	44	32	50	38	56	44	62	57	75												
12	200	565	20	33	25	38	30	44	35	49	40	55														
16	100	2011	53	102	65	122	77	142	90	162	104	182	131	222	160	263	190	303	221	343	288	422	399	536	523	651
16	125	1608	43	85	53	101	62	117	72	133	83	149	105	181	127	213	152	246	177	276	233	337	326	429	433	521
16	150	1340	36	72	44	86	52	99	61	113	69	126	87	153	107	179	128	205	150	230	198	281	281	358	377	434
16	175	1149	32	63	38	75	45	86	53	98	60	109	76	132	93	154	111	176	131	197	175	241	251	306		
16	200	1005	28	56	34	66	40	76	47	86	53	96	68	115	83	134	100	154	118	173	159	211				
16	225	894	26	50	31	59	37	68	42	77	49	86	62	103	76	120	92	137	109	153						
16	250	804	24	46	29	54	34	62	39	69	45	77	57	92	71	108	86	123								
16	275	731	22	42	27	49	31	56	36	63	42	70	54	84	67	98										
20	100	3142	71	124	89	168	107	201	125	233	144	264	182	327	222	390	263	453	305	515	393	641	536	830	691	1015
20	125	2513	58	119	72	144	86	169	100	194	114	219	143	270	174	320	206	370	239	420	308	521	424	669	551	812
20	150	2094	49	103	60	124	71	145	83	166	94	187	118	229	143	271	169	313	196	355	255	438	353	557	464	676
20	175	1795	43	91	52	109	61	127	71	145	80	163	101	199	122	235	144	271	168	307	219	375	307	478	407	580
20	200	1571	38	82	46	97	54	113	62	129	71	145	88	176	107	207	127	239	148	269	194	328	274	418	367	507
20	225	1396	34	74	41	88	48	102	56	116	63	130	79	158	96	186	114	212	133	239	176	292	251	371	339	451
20	250	1257	31	67	37	80	44	93	51	105	57	118	72	143	88	167	104	191	123	215	163	263	234	334	319	406
20	275	1142	29	62	34	73	40	85	47	96	53	108	66	130	81	152	97	174	114	195	153	239	221	304		
25	100	4909	84	120	111	163	141	214	174	272	201	336	256	462	313	560	371	658	430	756	553	953	746	1247	952	1542
25	125	3927	78	120	98	163	118	214	138	271	159	310	201	389	243	468	287	546	332	625	425	782	575	1017	738	1253
25	150	3272	66	120	82	163	98	204	114	237	131	270	164	335	198	400	232	466	269	531	344	662	467	859	603	1054
25	175	2805	58	120	71	154	84	182	97	210	111	238	138	294	166	350	195	406	225	462	289	574	395	743	513	903
25	200	2454	51	114	62	139	73	163	85	188	96	212	119	261	143	311	169	360	195	409	251	507	345	651	451	790
25	225	2182	46	105	56	126	65	148	75	170	85	192	105	235	127	279	149	323	172	366	223	454	308	578	407	703
25	250	1963	42	96	50	116	59	136	68	155	77	175	95	214	114	253	134	293	155	332	202	409	281	520	374	632
25	275	1785	38	89	46	107	54	125	62	143	70	161	86	196	104	232	123	268	142	303	186	371	261	473	349	575
25	300	1636	35	83	42	99	50	116	57	132	64	148	80	181	96	214	113	247	132	278	173	340	245	434	329	527
32	100	8042	88	114	118	157	152	207	189	263	230	327	320	475	423	650	537	853	638	1083	821	1421	1107	1904	1404	2387
32	125	6434	85	114	113	157	145	207	181	263	219	327	292	475	357	650	422	804	489	932	626	1190	840	1576	1065	1962
32	150	5362	82	114	109	157	138	207	163	263	188	327	238	475	288	592	340	699	392	806	499	1021	669	1342	850	1664
32	175	4596	78	114	99	157	119	207	139	263	159	327	200	433	241	525	282	617	325	709	412	893	553	1168	705	1444
32	200	4021	70	114	87	157	104	207	121	263	138	310	172	391	206	471	241	552	276	632	351	793	472	1034	604	1275
32	225	3574	63	114	78	157	92	207	107	248	121	284	150	355	180	427	210	498	241	570	306	713	412	927	530	1142
32	250	3217	57	114	70	157	83	197	96	229	109	261	134	326	160	390	186	454	214	519	272	647	368	840	476	1032
32	275	2925	52	114	64	154	76	183	87	213	98	242	121	300	144	359	168	417	193	476	246	593	334	768	435	938
32	300	2681	48	114	59	145	69	172	80	198	90	225	110	279	132	332	153	386	176	440	225	547	308	707	402	860

Crack width = 0.2   Fcu = 35   Cover = 40

DSE4 Advanced Structural Design - Section B – Attachment B4 - Limiting moments (KNm)

TABLE B27

REINFORCEMENT / SLAB			200		225		250		275		300		350		400		450		500		600		750		900	
DIA.	c/c	As	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult
10	100	785	19	41	25	48	31	56	37	64	43	71	58	86	73	101										
10	125	628	17	33	22	39	27	45	32	51	38	57	51	69												
10	150	524	15	28	20	33	24	38	29	43																
10	175	449	14	24	18	28	22	32																		
10	200	393	13	21																						
12	100	1131	23	56	30	67	37	79	45	90	53	101	69	124	88	145	107	167	128	188	175	231				
12	125	905	20	46	26	55	32	64	38	73	45	82	60	99	75	116	93	133	112	151						
12	150	754	18	39	23	46	28	54	34	61	40	68	53	83	67	97										
12	175	646	17	34	21	40	26	46	31	52	37	58	49	71												
12	200	565	15	30	19	35	24	40	29	46	34	51														
16	100	2011	33	89	42	109	53	129	63	149	75	169	98	209	123	250	149	290	177	330	236	410	336	524	449	639
16	125	1608	28	74	36	90	44	107	53	123	62	139	82	171	102	203	124	235	148	266	199	328	286	419	386	511
16	150	1340	25	64	31	77	39	91	46	104	54	117	71	144	88	171	108	197	128	222	174	273	253	349	345	426
16	175	1149	22	56	28	67	34	79	41	90	48	102	63	125	79	147	96	169	115	190	157	234	231	299		
16	200	1005	20	50	26	60	31	70	37	80	44	90	57	109	72	128	88	147	106	167	145	205				
16	225	894	19	45	24	53	29	62	34	71	40	80	53	97	67	114	82	131	99	148						
16	250	804	18	40	22	49	27	57	32	64	38	72	50	87	63	103	77	118								
16	275	731	17	37	21	44	26	52	30	59	36	66	47	79	60	93										
20	100	3142	42	99	56	139	70	181	85	213	100	244	132	307	166	370	200	432	237	495	313	621	439	809	577	996
20	125	2513	36	99	47	128	59	153	70	178	83	203	108	253	135	304	164	354	193	404	256	505	362	653	479	797
20	150	2094	32	90	41	111	51	132	60	153	71	174	92	216	115	258	139	299	164	341	219	425	311	544	416	664
20	175	1795	28	80	36	98	45	116	53	134	62	152	81	188	100	223	122	259	144	295	193	364	276	467	372	569
20	200	1571	26	72	33	87	40	103	48	119	56	134	72	166	90	197	109	229	129	259	174	319	251	408	341	498
20	225	1396	24	65	30	79	37	93	44	107	51	121	66	149	82	177	99	204	118	230	160	283	233	363	319	443
20	250	1257	22	59	28	72	34	84	40	97	47	110	61	135	76	159	92	183	110	207	149	255	219	327	302	398
20	275	1142	21	55	26	66	32	77	38	89	44	100	57	123	71	145	87	167	103	188	141	232	208	297		
25	100	4909	53	95	72	135	92	181	113	234	135	294	180	430	227	529	275	627	325	725	429	921	596	1216	775	1510
25	125	3927	46	95	61	135	77	181	94	234	111	285	147	364	184	442	222	521	261	599	344	757	479	992	626	1228
25	150	3272	41	95	53	135	67	181	81	216	95	249	124	314	154	380	186	445	218	510	288	641	402	838	528	1034
25	175	2805	36	95	47	135	59	164	71	192	83	220	107	276	133	332	160	388	188	444	248	556	348	725	460	886
25	200	2454	33	95	43	123	53	148	63	172	73	197	95	246	117	295	141	344	166	393	219	491	309	636	411	776
25	225	2182	30	91	39	112	48	134	57	156	66	178	85	221	106	265	127	309	149	352	198	440	281	565	376	689
25	250	1963	28	84	36	103	44	123	52	143	60	162	78	202	96	241	116	280	136	319	181	397	259	508	349	620
25	275	1785	26	78	33	96	41	113	48	131	56	149	72	185	89	221	107	256	126	292	169	361	242	462	328	564
25	300	1636	25	72	31	89	38	105	45	122	52	138	67	171	83	203	100	236	118	268	158	330	229	424	312	517
32	100	8042	65	90	92	129	121	174	152	226	184	286	252	425	322	591	394	785	469	1006	622	1370	862	1853	1114	2335
32	125	6434	58	90	80	129	103	174	128	226	153	286	206	425	261	591	317	763	374	891	493	1149	681	1535	881	1921
32	150	5362	52	90	70	129	90	174	110	226	131	286	174	425	218	557	263	665	310	772	406	986	560	1308	725	1630
32	175	4596	47	90	63	129	79	174	97	226	114	286	150	404	187	496	225	588	263	680	344	863	475	1139	617	1415
32	200	4021	43	90	57	129	71	174	86	226	101	285	132	365	163	445	196	526	229	606	299	767	413	1008	539	1250
32	225	3574	39	90	52	129	65	174	78	225	91	261	118	333	145	404	174	476	203	547	265	690	367	904	481	1119
32	250	3217	36	90	48	129	59	174	71	209	83	241	107	305	131	370	157	434	183	498	239	627	332	820	437	1012
32	275	2925	34	90	44	129	55	165	65	194	76	223	97	282	120	340	143	399	167	457	218	574	304	750	402	920
32	300	2681	32	90	41	128	51	154	61	181	70	208	90	262	110	315	132	369	154	422	202	530	283	691	375	843

Crack width = 0.2   Fcu = 35   Cover = 56

TABLE B28

REINFORCEMENT / SLAB			200		225		250		275		300		350		400		450		500		600		750		900	
DIA.	c/c	As	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult	Ms	Mult
10	100	785	18	39	23	47	29	55	35	63	41	70	55	85	70	100										
10	125	628	16	32	20	38	25	44	30	50	36	56	49	68												
10	150	524	14	27	18	32	23	37	28	42																
10	175	449	13	23	17	27	21	32																		
10	200	393	13	20																						
12	100	1131	21	54	28	65	34	77	42	88	49	99	65	122	83	144	102	165	123	187	169	229				
12	125	905	19	44	24	53	30	62	36	71	43	80	57	98	72	115	89	132	108	149						
12	150	754	17	38	21	45	27	53	32	60	38	67	51	81	65	96										
12	175	646	15	33	20	39	24	45	30	51	35	57	47	70												
12	200	565	14	29	18	34	23	40	28	45	33	50														
16	100	2011	29	88	38	106	48	126	58	146	69	166	91	206	115	246	141	287	168	327	226	406	323	521	434	636
16	125	1608	25	72	33	88	41	104	49	120	58	136	77	168	97	200	118	233	141	264	191	325	277	417	376	509
16	150	1340	22	62	29	75	36	88	43	102	51	115	67	142	84	169	103	195	124	220	169	271	247	347	338	424
16	175	1149	20	54	26	65	32	77	39	88	45	100	60	123	76	145	93	167	112	189	153	232	226	298		
16	200	1005	19	48	24	58	29	68	35	78	41	88	55	108	69	127	85	146	103	165	142	203				
16	225	894	17	43	22	52	27	61	33	70	38	79	51	96	65	113	80	130	96	147						
16	250	804	16	39	21	47	26	55	31	63	36	71	48	86	61	101	75	117								
16	275	731	15	36	20	43	24	51	29	58	34	64	45	78	58	92										
20	100	3142	37	93	50	132	63	176	77	207	92	239	122	302	154	365	188	427	223	490	297	616	419	804	554	991
20	125	2513	32	93	42	124	53	149	65	174	77	199	101	249	127	300	155	350	184	400	245	501	348	649	464	793
20	150	2094	28	87	37	108	46	129	56	149	66	170	87	212	109	254	132	296	157	338	211	422	301	541	405	661
20	175	1795	26	77	33	95	41	113	50	131	58	149	76	185	96	221	116	256	138	292	186	362	269	464	364	566
20	200	1571	23	69	30	85	37	101	45	116	52	132	69	163	86	195	105	226	125	257	169	316	246	406	335	495
20	225	1396	22	63	28	77	34	91	41	105	48	119	63	146	79	174	96	202	115	228	156	281	228	361	314	440
20	250	1257	20	57	26	70	32	82	38	95	44	108	58	133	73	158	89	181	107	205	146	253	215	325	298	396
20	275	1142	19	53	24	64	30	76	36	87	42	98	55	121	69	143	84	165	101	187	138	230	205	295		
25	100	4909	46	89	64	128	82	173	102	225	123	284	165	422	210	521	257	619	305	717	405	913	566	1208	739	1502
25	125	3927	40	89	55	128	70	173	86	225	102	279	136	358	172	436	209	515	247	593	327	750	458	986	602	1221
25	150	3272	36	89	48	128	61	173	74	211	88	243	116	309	145	374	176	440	208	505	275	636	387	832	511	1029
25	175	2805	32	89	43	128	54	159	65	187	77	215	101	271	126	327	152	384	180	440	239	552	337	720	448	882
25	200	2454	30	89	39	119	48	144	58	168	69	193	90	242	112	291	135	340	159	389	212	487	301	632	402	772
25	225	2182	27	87	36	109	44	131	53	153	62	174	81	218	101	262	122	305	144	349	192	436	274	562	369	686
25	250	1963	25	81	33	100	41	120	49	139	57	159	74	198	92	238	112	277	132	316	177	394	254	505	343	617
25	275	1785	24	75	31	93	38	111	45	128	53	146	69	182	85	218	103	253	122	289	165	358	238	460	323	561
25	300	1636	22	70	29	86	36	103	42	119	49	135	64	168	80	201	97	233	115	266	155	328	225	421	308	515
32	100	8042	56	84	80	122	107	166	136	218	166	276	229	412	296	577	365	768	436	987	582	1357	813	1840	1056	2322
32	125	6434	50	84	70	122	92	166	115	218	139	276	190	412	242	577	296	752	351	881	466	1138	648	1524	842	1910
32	150	5362	45	84	62	122	81	166	100	218	120	276	161	412	204	549	247	656	293	763	386	978	536	1299	698	1621
32	175	4596	41	84	56	122	72	166	88	218	105	276	140	396	176	488	212	580	250	672	329	856	457	1132	597	1407
32	200	4021	38	84	51	122	65	166	79	218	94	276	124	359	154	439	186	519	219	600	288	761	400	1002	524	1243
32	225	3574	35	84	47	122	59	166	72	218	85	255	111	327	138	398	166	470	195	541	256	684	357	899	469	1113
32	250	3217	33	84	43	122	54	166	66	204	77	236	101	300	125	364	150	429	176	493	231	622	323	815	427	1007
32	275	2925	31	84	40	122	50	160	61	189	71	219	92	277	114	336	137	394	161	453	212	570	297	745	395	916
32	300	2681	29	84	38	122	47	150	57	177	66	204	86	257	106	311	127	365	149	418	196	525	277	686	369	839

Crack width = 0.2 Fcu = 35 Cover = 60