UNIVERSITI SAINS MALAYSIA

First Semester Examination
2011/2012 Academic Session

January 2012

EAS 353/3 – Reinforced Concrete Structural Design I
[*Rekabentuk Struktur Konkrit Bertetulang I*]

Duration : 3 hours
[*Masa : 3 jam*]

Please check that this examination paper consists of **FIFTEEN (15)** pages of printed material and 12 appendices before you begin the examination.
[*Sila pastikan bahawa kertas peperiksaan ini mengandungi **LIMA BELAS (15)** muka surat yang bercetak 12 lampiran sebelum anda memulakan peperiksaan ini.*]

Instructions : This paper contains **SIX (6)** questions. Answer **FIVE** questions.
[***Arahan** : Kertas ini mengandungi **ENAM (6)** soalan. Jawab **LIMA** soalan.*

You may answer the question either in Bahasa Malaysia or English.
[*Anda dibenarkan menjawab soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris*].

All questions **MUST BE** answered on a new page.
[*Semua soalan **MESTILAH** dijawab pada muka surat baru*].

In the event of any discrepancies, the English version shall be used.
[*Sekiranya terdapat percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai*].

1. (a) Briefly describe the different between the two principal unit states.

[5 marks]

(b) Figure 1.0 shows a cross-section of doubly reinforced rectangular beam. Using the analysis of a doubly reinforced section, determine the ultimate moment of resistance of the cross-section given that the characteristic strength are $f_y = 460\ N/mm^2$ for steel reinforcement and $f_{cu} = 30\ N/mm^2$ for concrete.

Assume:-

- The tensile and compressive forces on the section are equilibrium.
- The steel stresses, f_{st} and f_{sc} are at the design yield values.

[10 marks]

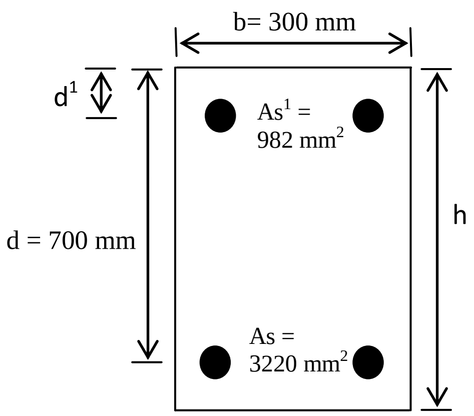


Figure 1 Cross-section at doubly reinforced rectangular beam

(c) The T-section beam shown in Figure 2 is required to resist an ultimate design moment at 200 kNm. Given the depth of the stress block below the flange and the characteristic strength of steel reinforcement is $f_y = 460\ N/mm^2$ and concrete is $f_{cu} = 30\ N/mm^2$. Calculate the moment resistance, M_f of the flange.

[5 marks]

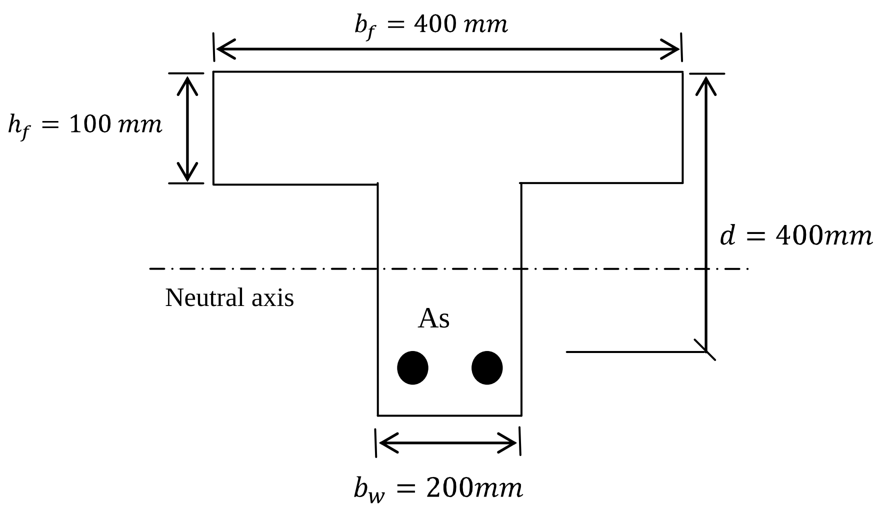


Figure 2 Cross section of T-beam

2. (a) The following conditions are given for all slabs at design load throughout all panels.

   (i) In a one-way slab, the area of each 'bay' $> 25\ m^2$
   (ii) Imposed load $q_k < 1.25$ dead load, g_k.
   (iii) Imposed load, $q_k > 5\ kN/m^2$ excluding partitions.

   Based on the above three load conditions, verify their compliances in accordance with BS 8110.

   [5 marks]

   (b) Two-way spanning ribbed slabs are termed as waffle slabs. The cross-section of waffle slab is shown in Figure 3 with characteristic dead load of including self weight of 6.0 kN/m^2 and imposed load of 2.5 kN/m^2. Grade 30 concrete and Grade 460 reinforcement are used for the design. Design a waffle slab for an internal panel of a floor system which spans 6.0 m in each direction.

   [15 marks]

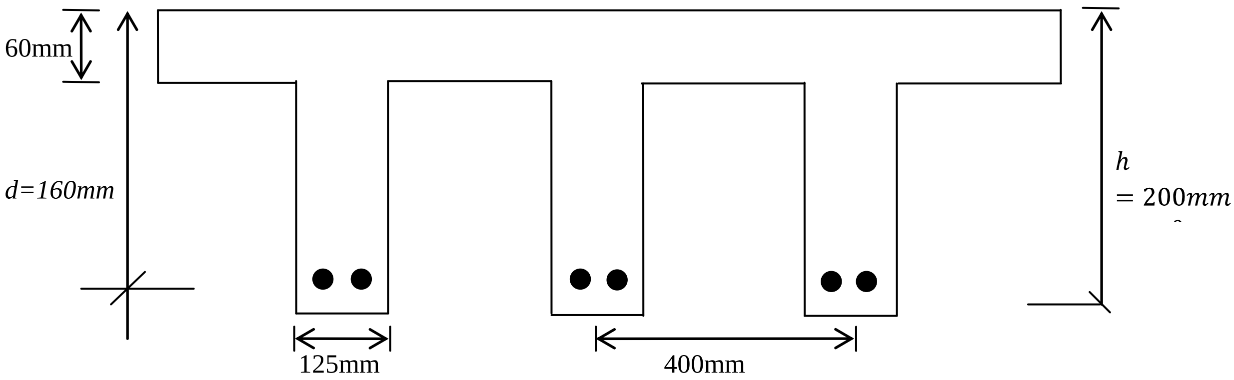


Figure 3 Ribbed Slab

3. (a) A beam which is designed inside a building is of width 175mm is required to support dead load of 3.5 kN/m^2 and live load of 6.0 kN/m^2. The characteristic strength of concrete (f_{cu}) is 30N/mm^2 and the characteristic strength of steel reinforcement (fy) is 500N/mm^2. The diameter of the main reinforcement bars is 20mm and shear links is 10mm. The nominal aggregate size (h_{agg}) is 20mm. Assume a 50 years design life and the fire resistance is 1 hour. Determine the nominal cover of the beam using BS8110-1:1997

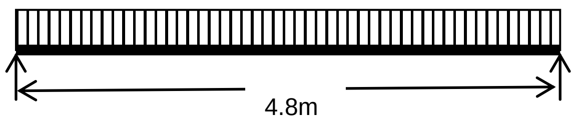


Figure 4 Simply supported beam

[5 marks]

(b) A second floor of a building is to be designed shown in Figure 5 below. All beams are of dimensions 250mm x 600mm, and slabs of 150mm thick. Assuming the slab carries an imposed load of 3.5N/m^2 and finishes of 1.5kN/m^2. The beam nominal cover is 35mm, the characteristic strength of concrete (f_{cu}) is 30N/mm^2, the characteristic strength of steel reinforcement (f_y) is 500N/mm^2 and the characteristic strength of shear links (f_{yv}) is 250N/mm^2. The diameter of the main reinforcement bars (Φ) is 25mm, diameter of the shear links (Φ') is 10mm. The nominal aggregate size (h_{agg}) is 20mm. The beam has a 50 years design life and fire resistance is 1 hour.

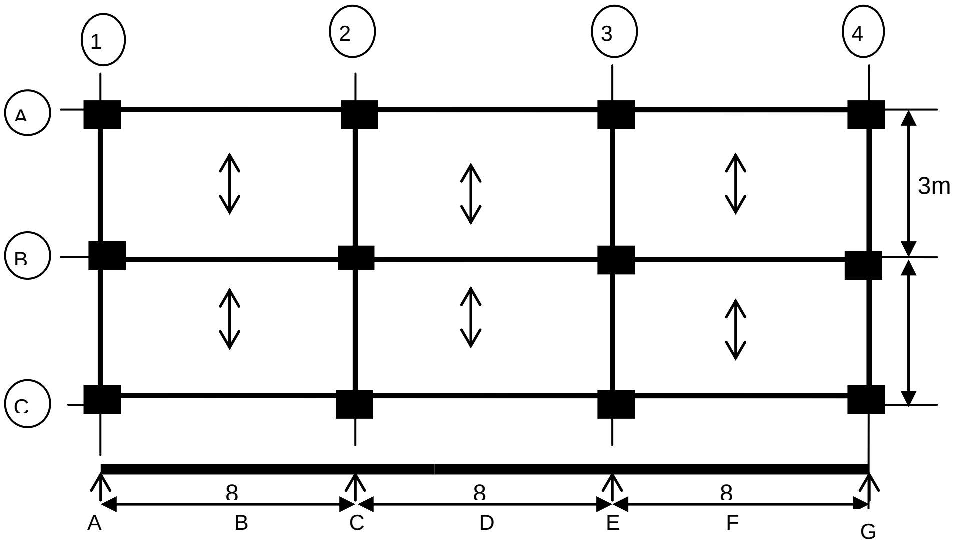


Figure 5 Second floor plan layout

For Beam B/1-4,

(a) Calculate the bending moment and shear force.

[3 marks]

(b) Sketch the bending moment diagram and shear force diagram.

[2 marks]

(c) Design the flexural and shear reinforcements for the beam.

[10 marks]

4. (a) Calculate the anchorage lengths in tension and compression for a grade 460 type 2 deformed bar of diameter φ in grade 30 concrete.

[6 marks]

(b) Column can be designed as either in braced and unbraced conditions. Define the braced and unbraced in column design.

[4 marks]

(c) A braced slender column resists two end moments of 120 kNm and 100 kNm at ultimate limit state as shown in Figure 6. Design and provide the relevant detailing based on the given data. Assume the *K* value is taken as 1.0.

(i)	ultimate axial load	= 2500 kN
(ii)	characteristic strength of concrete, f_{cu}	= 30 N/mm^2
(iii)	characteristic strength of main reinforcement, f_y	= 460 N/mm^2
(iv)	characteristic strength of link, f_{yv}	= 250 N/mm^2
(v)	nominal cover	= 30 mm
(vi)	effective height of column (major and minor)	= 6.5 m

[10 marks]

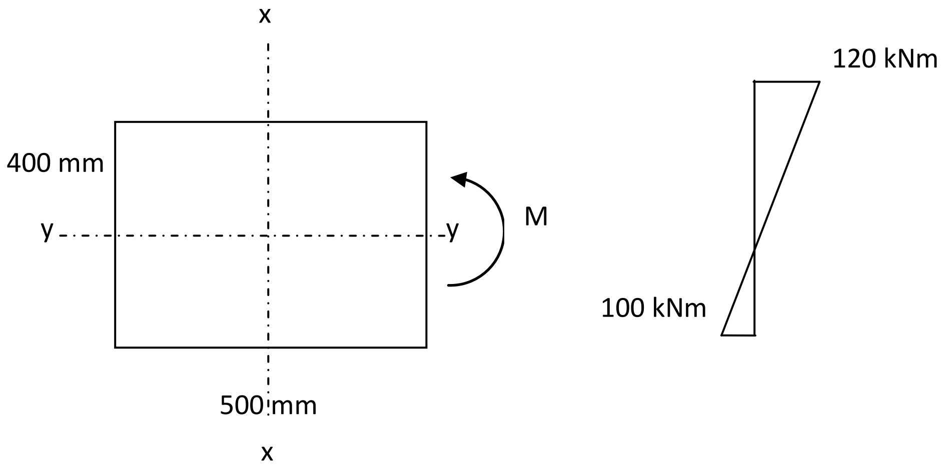


Figure 6

5. A combined footing supporting two columns of a concrete building with unfactored loads is shown in Table 1. The distance between the two columns are 3 m. The allowable bearing pressure is 200 kN/m^2. The characteristic material strengths are f_{cu} = 35 N/mm^2 and f_y = 460 N/mm^2. Assume nominal cover as 40 mm and the size of footing is 2.5 x 5.5 x 0.5 m (B x H x h). Design and provide typical sectional detailing of the combined footing.

(a) Calculate

(i) Design loading analysis

[4 marks]

(ii) Main reinforcement

[4 marks]

(iii) Shear resistance

[4 marks]

(iv) Cracking

[2 marks]

(v) Detailing.

[2 marks]

Table 1: Data

Column	Size (mm x mm)	Load (kN)	
		G_k	Q_k
Column A	300 x 300	800	300
Column B	400 x 400	1000	350

(b) Discuss the primary function of foundation and factors require in foundation design.

[4 marks]

6. A reinforced concrete staircase for office use is shown in Figure 7. It is connected to a landing and supported by a beam at the end of the landing. The other end is supported by a beam and continuous with the floor slab. Design the staircase by using concrete grade 30 and strength of reinforcement is 460 N/mm^2. The imposed load is 4.0 kN/m^2 and finishes is 0.5 kN/m^2. Nominal cover is 25 mm. Assume the width of staircase is 1500 mm, the thickness of landing is 150 mm and the waist thickness (h) is 150 mm.

(a) Calculate

(i) Design loading analysis

[3 marks]

(ii) Main reinforcement

[4 marks]

(iii) Shear resistance

[3 marks]

(iv) Deflection

[3 marks]

(v) Cracking

[2 marks]

(vi) Detailing.

[2 marks]

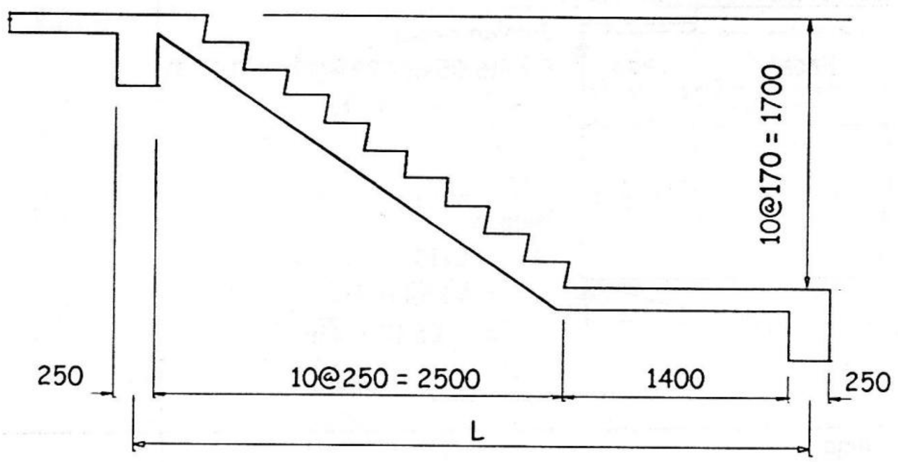


Figure 7

(b) State **THREE (3)** types of staircases and explain briefly the difference in terms of the design concept.

[3 marks]

1. (a) *Terangkan dengan ringkas perbezaan antara dua prinsip keadaan had.*

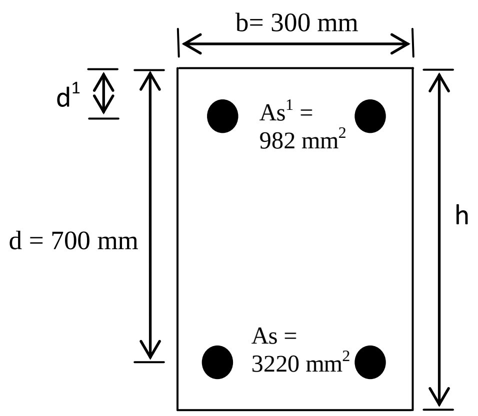
[5 markah]

(b) *Rajah 1 menunjukkan keratan rentas rasuk segiempat bertetulang berkembar. Dengan menggunakan analisis keratan tetulang berkembar, tentukan momen rintangan muktamad keratan. Diberi kekuatan ciri keluli tetulang* $f_y = 460\ N/mm^2$ *dan konkrit* $f_{cu} = 30\ N/mm^2$.

Anggapkan :-

- *Daya mampatan dan tegangan ke atas keratan berada dalam keseimbangan.*
- *Keluli menjalani tegasan,* f_{st} *dan* f_{sc} *pada ketika nilai rekabentuk alah.*

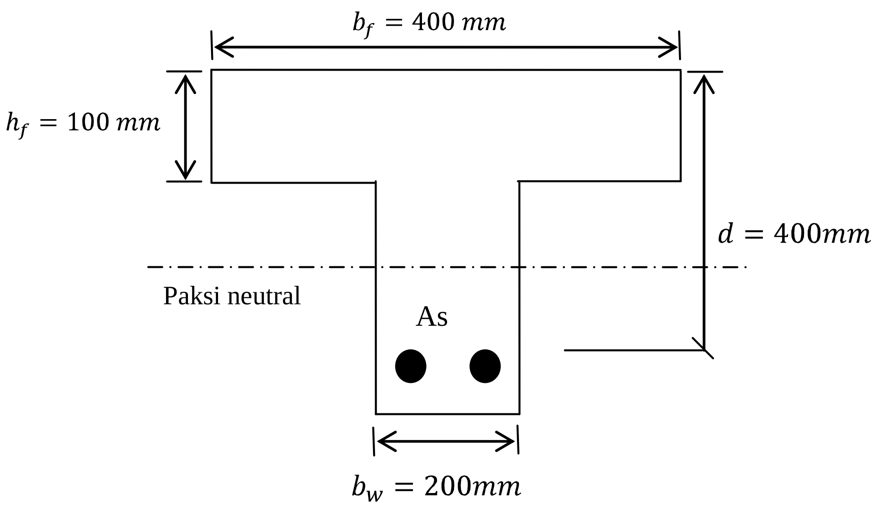
[10 markah]



Rajah 1 Keratan rentas rasuk segiempat bertetulang berkembar

(c) *Rasuk keratan-T seperti yang ditunjukkan dalam Rajah 2 untuk merintangi momen rekabentuk muktamad sebesar 200 kNm. Diberikan, kedalaman blok tegasan adalah dibawah bebibir dan kekuatan tetulang keluli ialah* $f_y = 460\ N/mm^2$ *dan* $f_{cu} = 30\ N/mm^2$. *Kirakan momen rintangan,*M_f *bebibir.*

[5 markah]



Rajah 2

2. (a) *Syarat-syarat berikut diberikan untuk beban rekabentuk semua papak lantai keseluruhan panel.*

   (i) *Papak sehala, keluasan setiap 'bay' > 25 m*^{2}.

   (ii) *Beban kenaan,* $q_k > 1.25$ *beban mati* g_k

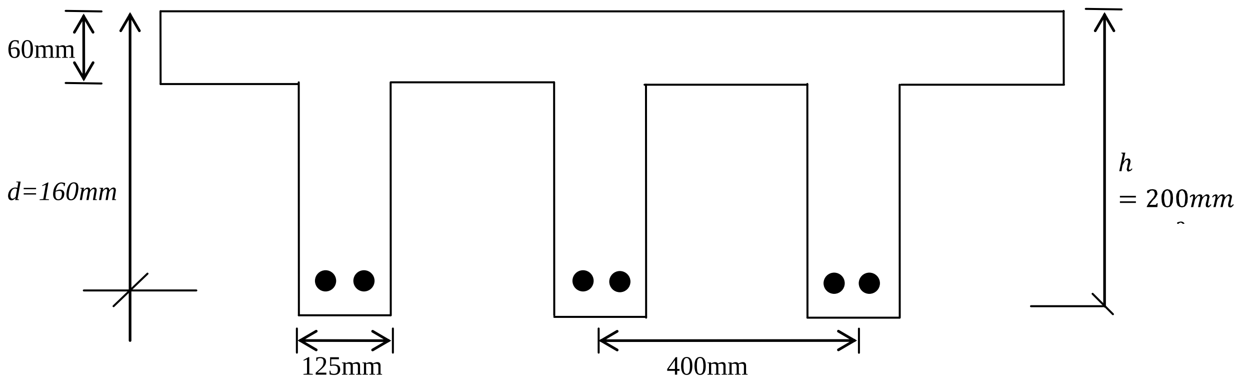
   (iii) *Beban kenaan,* $q_k > 5\ kN/m^2$ *tidak termasuk dinding sekatan.*

   Berdasarkan syarat-syarat beban diatas, nilaikan kepatuhan ketiga-tiga syarat-syarat tersebut kepada BS 8110.

   [5 markah]

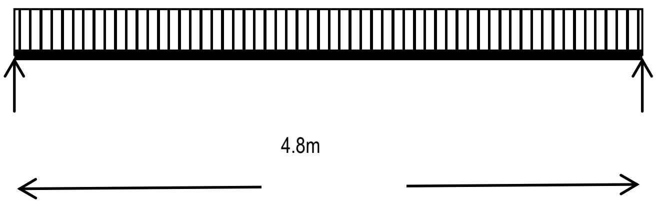
(b) *Papak rasuk rentang dua-hala dianggap sebagai papak wafel. Reka bentukkan papak wafel untuk panel dalam sistem lantai yang mempunyai panjang rentang 6.0m pada setiap arah. Keratan-rentas papak wafel ditunjukkan dalam Rajah 3 dengan beban ciri mati, (termasuk berat sendiri)* $6.0\ kN/m^2$ *dan beban kenaan ialah* $2.5\ kN/m^2$. *Bahan binaan ialah konkrit gred 30 dan tentulang gred 460 digunakan untuk rekabentuk.*

   [15 markah]



Rajah 3 Papak rasuk

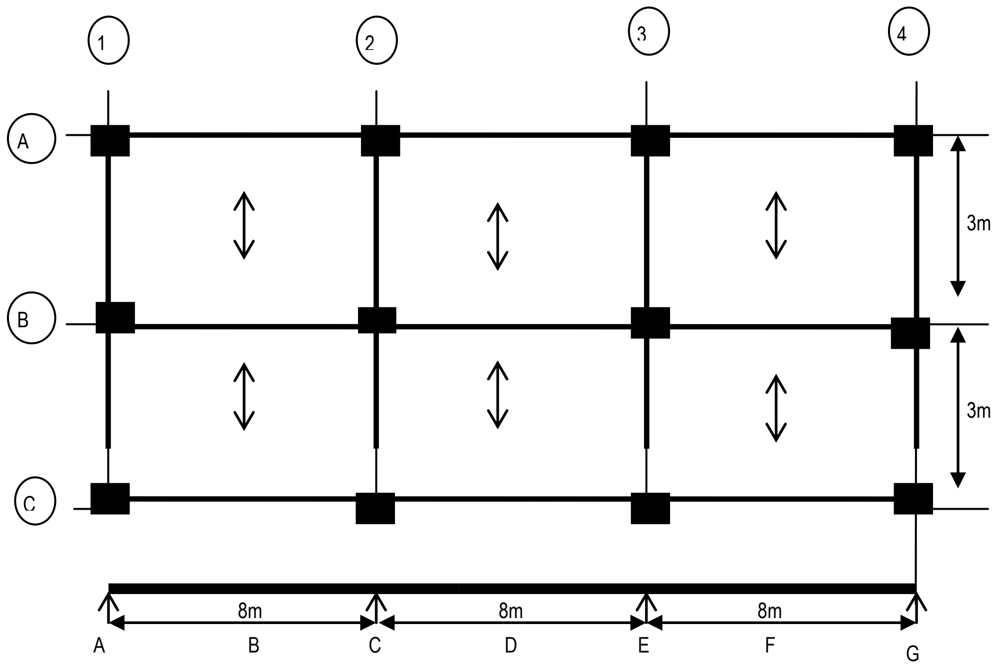
3. (a) *Sebuah rasuk direkabentuk dalam sebuah bangunan yang lebarnya ialah 175mm perlu menyokong beban mati 3.5 kN/m^2 dan beban kenaan 6.0 kN/m^2. Ciri kekuatan konkrit (f_{cu}) ialah 30N/mm^2 dan ciri kekuatan tetulang keluli (fy) 500N/mm^2. Garispusat bar tetulang utama ialah 20mm dan rangkai ricih ialah 10mm. Saiz aggregat (h_{agg}) ialah 20mm. Andaikan hayat rekabentuk ialah 50 tahun dan rintangan kebakaran ialah 1 jam. Peroleh tutupan nominal rasuk dengan menggunakan BS8110-1:1997*



Rajah 4 Rasuk sokong mudah

[5 markah]

(b) *Tingkat dua sebuah bangunan sedang direkabentuk sebagaimana dalam Rajah 5. Semua rasuk berdimensi 250mm x 600mm, dan papak tebal 150mm. Andaikan papak menanggung beban kenaan 3.5N/m^2 dan kemasan 1.5kN/m^2. Penutup nominal rasuk ialah 35mm, ciri kekuatan konkrit (f_{cu}) ialah 30N/mm^2, ciri kekuatan tetulang keluli (f_y) ialah 500N/mm^2 dan ciri kekuatan rangkai ricih (f_{yv}) ialah 250N/mm^2. Garispusat tetulang utama (Φ) ialah 25mm, garispusat rangkai ricih (Φ') ialah 10mm. Saiz aggregat (h_{agg}) ialah 20mm. Hayat rekabentuk rasuk ialah 50 tahun dan rintangan kebakaran ialah 1 jam.*



Rajah 5 Tata atur pelan tingkat dua

Untuk Rasuk /1-4,

(a) *Kirakan momen lenturan dan daya ricih*

[3 markah]

(b) *Lakar rajah momen lenturan dan rajah daya ricih*

[2 markah]

(c) *Rekabentuk tetulang lenturan dan ricih untuk rasuk*

[10 markah]

4. (a) *Kirakan panjang tambatan dalam tegangan dan mampatan untuk bar berbunga gred 460 Jenis 2 dengan diameter φ dalam gred konkrit 30.*

[6 markah]

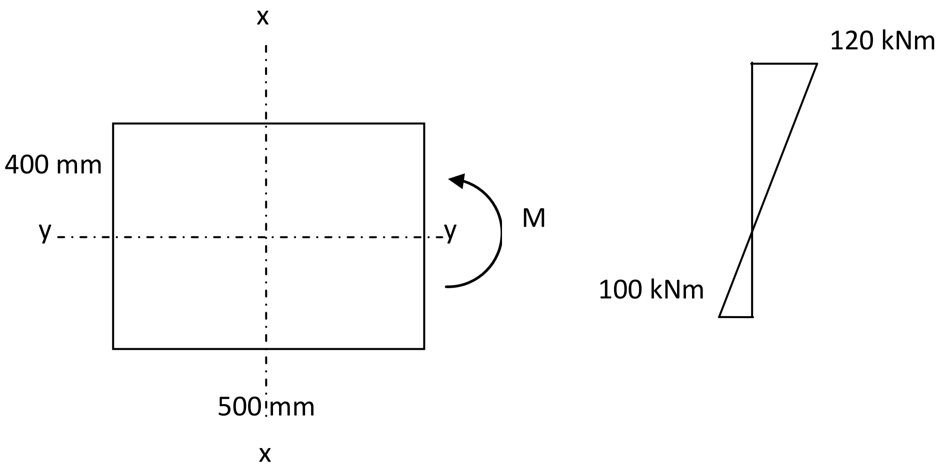
(b) *Tiang boleh direkabentuk dalam keadaan dirembat atau tidak dirembat. Takrifkan istilah dirembat dan tidak dirembat dalam rekabentuk tiang.*

[4 markah]

(c) *Satu tiang langsing terembat merintangi dua momen hujung 120 kNm dan 100 kNm pada had muktamad seperti di Rajah 6. Rekabentuk dan sediakan perincian yang berkaitan dengan berpandukan data-data yang diberikan. Anggap nilai K diambil sebagai 1.0.*

(i)	*Beban paksi muktamad*	*= 2500 kN*
(ii)	*Kekuatan ciri konkrit,* f_{cu}	*=* $30\ N/mm^2$
(iii)	*Kekuatan ciri tetulang utama,* f_y	*=* $460\ N/mm^2$
(iv)	*Kekuatan ciri rakap,* f_{yv}	*=* $250\ N/mm^2$
(v)	*Penutup nominal*	*= 30 mm*
(vi)	*Tinggi berkesan tiang (paksi major dan minor)*	*= 7.5 m*

[10 markah]



Rajah 6

5. *Satu asas tergabung menanggung dua tiang bagi sebuah bangunan konkrit dengan beban kebolehkhidmatan adalah seperti yang ditunjukkan dalam Jadual 1. Jarak antara dua tiang tersebut adalah 3 m. Keupayaan galas dibenarkan adalah 200* kN/m^2*. Kekuatan ciri bahan-bahan adalah* $f_{cu} = 35\ N/mm^2$ *dan* $f_y = 460\ N/mm^2$*. Anggap penutup nominal sebagai 40 mm dan saiz penapak adalah 2.5 x 5.5 x 0.5 m (B x H x h). Rekabentuk dan sediakan keratan perincian tipikal bagi penapak bergabung tersebut.*

(a) *Kirakan*

(i) *Analisis beban rekabentuk*

[4 markah]

(ii) *Tetulang utama*

[4 markah]

(iii) *Keupayaan ricih*

[4 markah]

(iv) *Keretakan*

[2 markah]

(v) *Perincian.*

[2 markah]

Jadual 1: Data:

Column	*Size (mm* x *mm)*	*Load (kN)*	
		G_k	Q_k
Tiang A	*300* x *300*	*800*	*300*
Tiang B	*400* x *400*	*1000*	*350*

(b) *Bincangkan fungsi utama asas dan faktor-faktor yang diperlukan dalam rekabentuk asas.*

[4 markah]

6. *Sebuah tangga konkrit bertetulang untuk sebuah bangunan pejabat ditunjukkan dalam Rajah 7 di bawah. Satu hujung tangga bersambung dengan pelantar dan disokong oleh rasuk pada hujung luar pelantar. Satu hujung lagi disokong oleh rasuk dan selanjar dengan papak lantai melepasi rasuk tersebut. Rekabentukkan tangga tersebut menggunakan konkrit gred 30 dan tetulang keluli gred 460 N/mm^2. Beban kenaan adalah 4.0 kN/m^2 dan berat kemasan adalah 0.5 kN/m^2 . Tebal penutup konkrit adalah 25 mm. Anggap lebar tangga adalah 1500 mm, tebal pelantar 150 mm dan tebal cekak (h) adalah 150 mm.*

(a) *Kirakan*

(i) *Analisis beban rekabentuk*

[3 markah]

(ii) *Tetulang utama*

[4 markah]

(iii) *Keupayaan Ricih*

[3 markah]

(iv) *Pesongan*

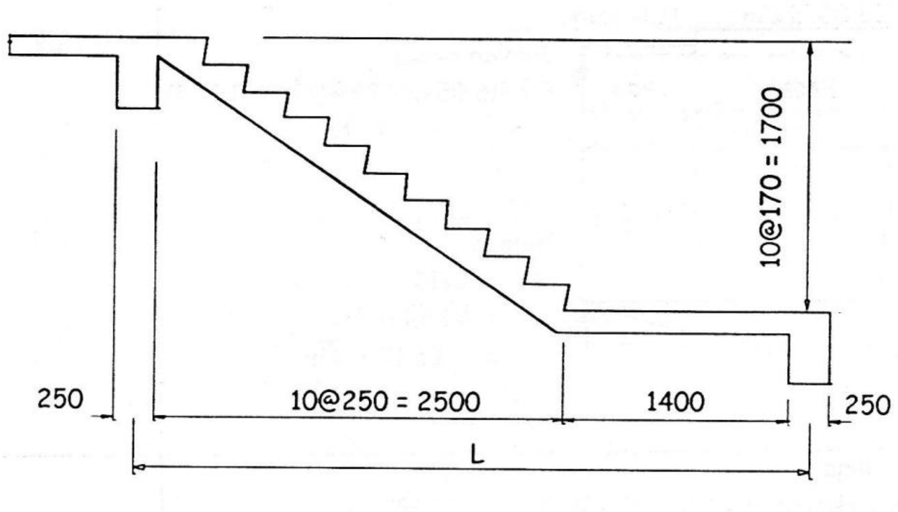
[3 markah]

(v) *Keretakan*

[2 markah]

(vi) *Perincian*

[2 markah]



Rajah 7

(b) *Nyatakan* ***TIGA (3)*** *jenis tangga dan terangkan secara ringkas perbezaannya dari segi konsep rekabentuk.*

[3 markah]

Appendix 1 [a]

Lampiran 1 [a]

Bar Areas and Perimeters

Sectional areas of groups of bars (mm^2)

Bar size (mm)	Number of bars									
	1	2	3	4	5	6	7	8	9	10
6	28.3	56.6	84.9	113	142	170	198	226	255	283
8	50.3	101	151	201	252	302	352	402	453	503
10	78.5	157	236	314	393	471	550	628	707	785
12	113	226	339	452	566	679	792	905	1020	1130
16	201	402	603	804	1010	1210	1410	1610	1810	2010
20	314	628	943	1260	1570	1890	2200	2510	2830	3140
25	491	982	1470	1960	2450	2950	3440	3930	4420	4910
32	804	1610	2410	3220	4020	4830	5630	6430	7240	8040
40	1260	2510	3770	5030	6280	7540	8800	10100	11300	12600

Appendix 1[b]

Lampiran 1 [b]

Sectional areas per metre width for various bar spacings (mm^2)

Bar size (mm)	Spacing of bars								
	50	75	100	125	150	175	200	250	300
6	566	377	283	226	189	162	142	113	94.3
8	1010	671	503	402	335	287	252	201	168
10	1570	1050	785	628	523	449	393	314	262
12	2260	1510	1130	905	754	646	566	452	377
16	4020	2680	2010	1610	1340	1150	1010	804	670
20	6280	4190	3140	2510	2090	1800	1570	1260	1050
25	9820	6550	4910	3930	3270	2810	2450	1960	1640
32	16100	10700	8040	6430	5360	4600	4020	3220	2680
40	25100	16800	12600	10100	8380	7180	6280	5030	4190

Shear Reinforcement

A_{sv}/s_v for varying stirrup diameter and spacing

Stirrup diameter (mm)	Stirrup spacing (mm)									
	85	90	100	125	150	175	200	225	250	275	300
8	1.183	1.118	1.006	0.805	0.671	0.575	0.503	0.447	0.402	0.366	0.335
10	1.847	1.744	1.57	1.256	1.047	0.897	0.785	0.698	0.628	0.571	0.523
12	2.659	2.511	2.26	1.808	1.507	1.291	1.13	1.004	0.904	0.822	0.753
16	4.729	4.467	4.02	3.216	2.68	2.297	2.01	1.787	1.608	1.462	1.34

Appendix 2

Lampiran 2

From BS8110-1:1997

Table 3.4 — Nominal cover to all reinforcement (including links) to meet specified periods of fire resistance (see NOTE 1 and NOTE 2)

Fire resistance	Nominal cover mm						
	Beams[a]		Floors		Ribs		Columns[a]
h	Simply supported	Continuous	Simply supported	Continuous	Simply supported	Continuous	
0.5	20[b]	20[b]	20[b]	20[b]	20[b]	20[b]	20[b]
1	20[b]	20[b]	20	20	20	20[b]	20[b]
1.5	20	20[b]	25	20	35	20	20
2	40	30	35	25	45	35	25
3	60	40	45	35	55	45	25
4	70	50	55	45	65	55	25

NOTE 1 The nominal covers given relate specifically to the minimum member dimensions given in Figure 3.2. Guidance on increased covers necessary if smaller members are used is given in Section 4 of BS 8110-2:1985.

NOTE 2 Cases that lie below the bold line require attention to the additional measures necessary to reduce the risks of spalling (see Section 4 of BS 8110-2:1985).

[a] For the purposes of assessing a nominal cover for beams and columns, the cover to main bars which would have been obtained from Table 4.2 and Table 4.3 of BS 8110-2:1985 has been reduced by a notional allowance for stirrups of 10 mm to cover the range 8 mm to 12 mm (see also **3.3.6**).

[b] These covers may be reduced to 15 mm provided that the nominal maximum size of aggregate does not exceed 15 mm (see **3.3.1.3**).

Table 3.7 — Form and area of shear reinforcement in beams

Value of v N/mm²	Form of shear reinforcement to be provided	Area of shear reinforcement to be provided
Less than $0.5v_c$ throughout the beam	See NOTE 1	—
$0.5v_c < v < (v_c + 0.4)$	Minimum links for whole length of beam	$A_{sv} \ge 0.4 b_v s_v / 0.87 f_{yv}$ (see NOTE 2)
$(v_c + 0.4) < v < 0.8\sqrt{f_{cu}}$ or 5 N/mm²	Links or links combined with bent-up bars. Not more than 50 % of the shear resistance provided by the steel may be in the form of bent-up bars (see NOTE 3)	Where links only provided: $A_{sv} \ge b_v s_v (v - v_c) / 0.87 f_{yv}$ Where links and bent-up bars provided: see **3.4.5.6**

NOTE 1 While minimum links should be provided in all beams of structural importance, it will be satisfactory to omit them in members of minor structural importance such as lintels or where the maximum design shear stress is less than half v_c.

NOTE 2 Minimum links provide a design shear resistance of 0.4 N/mm².

NOTE 3 See 3.4.5.5 for guidance on spacing of links and bent-up bars.

Appendix 3

Lampiran 3

Table 3.8 — Values of v_c design concrete shear stress

$\frac{100A_s}{b_v d}$	Effective depth mm							
	125	150	175	200	225	250	300	400
	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²
≤ 0.15	0.45	0.43	0.41	0.40	0.39	0.38	0.36	0.34
0.25	0.53	0.51	0.49	0.47	0.46	0.45	0.43	0.40
0.50	0.67	0.64	0.62	0.60	0.58	0.56	0.54	0.50
0.75	0.77	0.73	0.71	0.68	0.66	0.65	0.62	0.57
1.00	0.84	0.81	0.78	0.75	0.73	0.71	0.68	0.63
1.50	0.97	0.92	0.89	0.86	0.83	0.81	0.78	0.72
2.00	1.06	1.02	0.98	0.95	0.92	0.89	0.86	0.80
≥ 3.00	1.22	1.16	1.12	1.08	1.05	1.02	0.98	0.91

NOTE 1 Allowance has been made in these figures for a γ_m of 1.25.

NOTE 2 The values in the table are derived from the expression:

$0.79\{100A_s/(b_v d)\}^{1/3} (400/d)^{1/4}/\gamma_m$

where

$\frac{100A_s}{b_v d}$ should not be taken as greater than 3;

$\left(\frac{400}{d}\right)^{\frac{1}{4}}$ should not be taken as less than 0.67 for members without shear reinforcement;

$\left(\frac{400}{d}\right)^{\frac{1}{4}}$ should not be taken as less than 1 for members with shear reinforcement providing a design shear resistance of ≥ 0.4 N/mm².

For characteristic concrete strengths greater than 25 N/mm², the values in this table may be multiplied by $(f_{cu}/25)^{1/3}$. The value of f_{cu} should not be taken as greater than 40.

Appendix 4

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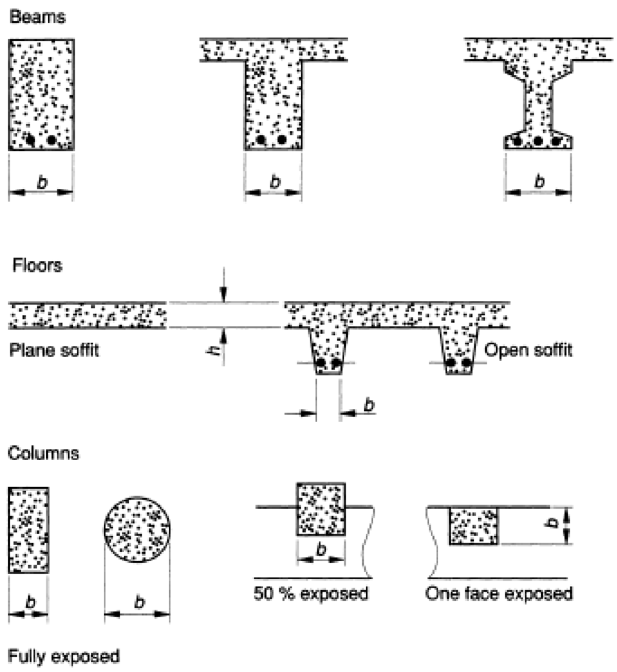

Fire resistance	Minimum beam width (b)	Rib width (b)	Minimum thickness of floors (h)	Column width (b)			Minimum wall thickness		
				Fully exposed	50 % exposed	One face exposed	$p < 0.4$ %	$0.4 \% \leq p \leq 1 \%$	$p > 1$ %
h	mm	mm	mm	mm	mm	mm	mm	mm	mm
0.5	200	125	75	150	125	100	150	100	75
1	200	125	95	200	160	120	150	120	75
1.5	200	125	110	250	200	140	175	140	100
2	200	125	125	300	200	160	—	160	100
3	240	150	150	400	300	200	—	200	150
4	280	175	170	450	350	240	—	240	180

NOTE 1 These minimum dimensions relate specifically to the covers given in Table 3.4 and Table 4.9.

NOTE 2 p is the area of steel relative to that of concrete.

Figure 3.2 — Minimum dimensions of reinforced concrete members for fire resistance

Appendix 5

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Table A.1 Exposure classes (*continued*)

Class designation	Class description	Informative examples applicable in the United Kingdom
XC3 and XC4	Moderate humidity or cyclic wet and dry	External reinforced and prestressed concrete surfaces sheltered from, or exposed to, direct rain
		Reinforced and prestressed concrete surfaces subject to high humidity (e.g. poorly ventilated bathrooms, kitchens)
		Reinforced and prestressed concrete surfaces exposed to alternate wetting and drying
		Interior concrete surfaces of pedestrian subways not subject to de-icing salts, voided superstructures or cellular abutments
		Reinforced or prestressed concrete beneath waterproofing
Corrosion induced by chlorides other than from sea water (XD classes) [A] *(where concrete containing reinforcement or other embedded metal is subject to contact with water containing chlorides, including de-icing salts, from sources other than from sea water)*		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
		Reinforced and prestressed concrete wall and structure supports more than 10 m horizontally from a carriageway
		Bridge deck soffits more than 5 m vertically above the carriageway
		Parts of structures exposed to occasional or slight chloride conditions
XD2	Wet, rarely dry	Reinforced and prestressed concrete surfaces totally immersed in water containing chlorides [C]
		Buried highway structures more than 1 m below adjacent carriageway
XD3	Cyclic wet and dry	Reinforced and prestressed concrete walls and structure supports within 10 m of a carriageway
		Bridge parapet edge beams
		Buried highway structures less than 1 m below carriageway level
		Reinforced pavements and car park slabs
Corrosion induced by chlorides from sea water (XS classes) [A], [D] *(where concrete containing reinforcement or other embedded metal is subject to contact with chlorides from sea water or air carrying salt originating from sea water)*		
XS1	Exposed to airborne salt but not in direct contact with sea water	External reinforced and prestressed concrete surfaces in coastal areas
XS2	Permanently submerged	Reinforced and prestressed concrete surfaces completely submerged and remaining saturated, e.g. concrete below mid-tide level [C]
XS3	Tidal, splash and spray zones	Reinforced and prestressed concrete surfaces in the upper tidal zones and the splash and spray zones [E]
Freeze-thaw attack (XF classes) *(where concrete is exposed to significant attack from freeze-thaw cycles whilst wet)*		
XF1	Moderate water saturation without de-icing agent	Vertical concrete surfaces such as façades and columns exposed to rain and freezing
		Non-vertical concrete surfaces not highly saturated, but exposed to freezing and to rain or water
XF2	Moderate water saturation with de-icing agent	Concrete surfaces such as parts of bridges, which would otherwise be classified as XF1, but which are exposed to de-icing salts either directly or as spray or run-off

Appendix 6

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Table A.1 **Exposure classes** (*continued*)

Class designation	Class description	Informative examples applicable in the United Kingdom
XF3	High water saturation without de-icing agent	Horizontal concrete surfaces, such as parts of buildings, where water accumulates and which are exposed to freezing Concrete surfaces subjected to frequent splashing with water and exposed to freezing
XF4	High water saturation with de-icing agent or sea water [F)]	Horizontal concrete surfaces, such as roads and pavements, exposed to freezing and to de-icing salts either directly or as spray or run-off Concrete surfaces subjected to frequent splashing with water containing de-icing agents and exposed to freezing

Chemical attack (XA classes)
(where concrete is exposed to chemical attack)
Use Table A.2 to determine the ACEC-class.
See BRE Special Digest 1 [1] for guidance on site investigation.

A) The moisture condition relates to that in the concrete cover to reinforcement or other embedded metal but, in many cases, conditions in the concrete cover can be taken as being that of the surrounding environment. This might not be the case if there is a barrier between the concrete and its environment (see A.3).

B) For concrete in soil classed as AC-2 or above or an element with a hydraulic gradient greater than 5, the ACEC class is used to determine the concrete quality and minimum cover to reinforcement (see A.4.4).

C) Reinforced and prestressed concrete elements where one surface is immersed in water containing chlorides and another is exposed to air are potentially a more severe condition, especially where the dry side is at a high ambient temperature. Specialist advice should be sought where appropriate, to develop a specification that is appropriate to the actual conditions likely to be encountered.

D) The rate of ingress of chloride into the concrete will depend on the concentration at its surface: brackish groundwater (chloride content less than 18 g/l) will be less severe than exposure to sea water.

E) Exposure XS3 covers a range of conditions. The most extreme conditions are in the spray zone. The least extreme is in the tidal zone where conditions can be similar to those in XS2. The recommendations given in this annex take into account the most extreme conditions within this class.

F) It is not normally necessary to classify in the XF4 exposure class those parts of structures located in the United Kingdom which are in frequent contact with the sea.

Appendix 7

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Table A.2 Classification of ground conditions

Sulfate and magnesium					Design sulfate class	Natural soil		Brownfield [A)]		ACEC-class (design sulfate class)
2:1 water/soil extract		Groundwater		Total potential sulfate [B)]		Static water	Mobile water	Static water	Mobile water	
SO_4 mg/l	Mg [C)] mg/l	SO_4 mg/l	Mg [C)] mg/l	SO_4 %		pH	pH	pH [D)]	ph [D)]	
<500	—	<400	—	<0.24	DS-1	≥2.5	—	≥2.5	—	AC-1s
						—	>5.5	—	>6.5	AC-1 [E)]
						—	2.5 to 5.5	—	5.6 to 6.5	AC-2z
						—	—	—	4.5 to 5.5	AC-3z
						—	—	—	2.5 to 4.5	AC-4z
500 to 1 500	—	400 to 1 400	—	0.24 to 0.6	DS-2	>3.5	—		—	AC-1s
						—	>5.5	—	>6.5	AC-2
						2.5 to 3.5	—		—	AC-2s
						—	2.5 to 5.5	—	5.6 to 6.5	AC3z
						—	—	—	4.5 to 5.5	AC-4z
						—	—	—	2.5 to 4.5	AC-5z
1 600 to 3 000	—	1 500 to 3 000	—	0.7 to 1.2	DS-3	>3.5	—	>5.5	—	AC-2s
						—	>5.5	—	>6.5	AC-3
						2.5 to 3.5	—	2.5 to 5.5	—	AC-3s
						—	2.5 to 5.5	—	5.6 to 6.5	AC-4
						—	—	—	2.5 to 5.5	AC-5
3 100 to 6 000	≤1 200	3 100 to 6 000	≤1 000	1.3 to 2.4	DS-4	>3.5		>5.5	—	AC-3s
						—	>5.5	—	>6.5	AC-4
						2.5 to 3.5	—	2.5 to 5.5	—	AC-4s
						—	2.5 to 5.5	—	2.5 to 6.5	AC-5
3 100 to 6 000	>1 200 [C)]	3 100 to 6 000	>1 000 [C)]	1.3 to 2.4	DS-4m	Not found in UK natural ground		>5.5		AC-3s
									>6.5	AC-4m
								2.5 to 5.5		AC-4ms
									2.5 to 6.5	AC-5m
>6 000	≤1 200	>6 000	≤1 100	>2.4	DS-5	>3.5	—	>5.5	—	AC-4s
						2.5 to 3.5	≥2.5	2.5 to 5.5	≥2.5	AC-5
>6 000	>1 200 [C)]	>6 000	>1 100 [C)]	>2.4	DS-5m	Not found in UK natural ground		>5.5	—	AC-4ms
								2.5 to 5.5	≥2.5	AC-5m

[A)] "Brownfield" sites are those that might contain chemical residues remaining from previous industrial use or from imported wastes.

[B)] Applies only to sites where concrete will be exposed to sulfate ions (SO_4), which can result from the oxidation of sulfides such as pyrite, following ground disturbance.

[C)] The limit on water-soluble magnesium does not apply to brackish groundwater (chloride content between 12 g/l and 18 g/l). This allows these sites to be classified in the row above. This table does not cover sea water and stronger brines.

[D)] An additional account is taken of hydrochloric and nitric acids by adjustment to sulfate content (see BRE Special Digest 1 [1]).

[E)] For flowing water that is potentially aggressive to concrete owing to high purity or an aggressive carbon dioxide level greater than 15 mg/l, increase the ACEC class to AC-2z (see BRE Special Digest 1 [1]).

Appendix 8

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Table A.3 **Typical reinforced concrete applications in buildings (intended working life at least 50 years) for designated concretes**

Use	Exposure class	Nominal cover [A)] mm	Minimum designated concrete [B)]
Reinforced and prestressed concrete inside enclosed buildings except poorly ventilated rooms with high humidity	XC1	(15 + Δc)	RC20/25
External reinforced and prestressed vertical elements of buildings sheltered from, or exposed to, rain [C)]	XC3/XC4 + XF1	(20 + Δc) (25 + Δc) (30 + Δc)	RC40/50 RC32/40 RC28/35
Horizontal elements with high saturation without de-icing agent and subject to freezing while wet [C)]	XC4+XF3	(20 + Δc) (30 + Δc) (35 + Δc)	RC40/50XF PAV2 PAV1
Reinforced or prestressed buried foundation in AC-1 where the hydraulic gradient is not greater than 5	XC2/AC-1	50 [D)] 75 [E)]	RC25/30
C25/30 reinforced or prestressed buried foundation in AC-2 or more aggressive ground conditions	AC-2 to AC-5m	50 [D)] 75 [E)]	See [F)]

A) Check the appropriate design code to see if it is recommended that the minimum cover to prestressing steel is adjusted by a factor $\Delta c_{dur,\gamma}$.
B) See A.4.5 (Table A.14) for details of the specification associated with the designation.
C) If IVB-V cements and combinations are to be specifically permitted under 4.2.3a), increase the minimum cover by 5 mm.
D) For casting against blinding.
E) For casting directly against soil.
F) Provided that a minimum compressive strength class of C25/30 is adequate, use A.4.4 (Table A.9) to determine the DC-class and replace the "DC-" with "FND" to obtain the designation of the appropriate designated concrete, e.g. "DC-3s" becomes "FND3s". If a higher compressive strength class is required, specify a designed concrete using the required compressive strength class and the DC-class.

Appendix 9

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Table A.4 Durability[A] recommendations for reinforced or prestressed elements with an intended working life of at least 50 years

Nominal cover[B]	Compressive strength class where recommended, maximum water-cement ratio and minimum cement or combination content for normal-weight concrete[C] with 20 mm maximum aggregate size[D]								Cement/combination types
mm	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc	
Corrosion induced by carbonation (XC exposure classes)									
XC1	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	All in Table A.6
XC2	—	—	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6
XC3/4	—	C40/50 0.45 340	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6 except IVB-V
	—	—	C40/50 0.45 340	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	IVB-V
Corrosion induced by chlorides (XS from sea water, XD other than sea water) *Also adequate for any associated carbonation induced corrosion (XC)*									
XD1	—	—	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	All in Table A.6
XS1	—	—	—	C45/55[E] 0.35[F] 380	C35/45[E] 0.45 360	C32/40[E] 0.50 340	C32/40[E] 0.50 340	C32/40[E] 0.50 340	CEM I, IIA, IIB-S, SRPC
	—	—	—	C40/50[E] 0.35[F] 380	C32/40[E] 0.45 360	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	C32/40[E] 0.40 380	C25/30 0.50 340	C25/30 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IIIB
	—	—	—	C32/40[E] 0.40 380	C28/35 0.50 340	C25/30 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IVB-V
XD2 or XS2	—	—	—	C40/50[E] 0.40 380	C32/40[E] 0.50 340	C28/35 0.55 320	C28/35 0.55 320	C28/35 0.55 320	CEM I, IIA, IIB-S, SRPC
	—	—	—	C35/45[E] 0.40 380	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	C32/40[E] 0.40 380	C25/30 0.50 340	C20/25 0.55 320	C20/25 0.55 320	C20/25 0.55 320	IIIB, IVB-V

Appendix 10

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Table A.4 **Durability [A] recommendations for reinforced or prestressed elements with an intended working life of at least 50 years** (*continued*)

Nominal cover [B] mm	Compressive strength class where recommended, maximum water-cement ratio and minimum cement or combination content for normal-weight concrete [C] with 20 mm maximum aggregate size [D]								Cement/combination types
	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc	
XD3	—	—	—	—	—	C45/55[E] 0.35[F] 380	C40/50[E] 0.40 380	C35/45[E] 0.45 360	CEM I, IIA, IIB-S, SRPC
	—	—	—	—	—	C35/45[E] 0.40 380	C32/40[E] 0.45 360	C28/35 0.50 340	IIB-V, IIIA
	—	—	—	—	—	C32/40[E] 0.40 380	C28/35 0.45 360	C25/30 0.50 340	IIIB, IVB-V
XS3	—	—	—	—	—	—	C45/55[E] 0.35[F] 380	C40/50[E] 0.40 380	CEM I, IIA, IIB-S, SRPC
	—	—	—	—	—	C35/45[E] 0.40 380	C32/40[E] 0.45 360	C28/35 0.50 340	IIB-V, IIIA
	—	—	—	—	—	C32/40[E] 0.40 380	C28/35 0.45 360	C25/30 0.50 340	IIIB, IVB-V

A dash (—) indicates that greater cover is recommended.

[A] Where appropriate, account should be taken of the recommendations to resist freeze-thaw damage (see A.4.3, Table A.8), aggressive chemicals (see A.4.4, Table A.11) and abrasion (no guidance provided).

[B] Expressed as the minimum cover to reinforcement plus an allowance in design for deviation, c, e.g. to allow for workmanship. Check the appropriate design code to see whether it is recommended that the minimum cover to prestressing steel is adjusted by a factor $\Delta c_{dur,\gamma}$

[C] Also applies to heavyweight concrete. For lightweight concrete the maximum w/c ratio and minimum cement or combination content applies, but the compressive strength class needs to be changed to a lightweight compressive strength class (see BS EN 206-1:2000, Table A.8 and A.4.1, Note 2) on the basis of equal cylinder strength if designing to BS EN 1992.

[D] For adjustments to cement content for different maximum size of aggregate, see Table A.7.

[E] If the concrete is specified as being air entrained in accordance with the XF2 or XF4 recommendations in Table A.8, the minimum compressive strength class for corrosion induced by chlorides may be reduced to C28/35.

[F] In some parts of the UK it is not possible to produce a practical concrete with a maximum w/c ratio of 0.35.

Appendix 11

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Table A.9 Selection of the nominal cover and DC-class or designated concrete and the number of APM for in-situ concrete elements A) where the hydraulic gradient due to groundwater is five or less B), C), D)

ACEC-class	Lowest nominal cover E), mm	Intended working life F)	
		At least 50 years G), H)	At least 100 years
AC-1s, AC-1	50 I), 75 J)	DC-1 (RC25/30 if reinforced)	DC-1 (RC25/30 if reinforced)
AC-2s, AC-2	50 I), 75 J)	DC-2 (FND2)	DC-2 (FND2)
AC-2z	50 I), 75 J)	DC-2z (FND2z)	DC-2z (FND2z)
AC-3s	50 I), 75 J)	DC-3 (FND3)	DC-3 (FND3)
AC-3z	50 I), 75 J)	DC-3z (FND3z)	DC-3z (FND3z)
AC-3	50 I), 75 J)	DC-3 (FND3)	DC-3 + one APM of choice, FND3 + one APM of choice, DC-4 or FND4
AC-4s	50 I), 75 J)	DC-4 (FND4)	DC-4 (FND4)
AC-4z	50 I), 75 J)	DC-4z (FND4z)	DC-4z (FND4z)
AC-4	50 I), 75 J)	DC-4 (FND4)	DC-4 + one APM from APM2 to APM5, or FND4 + one APM from APM2 to APM5
AC-4ms	50 I), 75 J)	DC-4m (FND4m)	DC-4m (FND4m)
AC-4m	50 I), 75 J)	DC-4m (FND4m)	DC-4m + one APM from APM2 to APM5, or FND4m + one APM from APM2 to APM5
AC-5z	50 I), 75 J)	DC-4z (FND4z) + APM3 K)	DC-4z (FND4z) + APM3 K)
AC-5	50 I), 75 J)	DC-4 (FND4) + APM3 K)	DC-4 (FND4) + APM3 K)
AC-5m	50 I), 75 J)	DC-4m (FND4m)+ APM3 K)	DC-4m (FND4m) + APM3 K)

A) For guidance on precast concrete products, see BRE Special Digest 1 [1].

B) Where the hydraulic gradient across a concrete element is greater than 5, one step in DC-class or one APM over and above the number indicated in the table should be applied except where the original provisions included APM3. Where APM3 is already required, or has been selected, an additional APM is not necessary.

C) A section thickness of 140 mm or less should be avoided in in-situ construction but where this is not practicable, apply one step higher DC-class (designated concrete) or an additional APM except where the original provisions included APM3. Where APM3 is already required, or has been selected, an additional APM is not necessary.

D) Where a section thickness greater than 450 mm is used and some surface chemical attack is acceptable, a relaxation of one step in DC-class (designated concrete) may be applied. For reinforced concrete, the cover should be sufficiently thick to allow for estimated surface degradation during the intended working life.

E) Where the ground contains chlorides, the nominal cover should comprise the recommended minimum cover for the associated XD or XS class plus an allowance for deviation, Δc, of at least 25 mm for concrete to be cast against blinding and at least 50 mm for concrete to be cast directly against soil, and the more onerous limiting values for the concrete should be selected.

F) Designated concrete classes are given in parentheses.

G) Foundations of low-rise housing that has an intended working life of "at least 100 years" may be constructed with concrete selected from the column headed "at least 50 years".

H) Structures with an intended working life of "at least 50 years" but for which the consequences of failure would be relatively serious, should be classed as having an intended working life of "at least 100 years" for the selection of the DC-class (designated concrete) and APM.

I) For concrete cast against blinding.

J) For concrete cast directly against the soil.

K) Where APM3 is not practical, select an alternative APM.

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