Howes Atkinson Crowder LLP

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EC2 DESIGN TOOL

HAC-PRO - 1 - 5 - 2

Excel Program

By

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Link to Download Updates and Licence Information

http://www.hac.idc5.co.uk/hacrc/Info.htm

CONTENTS AND PAGE NUMBERS

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INTRODUCTION

Background

The author has over 30 years experience in the design of concrete structures and this program has evolved over a period of 10 years by constant use. It was initially designed to introduce a repeatable procedure into the design of concrete tanks. It then developed into a universal design method suitable for slabs beams and columns as well. More recently it has been updated to incorporate design to EC2 and CIRIA C660. A particular feature is the ability to display the ultimate capacity unity ratio for combined axial and bending therefore removing the need for a plotted chart each time.

Aim

The primary aim of this program is to provide a powerful design tool that enables engineers to process and display a number of reinforced concrete designs to the British and Euro codes in a concise and orderly manner. It also aims to offer a useful training tool via the use of interactive charts and diagrams.

Method and Layout

The data is entered within the sheet called MAIN. It is divided into Global Data which controls all of the designs and Local Data which is adjustable for each individual design case. The user enters the Global Data first and then the Local section properties, reinforcement and loadings and the program displays the ultimate capacity ratios and service crack widths and other compliant related output including thermal and shrinkage. It does not provide the code clause by clause input style that is offered by other spreadsheets because its primary aim is to process multiple calculations in a tabular layout.

The detailed output demonstrates the compliance with the codes and is suitable for submission for checking by others. There are numerous interactive charts and diagrams which relate to a chosen design case and are displayed on the 2nd MAIN sheet and assist in the input and understanding of the process.

Guidance on input method and design matters is provided via comment boxes. This information is also reproduced within the Info sheet, thus providing an in depth guide which can be printed. Where data such as shear legs or additional bars or compression bars is not required, a zero should be entered. Defaults are suggested for thermal which can be used when a design is not thermal critical.

There are three styles for the design sheet. Normal is for every day use and only shows the notation for normal shear. Punch only shows the notation required for punching shear. All shows the notation required for all shear types on the same sheet. Adjustable data is displayed in bold green or violet.

Design Pages

The program offers 24 designs over 2 pages. Detailed charts are reproduced to a large scale on a separate page and can be printed out.

National Annex Values

The UK National Annex values have been used in all cases and key values are displayed. An αc value of 0.85 has been used for concrete in flexure and axial loading and a value of 1.0 has been used for shear and tension. This spreadsheet can easily be modified to incorporate other National Annexes.

Frequently Asked Questions

A selection of likely questions and some further elaboration is provided in the FAQ sheet.

KEY FEATURES

- Concise layout allows rapid input, review and adjustment
- Designs to BS8110 & BS8007 or EC2 can be side by side
- Column layout style allows multiple designs per page
- Simultaneous thermal, service and ultimate designs
- Automatic crack width calculation & bi-axial or slender column design
- User definable service or ultimate Axial & Moment capacity diagram
- Interactive stress and layout diagrams displayed on adjacent sheet
- FAQ and numerous informative comment boxes with input guidance notes
- Detailed BS and EC2 punching shear procedure guidance sheet
- Automatic Punching Shear β Value calculation and implementation
- Step by step design output sheets and Staad based Wood and Armer method
- Designed by an experienced engineer and tested against other spreadsheets

MEMBER & DESIGN TYPES

Member Types:-

- Beams
- Slabs
- Columns
- Walls
- Ties

Design Types:-

- Ultimate and Service Bending & Axial
- Shear or Punching Shear or Torsion
- Bi-Axial Bending or Slender or Redistribution
- Thermal & Shrinkage to Ciria C91 or C660
- Fatigue Stress Reduction

LAYOUT FEATURES

- Design case description boxes at head of page
- Local input and output data displayed on one sheet
- Global data with full descriptions on a separate sheet
- Interactive diagrams can be set to match any design case
- Diagrams are displayed on a separate printable sheet
- BS or EC2 code design applicable per design case
- Easy to input and edit data - values and diagrams update automatically
- Three sheet layout styles for shear input:-
  - **Normal** Normal shear or torsion
  - **Punch** Punching shear
  - **All** All types of shear or torsion

INPUT SEQUENCE

- Global data
- Design case description boxes
- Local design type and load factor, thermal, section and reinforcement data
- Local applied shear and moment (M) & axial force (N) data

OUTPUT FEATURES

- Global output includes cement type and nominal cover requirement
- Ultimate capacity is displayed as a unity factor
- Ultimate N & M capacity is based on the applied N / M ratio
- Service crack widths for Face 1 and Face 2 (if applicable)
- Reinforcement stresses for Face 1 and Face 2
- Compliance & other data including Span / Depth ratio
- Thermal and shrinkage data and crack widths

FREQUENTLY ASKED QUESTIONS

Has It Been Verified Itself

It has been checked against the Concrete Centre spreadsheets and the papers by Erhard Kruger and Erhard Kruger with Robin Atkinson (Structural Engineer 17 Sept 2002 and 17 May 2005). It has been checked against hand calculations and text books.

Is it Updated and How Do I Get Assistance

Yes, because this method is used constantly by HAC. Contact is: support@hacengineers.co.uk

Does It Need To Be So Comprehensive

Not necessarily. However, this method includes every type of design that you will normally need and since thermal and shear design require reinforcement information, it is convenient to have all of this on one sheet.

What Do The Charts Show

They show how the service and ultimate stress & strain diagrams differ. They can be used to check on the section behaviour and can assist in the use of the program. They show how X relates to the N - M curve and how the ult reinforcement stress is capped as the Strain x Es (equiv to reinf stress) value exceeds the allowable stress.

What Do the Capacity Ratios Mean

They are ultimate design unity checks. The combined N & M ratio is the applied combined forces divided by the combined section capacity value for the same Axial and Moment ratio. See the N - M capacity curve chart.

How Do I Print Results

The Excel sheets have been designed to print to an A4 size Adobe PDFat 90%.

What Does F1 & F2 & Extra Mean

F1 = Face 1 & F2 = Face 2 which are the flexural only tension and compression faces. Extra specifies extra bars and their usage. For Face 1 only bundled bars, enter B1 for once or B2 for twice. To bundle the same bars in Face 1 and Face 2, enter BE1 or BE2. For bars in layer 3 (L3), enter Lgap and it will place bars at F1 centres with a vertical gap. For column side bars (one each side), enter S1. For torsion longitudinal bars enter 4 or more.

What Is The C660 Method

CIRIA C660 introduces a more rigorous shrinkage End or Edge or Internal restraint approach than BS8007 & C91. Enter C91 to allow the traditional BS8007 and C91 design to be followed.

How Do I Design A Normal Beam or Slab With No Axial Load And Why Is X Limited.

Set axial load to 0. Set δ value; max (no red) to 0.85 for EC2 or 0.9 for BS and min (redistribution) for Reinf Class B & C or 0.7 and for Class A to 0.8. For pure bending, X must be <= Xu i.e. $(\delta - 0.4)D/(0.6 + 0.0014/\varepsilon_{cu2})$ equals $(\delta - 0.4)D$ for fck <= 50 N/mm² (where D is Eff Depth) so that the reinf yields first and sufficient rotations can occur. If the N - M value of X, (Xo) > Xu, the section is not in ultimate equilibrium about the centre unless the tens reinf is reduced or comp reinf is added. The Ult Mcap equals Mr, the minimum of the concrete stress block and comp reinf acting about the centroid of the tens reinf (Mc) or vice versa (Mt). The output displays if:- Z>0.95D or Mt equals Mc (where Xo ≤ Xu) or Mt > Mc (where Xo > Xu). Ensure also that M / Mcap ratio is < 1.

How Do I Design To EC2

Enter EC2 at the head of the output. The shear strut angle and leg angle can be adjusted. The shear shift value "a1" is displayed. Bi-axial bending requires a design for each axis and the combined ratios must be ≤ 1.0. Enter applied N and enter and adjust Mx until the capacity equals 1.00 to give Mr and then enter the applied moment in the Bi-axial cell. The program calculates $(Mb/Mr)^a$ value for each axis.

What Is The S / (D x 20 x Str Sys) Ratio

EC2 & BS8110 give a simply supported span /depth ratio of 20 for 0.5% As1, C30 and a service reinf stress of 310 N/mm² If this is multiplied by 20 and the structural system (for other span types) it gives the span / depth ratio.

How Do I Design For Punching Shear

Enter Pi or Pc or Pe or Pr and Px & Py dims and MED. Enter Shear V_{ED} & UDL w if applicable. For BS, initially, set leg dia to 0 and xD to 1.5, if cap ratio < 1.0, it is OK. If not, enter leg dia, out and transv spacing for all xDs within Dout (1.5D, 2.25D, 3D etc). Note: reinf is uneconomic if v > 1.6vc.

Display

The sheet has been designed to suit 1024 x 760 resolution. Zoom by 125% to view on a 1280 x 1024 screen.

1	BS 8110	Structural Use of Concrete — Part 1 For Design and construction Part 2 For special circumstances
2	BS 8007	Design of concrete structures for retaining aqueous liquids
3	BS EN 206 -1	Concrete - Part 1: specification, performance, production and conformity
4	BS8500 - 1	Concrete - Complimentary British Standard to BSEN 206 - 1 Part 1 : 2006 Method of specifying and guidance for the specifier
5	BS8500 - 2	Concrete - Complimentary British Standard to BSEN 206 - 1 Part 2 : 2006 Specification for constituent materials and concrete
6	CIRIA Report 91	Early-age thermal crack control in concrete - revised edition published 1991
7	CIRIA Report C660	Early-age thermal crack control in concrete - replaces Report 91 - published 2007
8	BS EN 1990:2002 + A1:2005	Eurocode 0. Basis of structural design UK National Annex to BS EN 1990:2002 + A1:2005
9	BS EN 1991-1-1:2002	Eurocode 1. Actions on Structures - Part 1-1: General Actions - Densities, self-weight, imposed loads for buildings UK National Annex to BS EN 1991-1-1-2002
10	BS EN 1991-4:2006	Eurocode 1. Actions on structures. Part 4: Silos and tanks UK National Annex to BS EN 1991-4-2006
11	BS EN 1991-5:2006	Eurocode 1. Actions on structures. Part 5: Thermal Actions UK National Annex to BS EN 1991-5-2006
12	BS EN 1992-1-1:2004	Eurocode 2. Design of concrete structures. Part 1 - 1: General rules and rules for buildings UK National Annex to BS EN 1992-1-1-2004 - Incorporating National Amendment No. 1
13	BS EN 1992-3-2006	Eurocode 2. Design of concrete structures. Part 3: Liquid retaining and containing structures UK National Annex to BS EN 1992-3-2006
14	The Concrete Centre	RC Spreadsheets V3 by Charles Goodchild and Rod Webster
15	W. Mosley & J. Bungey	Reinforced Concrete Design
16	Dr A.W. Beeby	The Prediction of Crack Widths in Hardened Concrete 1979 Cracking and Corrosion, Concrete in the Oceans Report 1978
17	H.G. Kruger	Crack Width Calculation to BS8007 for Combined Flexure and Tension Structural Engineer September 2002
18	CARES	The CARES Guide to Reinforcing Steels
19	R.S. Narayanan & A. Beeby	Designer's Guide to EN1992-1-1 and EN1992-1-2 Eurocode 2: Design of concrete structures. General rules and rules for buildings and structural fire design
20	C.R. Hendy & D.A. Smith	Designer's Guide to EN1992-2 Eurocode 2: Design of concrete structures. Part 2: Concrete bridges
21	Moody	Moments and Reactions For Rectangular Plates
22	Portland Cement Association	Circular Tanks Without Prestressing
23	Hordijl, Wolsink, de Vries TNO Building & Research	Fracture and fatigue behaviour of high strength limestone concrete as compared to gravel concrete
24	EuroLightCon	Fatigue of Normal Weight Concrete and Lightweight Concrete
25	C Edvardsen	Water Permeability and Autogenous Healing of Cracks in Concrete ACI Materials Journal July / August 1999

HOW TO USE THE MAIN SPREADSHEET

AIMS	COMMENTS
To be able to check a proposed cross section and reinforcement subjected to various direct or indirect actions and display compliance or otherwise.	Some Actions such as Axial and Moment and Shear are interdependant
To allow multiple designs on the same page	2 pages with 12 designs per page
To have one sheet which can be adapted as required	Provides a "One Stop Shop" program
To allow designs in one pass which do not require any goal seek or visual basic routines	Allows Instantaneous Update
To be able to switch simply from an EC2 check to a BS check.	Some data such as for shrinkage and shear will be different for each code
To provide live graphics to assist the designer	The off sheet diagrams are interactive

	METHOD	NOTES
A	Go to the Global Data Sheet and examine the Input Data. The program opens with a realistic set of values. The data changed most frequently is called Key Global Data and is reproduced at the head of each Design Sheet. Edit the Global Input Data as required. These values apply to every design in the spreadsheet. This sheet also displays the global ouput values used.	Many values will not require editing The output data on the right shows useful information and defaults for shrinkage Minimum cover and binder description do not affect the designs
B	Go to the first Design Sheet and select the Style of the sheet in respect of shear. This will adjust the shear related headings to give a simpler look if only normal shear or if only punching shear designs are used. The program opens with the All Style which shows both.	Punching Shear designs and Normal Shear designs will usually be kept separate. The layout will be clearer.
C	The program opens with lots of design examples. Save, print or create a pdf of these pages for reference.	This demonstrates the input options
D	Keep the first design case on the Design sheets and delete the rest. You will see that the output results clear.	To allow copying and pasting. Output clears if Load Factor is deleted.
E	The charts will be initially set to apply to Design Case 1. Edit the 4 lines of description at the top and the bold green input data. Set the Code to EC2 or BS.	Follow the instructions within the comment boxes and Info tab
F	Review the output results. The Shear and combined Axial and Moment values show a capacity factor like the unity check used in steelwork. The value must be less than 1.0 to comply.	The output results show most of the information traditionally required.
G	Note that non compliance is shown in Red.	Can be adjusted within the Global Input
H	Copy Design 1 over to next column and set Charts to 2. Edit Design 2 as required. Never cut and paste.	Specify the Shear Design. S = Normal Pi or Pr or Pe or Pc = Punch, T = Torsion.
I	Repeat for further designs.	Enter 0 in cells where there is no input
J	The off sheet diagrams are reproduced after the Designs. You can print one design case diagrams at a time to pdf or a printer.	Diagrams are bigger and have more information.
K	The background and formulae used in the program are displayed in detail in subsequent sheets in the FULL and PRO versions of the program.	These include additional graphics and completely interactive teaching aids and examples

GLOBAL DATA **Common For All Design Cases** Key = Data which is commonly varied

INPUT DATA

Reinforcement

Young's Modulus - Fixed Value kN/mm²	200	
Grade N/mm²	500	
Class - A, B or C	B	
Rib Profile - D2 or PR	D2	
Material Partial Safety Factor - γs	1.15	
Service Stress Max Design Value Factor - k3	.70	

Concrete

28 Day Cube Strength - fck,cube N/mm² or Mpa	37	Key
Load Duration Long (L) or Short (S)	L	
Liquid Tightness Class ΔWK1 % Active	1	30
BS8007 Stiffening N/mm² 0.667 or 1.0 or Auto	0.667	
Crack Width (W) Alert Value mm - Min of Wk1 or	0.20	
Material Partial Safety Factor - γc	1.50	
Ignore Fs2 in Tension in Flexural only analysis	Y	
Adjust Axial & Flexure W for Poor Bond. Y or N	Y	
Adjust C660 End Restr W for Good Bond. Y or N	N	
Slenderness Method - Curve (NC), Stiff (NS)	NC	
Minimum Lap Length / dia	20	
Lap Length / dia Alert Value	50	
Exposure Class - XC, XD, XS For Cover	XC2	Key
Design Life (DL) in Years for Cover Calculation	60	
Cover Permitted Deviation mm	10	
Service Stress / fck Limit Factor - k Ref 7.2 (3)	0.45	
Creep Coefficient (CC) used in MR or Auto	1.50	Key
Age at Loading in D or Y (to) for Auto CC	28D	
Final Age For Auto CC in D or Y	60Y	
Design & Crack Check Age in D or Y (t)	28D	

Binder

Strength Gain Class - R or N or S Ref 3.1.2 (6)	N	Key
Total Binder Content Kg/m³	350	Key
W / C Ratio	0.50	Key
PC or SRPC	PC	Key
GGBS % - Max = 80	50	Key
or PFA % - Max = 55	0	Key

Aggregate	Ec28	με28	μα	%	
Basalt	39.4	90	10.0	0	
Chert, Flint	38.5	93	12.0	0	
Quartzite	32.8	109	14.0	0	
Granite, Gabbro	33.1	108	10.0	0	
Limestone	29.6	122	9.0	0	
Sandstone	23.0	155	12.5	0	
Default (C660)	32.8	109	12.0	100	Key
Aggregate Size mm	Maximum			20	Key

Thermal & Shrinkage & Creep

Mean Daily Temperature	15	
Concrete Placing Temperature	20	
Min T1 values apply to EC2 C660 αct Factor	No	0.80
Auto C660 T1 Value - Uses Charts or C660 Prog	Prog	
Drying Period in (DP) Years Y i.e. 60Y	60Y	
LT fctm & εcap based on 28D or Later i.e. 60Y	28D	
Edge Restr Age for Min %As1/BZ 3D, 28D, LT	3D	
End Restr Age for Min %As1/BZ 3D, 28D, LT	28D	

Fatigue

Millions of Cycles 1 > N < 100 or N/A	N/A	
Cyclice σMin / σMax or N/A αcc,fat	N/A	1.00
Verify Compression via 6.72 or 6.77 Legs ζ	6.72	0.45

EC2 Lap Length a6 Factor

	ρ1	α6	αd	
Based on % of lapped bars relative to	<25%	1.00	Default	
the total cross section. See Figs 8.7 &	33%	1.15	Output	
8.8, Cl 8.7.3 & Table 8.3.	50%	1.40	Value	
For anchorage lengths use a6 = 1.0.	>50%	1.50	1.50	Key
Ult Lap or Adjust Lap Lengths by Service Stress (N/mm²) /			Ult	Key

OUTPUT VALUES

Refs relate to EC2 clauses

Reinforcement

Fyk - Yield Stress - N/mm²	500
Fyd - Maximum Stress - N/mm²	435
Δσsk - Fatigue Reduced Stress - N/mm²	N/A
Fs1 & Fs2 Output - nr of decimal places	0
k3 Fyk - Max Service Design Stress - N/mm²	350

Concrete

Cement / Combination Type			IIIA
Nominal Cover (Min + Perm Dev) mm			35
C fck / fck cube - at 28 Days - N/mm² or MPa		C 30 / 37	
EC2 & BS Modulus Ec - at 28 Days - KN/mm²		32.8	27.4
EC2 & BS Modular Ratio (MR) - at 28 Days		15.2	18.2
EC2 & BS Min %As1 / BH		0.15	0.13
EC2 & BS Min shear Legs %AsL / BSr		0.088	0.092
EC2 & BS Basic Anchorage / dia (<=32 EC2)		35.7	35.7
EC2 & BS Ult shear at support face N/mm²		5.3	4.9
3 & 28 & LT Ult Tensile Strength N/mm²	1.73	2.90	2.90
3 & 28 & LT Ult Tensile μStrain	76	109	109
3 & 28 & LT Autogenous μStrain	15	33	50
Min or Design or Max Service σ Limits	13.50	13.50	18.00

Shrinkage & Crack Control

C660 Creep Coefficient K1			0.65
C660 Sustained Load Coefficient K2			0.80
C91 Blended GGBS Mix T1 Factor Used			0.76
Aggregate Expansion α x 10E-6			12.0
High Bond Bars, Bond Fact = fct / fb Good, Poor		0.80	1.14
3 Day, 28 Day, LT ρcrit %As1 / BZ	0.35	0.58	0.58
Design Check Age (t) ρcrit %As1 / BZ			0.58

Useful UK National Annex (NA) and EC2 Values

αcc = LT effects coeff - Flexure & Axial - UK NA	0.85
αct = LT effects coeff - Tension - UK NA = EC2	1.00
αcc = LT effects coeff - Shear - UK NA = EC2	1.00
CRd,c = Shear factor - UK NA = EC2 value = 0.18 / γc	0.12
k1 = k3 - Redistribution - UK NA values	0.40
k2 = k4 - Redistribution - UK NA = 0.6 + (0.0014 / εcu2)	1.00
εcu2 = Ultimate Concrete Compressive Strain	0.0035
fcd = Design Compressive Strength - at 28 days - N/mm²	17.0
λ = Rectangular Compression Block Height / X	0.80
η = Effective Strength Factor	1.00
η λ = Effective Rectangular Compression Block Height / X	0.80
fcd = Design Shear Strength - at 28 days - N/mm²	20.0
v1 = Vert Leg Cracked Shear Factor = 0.6(1-(fck/250))	0.53
EC2 only Lap (Dia φ >32) = Basic Value x 100 /	132-φ

Provisional Design Data - if unknown or not relevant

Head of Liquid	N/A
Restraint Method BS	C91
Restraint Method EC2 /C660	Edge
Restraints R1, R2 & R3	0.50
Formwork	Ply
Drying Faces & Relative Humidity %	1 & 85
Temperature Drop T2	20

Fatigue Factors Used by Program

Concrete in Compression (including Shear Struts)			1.000
Concrete in Shear			1.000
Reinf - Straight, Bent m=7φ, Bent m=4φ	1.000	1.000	1.000

Default β Values for Near Equal Spans

	β	Veff/V
Pi = Internal	1.15	1.15
Pe = Edge	1.40	1.40
Pc = Corner	1.50	1.25
Pr = Re-entrant	1.30	1.30
EC2 & BS Basic Control Perimeters U1 distance	2.0D	1.5D
BS Circular Col Perimeter as a Square or Circle	Circle	

Howes Atkinson Crowder LLP	EC2 DESIGN TOOL MAIN SPREADSHEET 1	Project Info	
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DESIGN 1	Charts 1	Key Global Data	1	2	3	4	5	6	7	8	9	10	11	12
INPUT	Style: All	Binder 350 50 GGBS	Wall	Punch	Punch	Circ	Circ	Panel 2	Slab	Slab	Wall	Wall	Beam	Col
		Grade N C 30 / 37	Moment	Design	Design	Tank	Tank	Mv at	Y Dir at	X Dir at	H Edge	V Edge	Design	Slender
	Dims in mm	Agg 20 Default	&	with	with	Hor	Vert	Base	Pile	Span	Restr	Restr	30%	EC2
		Laps 1.5 Ult	Tension	Legs	Legs	Design	Design	S2	S2	S2	Base	Base	Red	Red
Design	Input - S=Service U=Ultimate	S or U	S	U	U	S	S	U	U	S	S	S	U	U
	Load Factor = Ult / Serv	LF	1.35	1.35	1.40	1.35	1.35	1.40	1.40	1.35	1.20	1.35	1.40	1.40
	Head of Liquid in mm or N/A	ho	7000	7000	N/A	4000	4000	7000	7000	7000	7000	7000	N/A	N/A
	Col - Leff or Bi-Ax or N/A	Leff, Bi-Ax	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9000
Restraint	C91 or Edge, End, Int (C660)	Restr	End	End	C91	Edge	Edge	Edge	Edge	End	Edge	Edge	Edge	Edge
	End Restrained Length Lr or N/A	Lr	16000	16000	N/A	N/A	N/A	N/A	16000	12000	N/A	N/A	N/A	N/A
	Curing Restraint - Up to 3 Days	R1	0.40	0.20	0.50	0.77	0.77	0.35	0.60	0.60	0.60	0.35	0.60	0.60
	28 Day / T2 Seasonal Restraint	R2	0.40	0.20	0.50	0.50	0.50	0.35	0.00	0.60	0.60	0.35	0.60	0.60
	Long Term Restraint	R3	0.40	0.20	0.00	0.50	0.50	0.00	0.00	0.60	0.30	0.00	0.60	0.60
Shrinkage	Formwork - Grnd, Ply, Steel	Fmwk	Ply	Grnd	Grnd	Ply	Ply	Ply	Grnd	Grnd	Ply	Ply	Ply	Ply
	Exposed Faces & Rel Hum %	EF & Rh	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85
	T1 or ΔT - or Auto for T1 Calc	T1, ΔT	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto
	Seasonal Temperature Drop	T2	20	15	15	20	20	20	15	15	20	20	20	20
Section	Type - Slab, Beam, Wall, Col	Type	Wall	Slab	Slab	Wall	Wall	Wall	Slab	Slab	Wall	Wall	Beam	Col
	Face 1 - top, bot, int, ext, any	Face 1	int	top	top	any	int	int	top	bot	int	int	bot	any
	Depth H	H	600	600	600	300	300	600	600	600	600	600	450	300
	Width B	B	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	600	600
Main Reinf	F1 φ or φ1 & φ2 for alt bars	F1 φ	32	20	20	12 & 16	20	25	20	32	20	16	32	25
	Bar spacing >49 or nr <50	@ or nr	150	150	150	150	150	150	150	150	150	150	4	4
	Cover to F1 main bars	Cov	60	50	50	40	56	50	50	60	40	40	52	52
	F2 φ or φ1 & φ2 for alt bars	F2 φ	25	20	20	12 & 16	12	20	20	20	20	16	20	25
	Bar spacing >49 or nr <50	@ or nr	150	150	150	150	150	150	150	150	150	150	4	4
	Cover to F2 main bars	Cov	60	50	50	40	56	50	50	60	40	40	52	52
	Extra φ or φ1 & φ2 for alt bars	Extra φ	0	0	0	16	0	0	0	0	0	0	0	25
	Bnr, BEnr, Lgap, S1, >3 Tors	Fact	0	0	0	BE1	0	0	0	0	0	0	0	S1
Shear or Torsion or Punching	S or T or Pi,Pe,Pc,Pr	Type	S	Pi	Pi	S	S	S	Pi	S	S	S	S	S
	Legs - φ or nxφ or φ1 & φ2	Leg φ	16	20	20	0	0	16	0	0	0	0	12	10
	Legs - long or rad ctrs <=0.75D	Sr	300	405	405	0	0	300	0	0	0	0	300	300
	Legs - long or rad start <=0.5D	Sr1	150	270	270	0	0	150	0	0	0	0	150	150
	Legs1 - transv ctrs >49 or nr <50	St , nr	150	12	405	0	0	150	0	0	0	0	4	4
	Legs2 - transv ctrs >49 or nr <50	nra	0	12	405	0	0	N/A	0	0	0	0	0	0
	Strut Angle or Punch X dim	θ°, Px	21.8	600	600	0	0	21.8	600	0	0	0	21.8	21.8
	Leg Angle or Punch Y dim	α°, Py	90	600	600	0	0	90	Dia	0	0	0	90	90
	(V between xD & 2D) / VED	Vratio	0	0	0	0	0	0	0	0	0	0	0	0
	Nr of Effective Depths From Supp	xD	2.00	2.00	1.50	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00	2.00
	Punch w (kN/m²) , Teff or Auto	w, Teff	0	0	0	0	0	0	0	0	0	0	0	0
	MEDxx (kNm) or Def or β or N/A	β MEDxx	N/A	Def	Def	N/A	N/A	N/A	Def	N/A	N/A	N/A	N/A	N/A
	MEDyy (kNm) or N/A	β MEDyy	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Forces	Shr or Pun VED(kN) orTor (kNM)	V or T	220	3750	3750	10	94	1382	2100	45	100	1	387	50
	Axial Force (kN) Tens is neg.	N	-137	0	0	-535	10	1	1	-200	-100	1	0	965
	Primary Moment (kNm)	M	296	140	140	0	-72	100	180	-120	100	1	436	50
Bi-Ax, Slen, δ	Bi-Ax, Mc1, 0.7 <= δ <= 0.9, blank	B, M, δ											0.70	30
OUTPUT	CODE OF PRACTICE	BS, EC2	EC2	EC2	BS	EC2	EC2	BS	BS	EC2	EC2	EC2	EC2	EC2
Results	Ult (S or P or T) / Capacity	S, P, T	0.17	0.99	0.91	0.16	0.78	1.01	1.16	0.21	0.54	0.01	0.69	0.24
	Ult (Axial & Moment) / Cap	N & M	0.40	0.30	0.30	0.35	0.51	0.14	0.39	0.20	0.32	0.00	1.00	1.00
	Serv F1 Crack Width or Info	W1	0.147	0.157	0.034	0.132	0.170	0.004	0.070	0.072	0.120	0.001	0.354	0.280
	Serv F2 Crack Width or Info	W2	0.000	0.000	0.000	0.132	0.000	0.000	0.000	0.000	0.000	0.000	Mt>Mc	SLEN
	X - serv or ult - refers to input	X	185	63	61	<-9999	93	77	61	150	113	152	115	141
Values	Fs1 N/mm² / β Value	Fs1 , β	-133	1.15	1.15	-112	-168	-435	1.15	-67	-118	-1	-435	-435
	Fs2 N/mm² / St / D at Dria	Fs2,St/D	44	1.3229	0.75	-112	37	137	N/A	14	17	0	304	362
Dark	S transv / D / St / D at Dro	St / D	0.29	1.06	0.75	0.00	0.00	0.28	N/A	0.00	0.00	0.00	0.39	0.72
Blue	Sp/(Dx20xSys) / AsL% at Dria	Sp/D,%L	1.821	0.109	0.192	2.000	1.601	>2	N/A	1.466	2.000	2.000	0.876	1.392
Denotes	%AsLegs / BSr / AsL% at Dro	%AsL	0.447	0.136	0.192	0.000	0.000	0.447	N/A	0.000	0.000	0.000	0.251	0.175
Punching	θ, (Mb/Mr)ᵃ, MEd / xD at Dria	θ,Bi,M,Dri	21.8	2.000	0.500	N/A	N/A	21.8	N/A	N/A	N/A	N/A	21.8	242.06
Shear	% As1 / BH / xD at Dro	%As1,Dro	0.893	3.500	1.250	0.795	0.698	0.545	N/A	0.893	0.349	0.223	1.191	1.363
Values	lap / (φx(α6/αd)) / xD at Uout	Lp,DUout	47	4.669	3.237	39	39	20	2.145	47	46	42	49	45
	EC2 Shr Shift / Perim at xD	a1, Ux	590	9185	8880	252	234	N/A	5277	524	550	552	430	233
Data	Reinf Area of F1 & Extra (mm²)	As1	5362	2094	2094	2388	2094	3272	2094	5362	2094	1340	3217	2454
	Avg Effective Depth	D	524	540	540	252	234	538	540	524	550	552	382	207
	Max Full Thickness Crack or Teff	Wk1	0.166	0.166	N/A	0.158	0.158	0.166	0.166	0.166	0.166	0.166	N/A	N/A
	Min Forces % As1 / BZ	nkc ρCrit	0.259	0.232	N/A	0.446	0.230	N/A	N/A	0.272	0.252	0.232	0.232	0.027
	EC2 Face 1 Bond Condition	Bond	Good	Poor	N/A	Good	Good	N/A	N/A	Good	Good	Good	Good	Good
Shrinkage	Zone Depth (BS) or k z H (EC2)	Z	255	255	250	150	150	255	255	255	255	255	208	150
	T1 or ΔT	T1, ΔT	31.3	29.7	24.4	21.5	21.5	31.3	29.7	29.7	31.3	31.3	24.0	21.5
	Drying Shrinkage μStrain	μεcd	138	138	138	145	145	138	138	138	138	138	142	145
	F1 Crack Width or Uncracked με	W , με	0.168	92	0.188	0.108	0.191	0.070	0.092	0.154	0.161	0.077	0.147	0.130
	Min Shrinkage % As1 / BZ	kc ρCrit	0.58	0.58	0.35	0.35	0.35	0.35	0.35	0.58	0.35	0.35	0.35	0.35
	% As1 / BZ	%As1	2.10	0.82	0.84	1.59	1.40	1.28	0.82	2.10	0.82	0.53	2.58	2.18
	Creep Coefficient (CC)	φ(∞,to)	1.52	1.52	1.52	1.57	1.57	1.52	1.52	1.52	1.52	1.52	1.54	1.57

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	HAC-PRO 1 - 5 - 2		MAIN 4

DESIGN 2	Charts	Key Global Data	13	14	15	16	17	18	19	20	21	22	23	24
INPUT	Style: Normal	Binder 350 50 GGBS	Beam	Beam	Beam	Col	Col	Col	Col	Col	Col	Torsion	Torsion	High
		Grade N C 30 / 37	Design	Design	Design	Short	Short	Short	Short	Slender	Slender	Only	Only	Tens
	Dims in mm	Agg 20 Default	10%	10%	30%		Bi-Ax	Bi-Ax	Bi-Ax	EC2	BS	EC2	BS	With
		Laps 1.5 Ult	Red	Red	Red		Mx	My	BS					Legs
Design	Input - S=Service U=Ultimate	S or U	U	U	U	U	U	U	U	U	U	U	U	U
	Load Factor = Ult / Serv	LF	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
	Head of Liquid or N/A	ho	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Col - Leff, Bi-Ax or Lr or N/A	Leff, Bi, Lr	N/A	N/A	N/A	N/A	Bi-Ax	Bi-Ax	Bi-Ax	5670	6050	N/A	N/A	N/A
Restraint	C91 or Edge, End, Int (C660)	Restr	Edge	Edge	Edge	Edge	Edge	Edge	C91	Edge	C91	Edge	C91	Edge
	End Restrained Length Lr or N/A	Lr	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Curing Restraint	R1	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	28 Day / T2 Restraint	R2	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	Long Term Restraint	R3	0.60	0.60	0.60	0.60	0.60	0.60	0.00	0.00	0.00	0.60	0.00	0.60
Shrinkage	Formwork - Grnd, Ply, Steel	Fmwk	Ply	Ply	Ply	Ply	Ply	Ply	Ply	Ply	Ply	Ply	Ply	Ply
	Exposed Faces & Rel Hum %	EF & Rh	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85	1 & 85
	T1 or ΔT - or Auto for T1 Calc	T1, ΔT	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto
	Seasonal Temperature Drop	T2	20	20	20	20	20	20	20	20	20	20	20	20
Section	Type - Slab, Beam, Wall, Col	Type	Beam	Beam	Beam	Col	Col	Col	Col	Col	Col	Beam	Beam	Wall
	Face 1 - top, bot, int, ext, any	Face 1	top	bot	bot	any	any	any	any	any	any	top	top	any
	Depth H	H	600	450	450	450	500	600	600	300	300	600	600	300
	Width B	B	1000	600	600	350	600	500	500	300	300	600	600	1000
Main Reinf	F1 φ or φ1 & φ2 for alt bars	F1 φ	25	20	40	16	32	32	32	32	32	25	25	25
	Bar spacing >49 or nr <50	@ , nr	8	4	4	2	3	3	3	2	2	2	2	150
	Cover to F1 main bars	Cov	52	52	52	52	52	52	52	40	40	60	60	40
	F2 φ or φ1 & φ2 for alt bars	F2 φ	20	16	20	16	32	32	32	32	32	25	25	25
	Bar spacing >49 or nr <50	@ , nr	8	4	4	2	3	3	3	2	2	2	2	150
	Cover to F2 main bars	Cov	52	52	52	52	52	52	52	40	40	60	60	40
	Extra φ or φ1 & φ2 for alt bars	Extra φ	0	0	0	0	32	32	32	0	0	25	25	0
	Bnr, BEnr, Lgap, S1, >3 Tors	Fact	0	0	0	0	S1	S1	S1	0	0	4	4	0
Shear or Torsion	S = Shear or T = Torsion	Type	S	S	S	S	S	S	S	S	S	T	T	S
	Legs - φ or nxφ (i.e. 2x12)	Leg φ	10	10	10	10	10	10	10	10	10	20	20	10
	Legs - Longitudinal ctrs <=0.75D	Sr	300	300	300	300	300	300	300	300	300	300	300	150
	Legs - Longitudinal start <=0.5D	Sr1	150	150	150	150	150	150	150	150	150	150	150	150
	Legs - transv ctrs >49 or nr <50	St , nr	4	4	4	3	3	3	3	3	3	2	2	150
	Not Used in Normal Shear	N/A	0	0	0	0	0	0	0	0	0	0	0	0
	Shear Strut Angle (norm = 21.8°)	θ°	21.8	21.8	21.8	21.8	21.8	21.8	45	21.8	45	45	45	29.8
	Shear Leg Angle (norm = 90°)	α°	90	90	90	90	90	90	90	90	90	90	90	90
	(V between xD & 2D) / VED	Vratio	0	0.6	0	0	0	0	0	0	0	0	0	0
	Nr of Effective Depths From Supp	xD	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	EC2 Torsion Teff or Auto	Teff	0	0	0	0	0	0	0	0	0	Auto	0	0
	Not Used	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Not Used	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Forces	Shear (kN) or Torsion (kNm)	V or T	393	397	387	50	275	337	275	50	50	150	150	400
	Axial Force (kN) Tens is neg.	N	0	0	0	1600	2500	2500	2500	1500	1500	1	1	-400
	Primary Moment (kNm)	M	285	186	425	5	665	830	410	80	80	1	1	5
Bi-Ax, Slen, δ	Bi-Ax, Mc1, 0.7 <= δ <= 0.9, blank	B, M, δ	0.90	0.90	0.70		410	410	410	-50	-50			
OUTPUT	CODE OF PRACTICE	BS, EC2	EC2	EC2	EC2	EC2	EC2	EC2	BS	EC2	EC2	EC2	BS	EC2
Results	Ult Shr or Tor / Cap at xD	Shr,Tor	0.72	1.00	1.00	0.17	1.00	1.00	0.50	0.50	0.67	1.08	0.97	0.68
	Ult (Axial & Moment) / Cap	N & M	0.34	0.94	1.00	0.54	1.00	1.00	0.94	0.95	0.99	0.00	0.00	0.15
	Serv F1 Crack Width or Info	W1	0.128	0.405	0.201	0.000	0.231	0.241	0.270	0.001	0.006	0.003	0.000	0.062
	Serv F2 Crack Width or Info	W2	Mt=Mc	Mt=Mc	Mt>Mc	0.000	21.8	21.6	18.9	SLEN	SLEN	0.000	0.000	0.048
	X - serv or ult - refers to input	X	89	63	113	1058	280	341	338	233	227	80	77	17
Values	Fs1 N/mm²	Fs1	-435	-435	-435	264	-379	-393	-403	-33	-52	-435	-435	-435
	Fs2 N/mm²	Fs2	197	37	300	402	418	418	418	418	418	62	30	-435
	S transv / D	St / D	0.47	0.39	0.40	0.30	0.56	0.38	0.38	0.41	0.41	0.57	0.57	0.61
	Sp/(Dx20xSys)	Span / D	2.000	1.164	0.726	2.000	1.410	1.415	1.019	2.000	2.000	2.000	>2	2.000
	%AsLegs / BSr	%AsL	0.105	0.175	0.175	0.224	0.131	0.157	0.157	0.262	0.262	0.349	0.349	0.349
	θ, (Mb/Mr)ᵃ, MEd	θ, Bi, MEd	21.8	21.8	21.8	21.8	0.564	0.434	45	116.55	124.43	45	45	29.8
	% As1 / BH	%As1	0.654	0.465	1.861	0.255	1.072	1.072	1.072	1.787	1.787	0.272	0.272	1.090
	lap / (φx(α6/αd))	Lap	64	41	56	54	49	49	44	52	52	61	20	49
	EC2 Shr Shift	a1	602	437	425	439	404	494	N/A	275	110	487	N/A	194
Data	Reinf Area of F1 & F1+ (mm²)	As1	3927	1257	5027	402	3217	3217	3217	1608	1608	982	982	3272
	Equivalent Effective Depth	D	536	388	378	390	359	439	439	244	244	528	528	248
	Max Full Thickness Crack or Teff	Wk1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Min Forces % As1 / BZ	nkc ρCrit	0.232	0.232	0.232	0.000	0.000	0.000	N/A	0.000	0.000	0.232	N/A	0.346
	EC2 Face 1 Bond Condition	Bond	Poor	Good	Good	Good	Good	Good	N/A	Good	Good	Poor	N/A	Good
Shrinkage	Zone Depth (BS) or k z H (EC2)	Z	255	208	208	208	225	255	250	150	150	255	250	150
	T1 or ΔT	T1, ΔT	29.7	24.0	24.0	27.1	28.6	31.3	29.1	21.5	18.9	29.7	24.4	21.5
	Drying Shrinkage μStrain	μεcd	138	142	142	142	141	138	138	145	145	138	138	145
	F1 Crack Width or Uncracked με	W , με	0.165	0.196	0.130	0.278	0.161	0.148	0.195	0.082	0.084	0.378	0.407	0.130
	Min Shrinkage % As1 / BZ	kc ρCrit	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	% As1 / BZ	%As1	1.54	1.01	4.03	0.55	1.79	1.89	1.93	3.57	3.57	0.64	0.65	2.18
	Creep Coefficient (CC)	φ(∞,to)	1.52	1.54	1.54	1.54	1.53	1.52	1.52	1.57	1.57	1.52	1.52	1.57

Howes Atkinson Crowder LLP	EC2 DESIGN TOOL	Project Info	
	MAIN SPREADSHEET 2		
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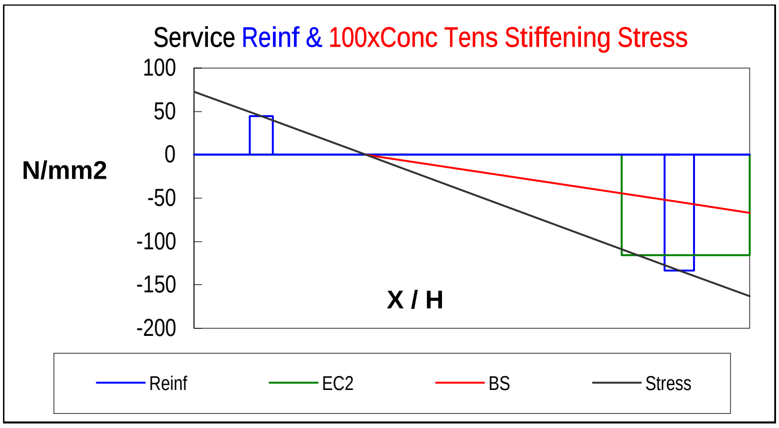
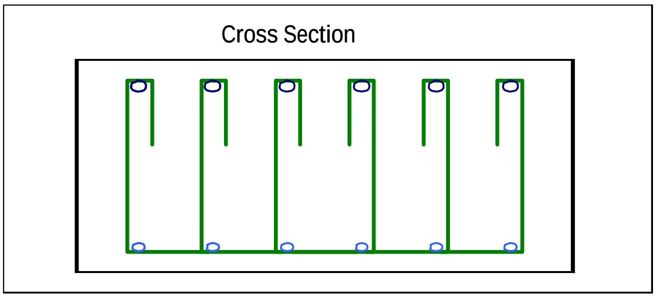
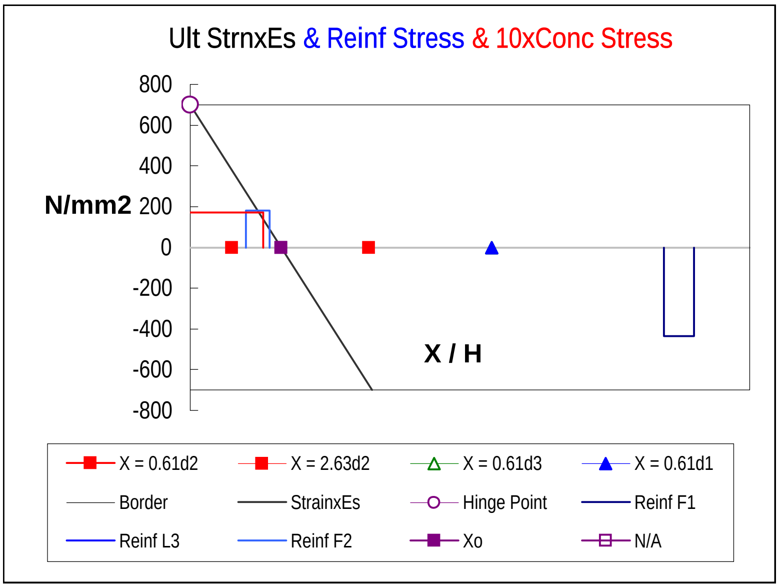
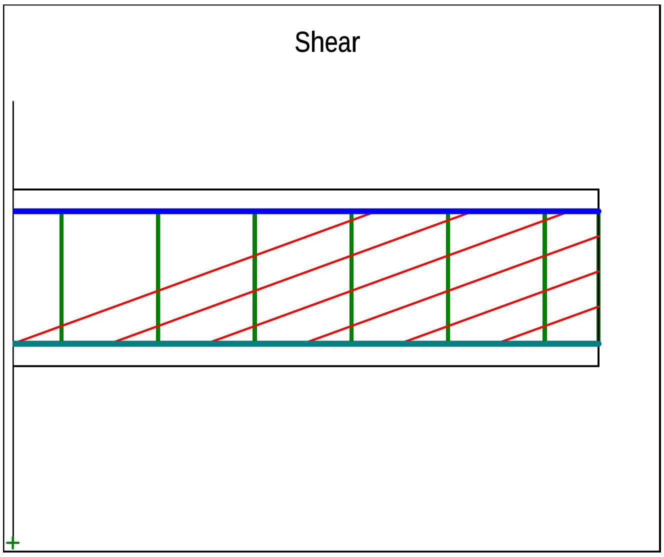
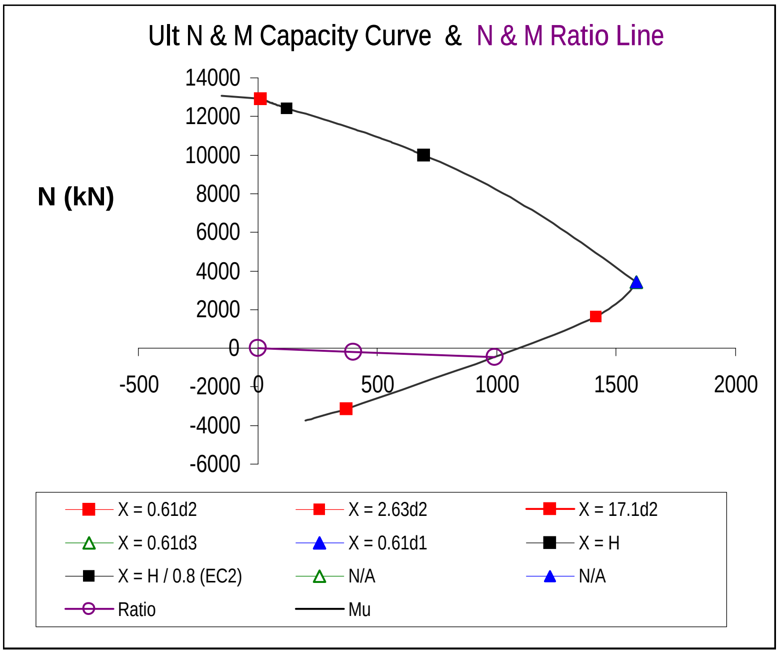
Charts refer to Design Case 1

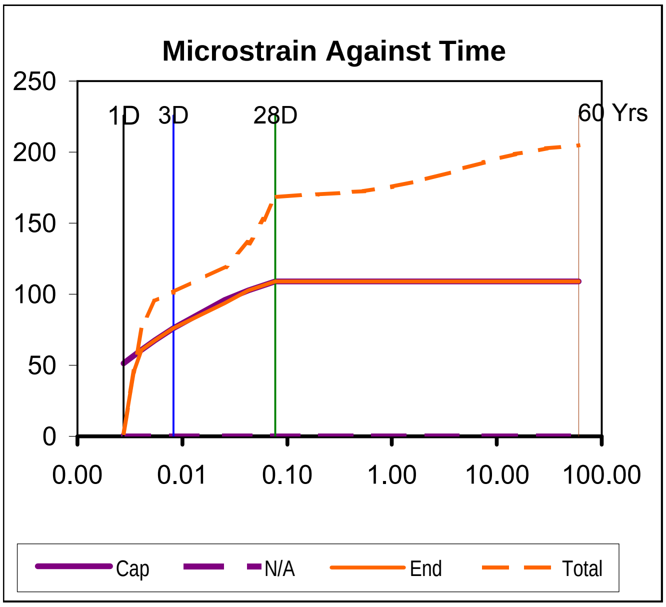


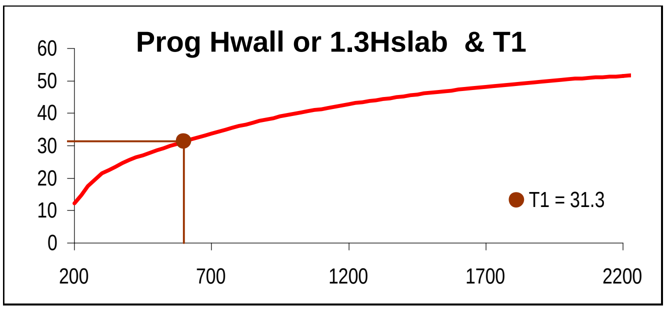












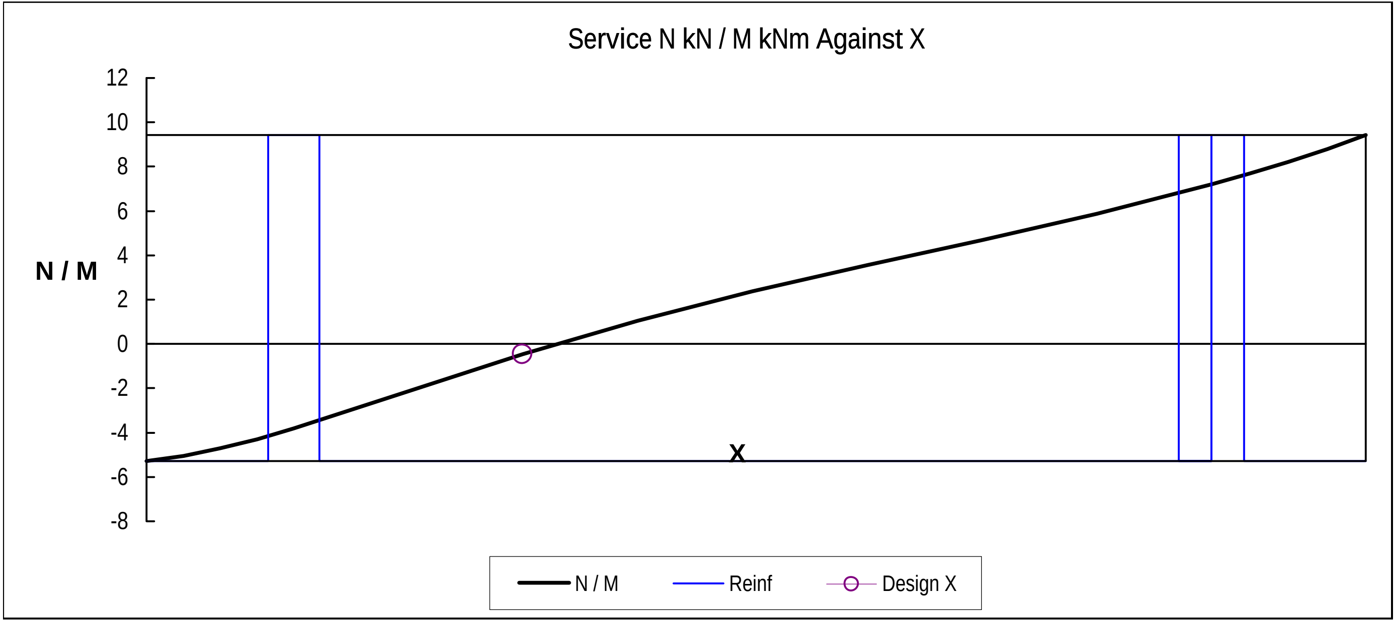
When δ is applied and X = Xu < Xo. This creates a kink in the N - M ratio line. This occurs when Tension Capacity > Compression Capacity.

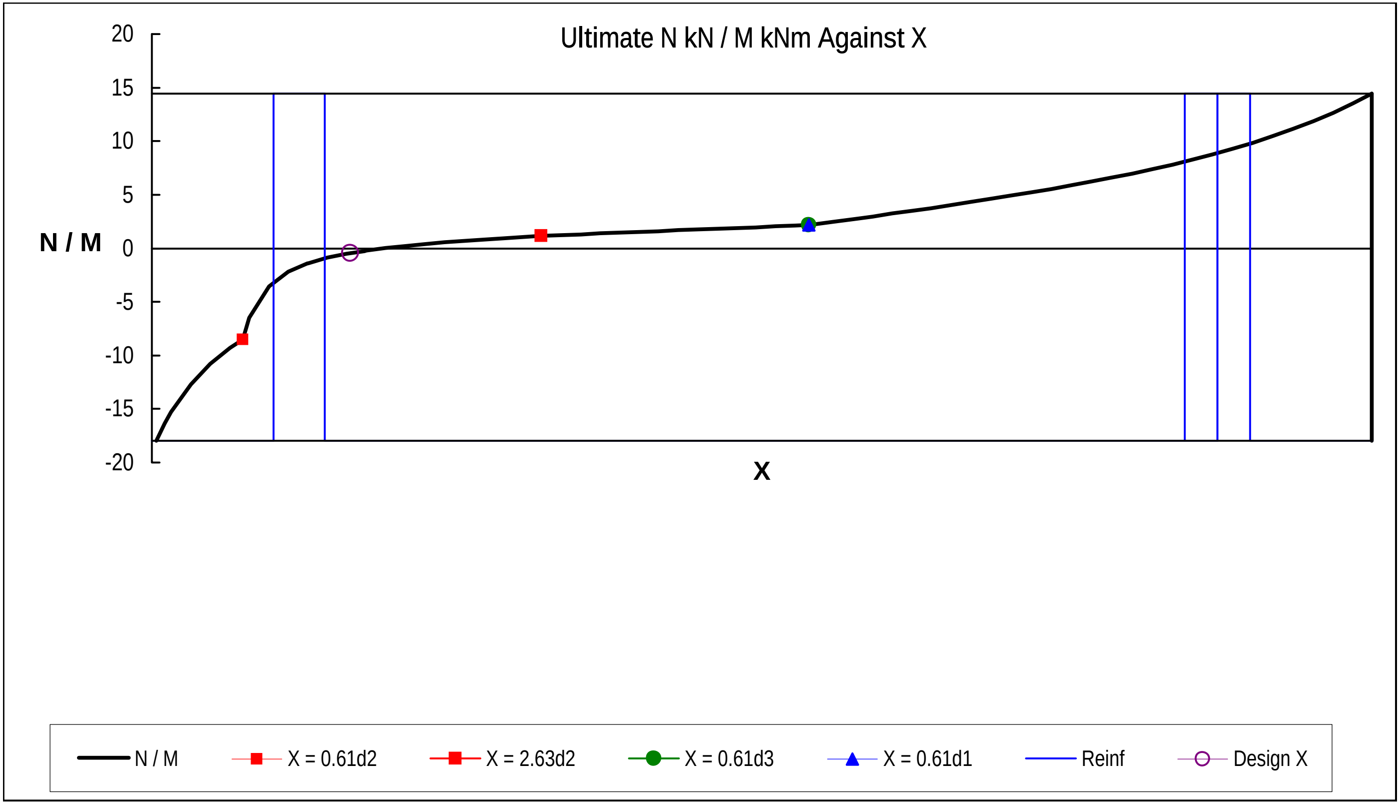
Charts refer to Design Case **1**

N / M Against X Curves

The following two charts show the cubic equation curves of N/M plotted against X between X = 0 & X = H for service and ultimate methods for the same design.

The normally used M/N = Ecc term has been inverted. As M reduces to zero, N/M approaches infinity beyond X = H when N is positive or at X = 0 or less when N is negative. Both curves intersect the axis between X = 0 & X = H when N = 0 i.e. pure flexure.





INFORMATION FROM COMMENT BOXES

GLOBAL INPUT

Reinforcement

Grade N/mm²
Yield Strength. Commonly 500 for HY and 250 for MS. Note:- Young's Modulus is fixed at 200 kN / mm²

Class - A, B or C
Determines Ductility and other properties. See CARES literature. Grade A is cold rolled and has low ductility. Grade B can be Micro-Alloy, Quench and Self Temper (QST) or Cold Stretched. Grade C can be Micro-Alloy or QST. Grades B or C should be chosen if any redistribution is likely. The key properties are:-

Class / Grade	Yield Stress N/mm²	Tensile / Yield ratio	Elongation Agt(5)
500 A	500	1.05	2.5
500 B	500	1.08	5.0
500 C	500	1.15	7.5

Rib Profile - D2 or PR
D2 = Deformed Type 2 or PR = Plain Round

Material Partial Safety Factor - γs
Factor of Safety For material. Typically 1.15 for Grade 500 and 1.05 for Grade 460 (Gives approx same result)

Service Stress Max Value Factor - k3
Sets a factor for an alert value on the maximum service stress as a K3 factor x Fyk. Max Value equals 0.8. See Cl 7.2

Concrete

28 Day Cube - Fck, cube N/mm²
Enter Required 28 Day Cube Strength. Program will calculate the Cylinder Strength. NOTE The cube value is always greater than the cylinder value. Specification is Cylinder / Cube. See Output. Be vigilant. Serious errors can be made.

Material Partial Safety Factor - γc
Factor of Safety for material, Typically 1.5

Exposure Class - XC, XD, XS

XC = Carbonation	**XD = Chlorides**	**XS = Sea Salts**
XC1 Dry or permanently wet	XD1 Moderate humidity	XS1 To airborne salt but not in direct contact with sea water
XC2 Wet, rarely dry	XD2 Wet, rarely dry	XS2 Permanently submerged
XC3&4 Moderate humidity or cyclic wet and dry	XD3 Cyclic wet and dry	XS3 Tidal, splash and spray zones

See BS EN 206-1:2000 for more details.

EC2 Pt3 Liquid Tightness Class

0	For no control	1	For standard compliance.
2	For very high control (max<=0.05mm)	3	For ultimate control (generally only achievable with Post/ Pre Tensioning).

NOTE:- EC2 Pt 3 suggests zero full depth crack width to satisfy Class 2. Note the term full depth. EC2 specifies that unless at least 20% of the section is in compression (i.e. X serv equals 0.2H or 50mm), it is considered to be full depth. This will seriously affect high tension elements such as circular walls. It will also apply to any full depth thermal cracks. CIRIA C660 Cl 2.6 suggests that a 0.05mm crack or less will self seal even with a pressure head of 35 or more. It therefore seems reasonable to set a max of 0.05 reducing to 0.025m at a head of 35 for class 2 rather than 0. If in doubt use Class 3.
However, if the value of X is greater than 0.2H or 50mm it may be acceptable to use a 0.3mm crack width.

Additional Wk1 % Active
EC3 and C660 defaults at WK1 actively increasing by 30% and back once a day. Enter 30 or 20 or 10. Agree with Client.

Crack Width Alert Value
Service crack width which triggers a red alert in the output

Cont.

INFORMATION FROM COMMENT BOXES

Concrete Cont.

Slender Method - NC or NS

Sets the EC2 method of slender column or strut design. Enter NC for Nominal Curvature or NS for Nominal Stiffness. The nominal curvature method is similar to the BS8110 method and is recommended.

Minimum Lap Length x dia

Minimum lap used in detailing. Greater values are shown in the output when requited.

Load Duration - Long (L) or Short (S)

L equals Long, S equals Short. This will affect crack widths as short term loading allows 50% more tension stiffening than long term. Normally L is specified. This could possibly be used at testing.

Design Life (DL) in yrs

Specifications often call for 60 years even though the code only gives values for 50 yrs or 100 yrs. The program interpolates between the two values. Enter value followed by Y i.e. 60Y

Cover Permitted Deviation

This is the tolerance allowed to the contractor when checking compliance against the specified cover on site. Other minimum specifications should be consulted and questions should be asked about site checking before accepting use of full tolerance.

Design Service Stress / fck Limit Factor - k

This is the value used in the service design to limit compressive stress. The stress willl display in the W2 ouput if this value is exceeded. It does not take account of the Non Linear Creep Coefficient as the non linearity will only occur beyond 0.45fck. See Cl 3.1.4. The increase in CC for K1 up to 0.6 is not significant but results in an increased Modular Ratio and slightly smaller crack widths. This program uses an upper limit of 0.6 but defaults to 0.45.

Creep Coefficient (CC) used in MR or Auto

This allows the user to over-ride the Local Auto calculation so that the values can be checked against traditional / previous methods. CC is used in calculating Modular Ratio (MR), where MR equals Es / (Ec/(1+CC)). Enter a value as described below OR enter Auto. It has been common practice to use CC equals 1 for flexure and tension crack width design. This will therefore half the value of Ec. So a typical MR would be 210 / (28 / 2) i.e. 15 but note EC2 Ec is higher than BS value.
However, a higher value may be appropriate for structures designed to ultimate criteria in order to check deflection serviceability. The EC2 Creep Coefficient (CC) values are displayed below and these values should be used. Typically a CC of 1.5 is more appropriate than 1.0. This results in adjusting the EC by dividing by 2.5. i.e. Eceff in analysis equals 0.4EC.
The effect on the crack widths between using CC of 1 or 1.5 is negligible on EC2 designs but can increase crack widths by approx 3% to BS designs. In water retaining structures the high relative humidity and lower average ambient (15 deg rather than 20 deg) will reduce the CC to below 1.5 in many cases. A factor of 1.5 rather than 1 may be more appropriate.

Age At Loading - days (to) for Auto CC or N/A

Age at first loading for the purposes of calculating the Creep Coefficient automatically. Often the first loading is not as much as the full loading and will only support Self Weight. CC is used for deflection even if it is fixed for MR. i.e. ValueD or ValueY.

Creep Coefficient (CC) Final Age For Auto CC or Max or N/A

Typically taken as Infinity or 1 Million for $\varphi(\infty, t0)$ if Max is entered but a lower value i.e. the design life may be entered. Note:- Table 3.1 does not match the Annex B values where fcm<35 (fcu<33) N/mm2. CC is used for deflection. ValueD or ValueY

Design Check Age - Days (t) or Years

Age at which the design is checked. The usual default is 28D but the user can check earlier or later (crack widths only). This alters the strength of the concrete in tension and hence the stiffening effect. A value more than 28 days will increase the stiffening by about 17%. A value of 3 days will reduce it by 40%. EC2 does not allow the use of an increase in compressive strength beyond 28 days to avoid retrospective validation of designs using higher strengths. Enter ValueD or ValueY
Early loading may occur in high rise construction. Once a crack occurs it will remain there. This is very useful for testing the strength before removing props or for supporting construction loads such as props and floors above.
Certain global values such as %As1 and AsL values are not altered. Thermal values are not altered because they are checked at 3 days and 28 days anyway and appropriate fctm and E values are used (the latter with no creep ratio factor). Tension strength for service moment and axial design is adjusted accordingly which means the tension stiffening will be less.

Cont.

INFORMATION FROM COMMENT BOXES

Design Check Age - Days (t) or Years Cont.

EC2 & BS

The values of fck are fcm(t) -8 between 3 and 28 days and fck thereafter. This will reduce the value of fcd accordingly.
For normal strength gain cements:- fcm (t) equals βcc(t) fcm where Ecm(t) equals ((fcm(t) / fcm)^0.3)^0.3 Ecm
βcc(t) equals exp ((0.25 (1 - ((28 / t)^0.25))) fctm (t) equals ((βcc (t))^(1 if t <28 or 2/3 if T >28)) fctm
Therefore the variation in Ecm is much less than fctm with the concrete reaching 86% of Ec28 but only 60% of fcm at 3 days. The reduction in Ecm will affect the Young's modulus used in the service design.

Formwork Striking

Section 6.2.6.3.2 of BS8110 advises that the concrete strength should be 10 N/mm2 or twice the stress it will be subjected i.e. if the material FOS is 1.5 and the load FOS is 1.4, 1.5 x 1.4 = 2.1 so a 5% temp reduction is adopted. This program can be used if Load Factor is set to 1.33 and the ultimate forces are entered. However, note that the 3 day value is 60% of the 28 day value which will exceed 10 N/mm2. Therefore, in order to check the design, the basic Fcu value should be reduced accordingly. i.e. use 20 N/mm2 and t=2 to reproduce 10 N/mm2 etc. The strength should always be verified by cube testing. Also ensure that any deflections and cracks are not excessive as these will be locked into the element for ever. The deflections would be based on the early age Young's Modulus. This is 86% of the 28 day value at 3 days and 81% at 2 days (note how fast the E value rises) so will be less inhibiting than the cracking. The crack prediction formulae will be based on a lower tensile strength of concrete which will reduce the tension stiffening and will therefore create proportionally greater cracking so beware if this is critical such as in the soffi

Binder

Strength Gain Class - R or N or S

Can be considered as R = Rapid or N = Normal or S = Slow Ref Cl 3.1.2 (6). Usual value is N
Also refer to Table A.1 of BS8500 - 2:2006 which is the Complimentary Standard to BSEN 206 - 1 Part 2 - 2006 - see Refs.
CEM 42.5R, CEM52.5N & CEM52.5R should achieve a cube strength >= 20 N/mm² at 3 days and are Class R
CEM 32.5R, CEM 42.5N should achieve a cube strength >= 10 N/mm² at 3 days and are Class N
CEM 32.5N should achieve a cube strength >= 16 N/mm² at 7 days and is Class S
The BCA document “Modern Cements and How to Specify Them” uses the following definitions for the suffixes used above:-
R = High early strength N = Normal strength development L = Low early strength
EC2 re-groups these according to the actual strengths achieved and does not define what R, N and S stand for. One would normally use Class N for water retaining structures as this gives the best compromise. Use of R may give a better 3 day strength and hence strain resistance but at the expense of a higher heat of hydration.

Total Content Kg/m³

This is the TOTAL amount i.e. (PC or SRPC) + (GGBS or PFA).

W / C Ratio

This will affect strength and durability and cover. Low values may affect workability.

PC or SRPC

PC = Portland Cement, SRPC = Sulfate Resisting Portland Cement

GGBS %

Ground Granulated Blastfurnace Slag - Often 50% but can be more in some circumstances. Will help reduce heat of hydration.

Or PFA %

Pulverised Fly Ash. This will help reduce the heat of hydration but is not as effective as GGBS. CIRIA C660 values are taken from the charts within the document. CIRIA 91 Method is as follows
For a 360kg/m3 OPC mix, it will be nec to use a higher total blended amount say 390kg/m3. BS8007 places a max of 35% PFA. If the mix has 275 Kg/m3 of OPC and 115 Kg/m3 of PFA, the program calculates T1 based on 275 kg/m3 OPC and then adds the specified concrete placing temp which is taken as the curing temp (usually 5 deg above the ambient). This combined temperature is then used to calculate the extra temp rise due to PFA as follows

Peak Combined Temperature	Add Temperature Due To PFA
<= 20	0
30	1.0
40	2.5
50	4.0
60	5.5
70	7.0
80	8.5

Cont.

INFORMATION FROM COMMENT BOXES

Concrete Cont.

Aggregate
Common Aggregates. The modulus, strain capacity and coefficient of expansion relate to the type of Aggregate.

Ec28
EC2 28 Day Modulus in kN/mm²

µε 28
Ult Tensile Microstrain Capacity at 28 days

α x 10E-6
Coefficient of Expansion Ref CIRIA 660

%
Adjust % to suit the aggregate used. It is often a mix. Total must = 100%

Aggregate Size mm
Maximum Aggregate size. One of the factors that determines the bar spacing and the gap for third layer. Variation in required for minimum binder content in kg / m3 for mixes with various W/C ratios and Max Agg sizes are as below. if you decrease the aggregate size you may need to increase the cement content to maintain equivalence which in turn leads to more cracking.

W / C ratio	20mm	40mm	14mm	10mm
0.6	280	-20	+20	+40
0.55	300 - 320	-20	+20	+40
0.5	320 - 340	-20	+20	+40
0.45	340 - 360	-20	+20	+20

Thermal & Drying & Creep

Mean Daily Temp Tm
UK value is taken as 15 deg as a mean day and night summer value. Enter an appropriate value for non UK work

Concrete Placing Temp Tp
UK normal value is 20 deg so Tp - Tm = 5 deg. T1 change is approx 75% x (Tp - Tm). Select Tp & Tm appropriate to the location. To CIRIA 91, with PFA additive, this is the concrete curing temp that must be added to the T1 calculated using the OPC part of the mix .

Min T1 Values Apply to EC2 **C660 αct Factor**
BS8007 and C91 impose minimum T1 = 15 deg for Slabs and 20 deg for Walls whereas EC2 and C660 does not. This option allows these values to be applied to EC2 and C660. A concrete in tension αct factor of 0.8 is recommended by P Bamforth.

Long Term (LT) Drying Period (DP) In Years
Period for Ultimate Long Term Drying Shrinkage and Thermal and Autogenous strain. This value can be adjusted separately from Design Life to show the effects. Beyond 30 years the drying shrinkage is small but the worst effect is still the Design Life (if > 30 yrs).

LT fctm & εcap based on 28D or nr of Years
C660 examples use the 28 Day values for Long Term design check. This facility allows a similar design approach but also allows the user to see what happens if the higher LT values are used. Note. blended mixes can develop high LT strengths.

Edge Restr Min Age for Min %As1/BZ Value 3D, 28D, LT
User can specify a minimum age that is used for calculating the Minimum %As1 / BZ for Edge Restraint Shrinkage. The earliest (default) age is 3D. For Edge Restraint, the Min% relates to the age at first cracking. These cracks then increase in width with more strain at later age.

End Restr Min Age for Min %As1/BZ Value 3D, 28D, LT
User can specify a minimum age that is used for calculating the Minimum %As1 / BZ for End Restraint. 28D or LT is suggested for End Restraint. This is because individual End Restraint cracks can form at later ages, so the age at last cracking determines the Min%.

Fatigue

Cycles x 10E6 or N/A
Frequency of oscillation x 10E6 or N/A if no Fatigue. i.e. for 4E6 enter 4. High values will reduce allowable fatigue stress range.

σ Min / Max or N/A
Program calculates the ratio of the oscillating stress range to the maximum stress (tension or compresion). So if σmin / σmax = 0.9, 10% of the stress range oscillates. The program shows the allowable ult reinforcement fatigue induced stress range Δσsk as per Fig 6.30 and then adjusts Fyk and Fyd to ensure this is not exceeded. Concrete Ult 28 day strength is reduced as per Equs 6.76 & 6.77.

Cont.

INFORMATION FROM COMMENT BOXES

GLOBAL OUTPUT

Reinforcement

Fyk - Yield Stress - N/mm²
This is the Yield Stress used in design which may be reduced by fatigue.

Fyd - Max Stress - N/mm²
The value used in ult design taking into account material FOS.

Δσsk - Fatigue Reduced Stress - N/mm²
The part of the steel stress range that is subject to fatigue reduction.

k3 Fyk - Max Service Stress - N/mm²
Max Service Stress Value = k3 x Fyk.
The program will display a value above this in red in the W1 Crack Width box.

Concrete

Type
A standard concrete binder mix notation. This is used in assessing durability and cover. The procedure is quite complex but the program works this out and displays it here.

Nominal Cover
This is the minimum value specified to the contractor on the drawings. Normally this will be increased to the next 5mm but check other code requirements.

C fck / fcu(t)
Cylinder / Cube Strengths in N/mm2 allowing for fatigue and time from casting. For t < 28 days this will be equivalent strengths used in analysis. This feature allows the display of strengths at different ages.

EC2 , BS Ec (t)
EC2, BS Equivalent static Concrete Modulus in KN / mm2 at time t in days. Based on the 28 day cube strength input value.
The values have also been adjusted for fatigue if relevant. They have not been adjusted for Creep.
See MR Creep Ratio item for reduction used in Applied Forces Crack calculations

EC2 , BS MR (t)
Modular Ratio used in service forces analysis to calculate crack widths = Es / (Ec/(1+Creep Coefficient)) or Local Values
EC2 & BS values. Early age values will be slightly higher than 28 day values.
Note 1: The difference between EC2 and BS values means the service analysis results, i.e. Neutral Axis X and reinforcement stresses and strains are slightly different.
Note 2. Econc value used to calculate MR includes a creep ratio value. If this is 1.0 the Ec value is halved and the MR values are similar to traditional values. However there could be a case for using the EC2 Creep Coeff values below which are closer to 1.5 in some cases. If Local is entered for CC value, the actual calculated local value of CC is used.

EC2 , BS %As1/BH
EC2, BS min As1 %
This is As1 (which is F1 & F1+ reinf) / BH
These are the 28 day values, since the design will be based on those.

EC2 , BS %AsL/BSr
EC2, BS Min %Area for shear legs on plan = Area of leg / (Spacing in Longitudinal Dir x Spacing in Transverse Direction)
These values are based on the 28 day concrete properties

EC2 , BS Min Lap
EC2, BS Code Minimum which may be less than the value specified in the Global Input.
Note this is based on the assumption of good bond.
These values are based on the 28 day strength stress values. The values in the design cases will be based on the reduced stresses. Obviously, the loading in early days will be less than at 28 days and after.

Cont.

INFORMATION FROM COMMENT BOXES

Concrete Cont.

EC2 , BS Max Shr

EC2, BS Max shear at Column Support Face. Note EC2 gives a higher value than BS8007 for the same strength (as a result of the National Annexe value for αc). See below.
EC2 also allows higher strengths than 32 / 40 to be considered in Shear design whereas BS8110 does not. Therefore it is possible that the use of higher strengths may become more commonplace under EC2 for non crack sensitive structures.
Note:- higher strength means more cement = higher risk of cracking which is therefore problematic for water retaining or excluding structures.
For EC2 design, this program uses a value of 1.0 for αc for shear as per the National Annexe. (0.85 is used for flexure and compression).
These values are based on the stresses allowable at time t.

3 Day , 28 Day & Long Term Ult Tensile fct

3Day, 28 Day & Long Term Ultimate Tensile Strength in N/mm2

3 Day , 28 Day & Long Term Ultimate Ten με

3Day, 28Day & Long Term Ultimate Tensile MicroStrain Capacity. This is determined by Aggregate type and strength.

3 Day , 28 Day & Long term Autog με

3Day, 28Day & Long Term Autogenous Shrinkage MicroStrain
This is the shrinkage as a result of the concrete setting. It is not a temperature or drying strain. The chemical reaction results in a small change in volume.

Linear or Design or Max Service σ Limits

Linear & Design & Max Service Stress Value
(k2 or K or K1) x Fck

Above k2 x fck (i.e. 0.45) a non linear creep factor should normally be applied to the basic creep coefficient.

This will in turn increase the Modular Ratio and reduce the crack widths by 0.1%. i.e. 0.2mm becomes 0.198mm - negligible difference.

Since the max NLCF is 1.252 at 0.6fck it is sufficiently accurate to use the linear value throughout as it is not practical or worthwhile to introduce non linearity into this spreadsheet.

This will give the correct values within the crack width assessment range.

Bearing in mind a fixed value of 1.0 is often proposed for the CC, the loss of accuracy is not significant.

The chart on the N & M sheet has the option to switch the non linearity beyond 0.45fck on or off so the effect can be seen.

Thermal & Creep

C660 Creep Coefficient K1

This is the value used for thermal calculations as opposed to flexural calculations. This is equivalent to reducing the restrained strain by 35%, See C660 Cl 4.9.1.

C660 Sust Load Coeff K2

This is the early age value that has been incorporated into the C660 equations.

C91 GGBS T1 Factor Used

Factor which has been used in the C91 method to multiply the Full OPC T1 value as a result of effects due to GGBS. It is displayed for information. PFA is calculated in a different way, see PFA comment box.

Aggregate α x 10E-6

Average Aggregate coefficient of expansion

Cont.

INFORMATION FROM COMMENT BOXES

Thermal & Creep Cont.

C660 Bond Factor fct / fb

Thermal reinf bond factor as per C660. This is the ratio of tensile strength / bond strength. EC2 suggests 0.8 where good bond is achieved and 0.8 / 0.7 i.e. 1.14 if that cannot be guaranteed. C660 uses the higher value. This factor is included to allow benchmarking against BS8007. You must use 1.14 to comply with CIRIA C660.

3 Day, 28 Day, LT ρcrit %As / BZ

Minimum default value per BS8007 Zone or EC2 k z H i.e. Z. These values are used where crack width control due to Indirect Actions (Shrinkage) is required. Otherwise use the values in the Concrete section above. For C660 these zones are as per table 3.1. See comment against Zone Depth. The Min % is 100 x the ratio between the 3 Day or 28 day or LT Concrete Tensile Strength and Reinforcement Grade (Typically 500 for HYS). There is very little difference between BS and EC2. The value appropriate to the time of first cracking for Edge restraint and the latest crack age for End Restraint is used. The 28 day value should be used unless 3 day cracking is absolutely certain. For Internal Restraint, the 3 Day values are used. These values are then multiplied by the Stress Distribution Factor kc for As1 / BZ compliance check. For End and Edge Restraint, kc = 1, for Internal Restraint kc = 0.5 See Crack Section for a fuller explanation.

Design Check Age (t) ρcrit %As / BZ

EC2 only. Minimum default value for Direct Actions i.e. Forces. The value appropriate to the specified design age (t) is shown. The normal age for Direct Actions (M & N) is 28 days. These values should then be multiplied by the Stress Distribution Factor kc for As1 / BZ compliance. The kc value for Direct Actions will vary from a min of 0 for High Compression to 0.4 for No Axial to a max of 1.0 for High Tension. See Crack Section for a fuller explanation.

LOCAL INPUT

Design

Input - S=Service U=Ultimate

It does not matter which you choose. The input is usually Service for a water retaining or excluding structure. Ultimate would normally be chosen for ordinary design. See Load Factor comment.

Load Factor = Ult / Serv

The ratio between factored forces and service forces for the Design Case considered. This allows both Service and Ultimate Designs to be carried out at the same time. This would be a composite value where there is a mix of Dead and Super Loading. If the design is not crack critical and the loads are entered in ultimate, a reasonable estimate would be acceptable i.e. 1.5 for offices and 1.45 for domestic.

Head of Liquid or N/A

This is used with the global tightness class in EC2 Pt3 to calculate the allowable crack width based on a ratio between head and section thickness (H). For designs where this is not relevant enter N/A.

Col - Leff or Bi-Ax or N/A

Effective length taking into account end conditions. See cl 5.8.3.2 (2). Max = 2l Min = 0.5l. If bi-axial or slenderness assessment is not applicable enter N/A. A slender column or strut assessment will only be undertaken if a value is entered here. Leff notation is used to avoid confusions between codes (BS L = lo, Leff = le, EC2 L = l, Leff = lo). Enter Bi-Ax if a bi-axial analysis is required. This tells the program to consider the additional moment as a bi-axial moment.

Restraint

C91 or Edge, End, Int (C660)

If C660 method is used, enter End or Edge or Int (for Internal) restraint. The T1 values and thermal / shrinkage crack width design will be based on this type of restraint. If C91 method and T1 values are used, enter C91. C660 has been written to be used with an EC2 based design and C91 should really be used with a BS design but either can be used in this spreadsheet FOR COMPARATIVE PURPOSES ONLY during the familiarisation process. C91 should not be used with a commercial EC2 design. However it is permissible (and even advisable) to use C660 with BS designs now. However the large amount of reinforcement that is required with the End restraint method must be pointed out to and discussed with the client.

Cont.

INFORMATION FROM COMMENT BOXES

Design Cont.

End Restrained Length Lr or N/A

End Restrained Length Lr or N/A. This will allow the length of the section to be taken into account in calculationg the end restraint crack width. For an infinite length enter N/A. For Edge and Internal restraints enter N/A.

Short Term Restraint - R1

The restraint that exists while the concrete is curing.
This is usually safely taken as a max of 0.5 for full restraint to BS8007 / CIRIA 91 because it includes a creep factor =0.5..
C660 procedure is more sophisticated and reference must be made to C660 however, the same concept is continued but 1.0 = Maximum for end restraint but see below for edge restraint. C660 then applies a creep factor of typically 0.65.
C660 End Restraint gives high crack width values compared to C91 and since the cracked section crack widths are dependent on the tensile strength of the concrete, the adjustment of restraints does not make any difference unless the section is uncracked.
TheC660 Edge restraint gives similar values to C91 & BS8007 for similar R x creep values. but note that R will be higher than 0.5 for a thin wall cast against a large foundation if the edge restraint formula is used. i.e Rjoint = 1 / (1 +((New ht x New H)/(Exist Width x Exist Depth))x(New Ec / Old Ec))
4.7.2 allows a simpler approach and takes New Ec / Existing Ec to be 0.7 i.e.
For a wall cast against the edge of a slab or For a slab cast against a slab
Rj = 1 / (1 + 0.7 x (New H / Old H))
For a wall cast remote from the edge of a slab
Rj = 1 / (1 + 0.7 x (New H /2x Old H)) i.e. the existing slab depth is doubled.

T2 / 28 day Restraint - R2

The restraint after seasonal temp drop which is taken at 28 days. This can be less than the short term value particularly in the vertical direction for walls where there will be no restraint from previous pours and the whole structure will move together and may even be in compression all the time. However if the structure is not likely to be complete, R2 should = R1.

Long Term Restraint - R3

The Restraint of the completed structure. This the Long Term Restraint that will be present during the drying phase. This can be different to R1 or R2.

Formwork - Grnd, Ply, Steel

The formwork used or if it is cast against ground. This effects the T1 value.

Drying Faces & Relative Humidity %

This controls the drying shrinkage value. Enter the number of exposed faces followed by the average Relative Humidity % i.e. 1 & 85. If drying only occurs from one face it will be less than if both faces are exposed. If a value of 1 is entered, ho = 2H. The average %Rh value is used taking into account the conditions on each face. The water retaining face would be at 100% Rh whereas the other face could be within a building at 60% Rh. The value used would be 80%. The common UK value for external use is 85% and for a dry internal environment it could be as low as 45%.

Curing Temp - Value or Auto

The program can calculate the T1 values according to BS8007 & C91 or C660 within 5%. C660 introduces different methods for calculating T1. These values differ from C91 slightly in respect of walls but more so for slabs where the results are typically 20% higher.
In order to design to C660 the C660 value must be used. The data from the published charts for Ply and Steel for Cem1, GGBS and PFA has been entered manually (a lengthy process). The variations in temperature values appears to vary between 220 kg/m3 and 500 kg/m3 in a linear and even manner so the values have been interpolated to create a bespoke single curve appropriate to the binder mix and formwork and this is displayed as a chart and used to calculate T1. Note, in the case of a slab, the wall & steel curve has been shifted to reflect the fact that the thickness of the slab is multiplied by 1.3 before calculating the T1. So the slab thickness appropriate to the wall curve will be thickness / 1.3.
Therefore the user has a choice.
If you want the program to calculate and use the appropriate Ciria values enter Auto.
If you want to have control over T1 and use another program or the Ciria document or program directly, enter the value.
IF H slab > 800 or H wall > 1000 Calculate T1 using CIRIA 660 adiabatic based Spreadsheet.

Seasonal Temperature Drop

The worst case is summer concreting and this must be assumed unless it can be guaranteed otherwise i.e. very short lead in. The UK drop is usually taken as 20 deg for externally exposed elements and 15 deg for internal or cast against the ground. Worse conditions can occur in the UK for short periods. The program assumes this drop to occur by 28 days.

Cont.

INFORMATION FROM COMMENT BOXES

Section

Type - Slab, Beam, Wall, Col
The type of section will effect the thermal calculation.
The selection of Beam will show a top closer link.
The selection of column will show a link all round and an intermediate cross link if centre bars are specified.

Face 1 - top, bot, int, ext, any
Face 1 is the face that is in Tension due to bending only. It defines the location of bars, cover and results. In the case of slabs it affects the zone depth and hence the crack width.

Depth H
The overall section depth

Width B
The overall section width. For a column and beam this would be the exact width on the drawing and the reinf and legs should, ideally be specified as an exact number (<50). For a slab or a wall, this dimension can be the width used in a grillage analysis (which may not be 1000) or the output width from Finite Element Analysis or other analysis (which would normally be 1000).

Reinforcement

F1 φ or φ1 & φ2 for alt bars
Face 1 bars closest to Face 1. If, for example, 25 and 20 dia alternate bars are used they should be entered thus.
25 & 20 i.e. with a gap between the 5 and & and 2. Min dia is 10

Bar spacing > 49 or nr < 50
Enter spacing or number of bars. The program will assume that a value less than 50 is the exact number of bars. Exact numbers are appropriate for beams and columns where the section width is the real width as opposed to an element width from the analysis of a slab or wall.

Cover to F1 main bars
The distance from F1 bars to F1 concrete face.

F2 φ or φ1 & φ2 for alt bars
Face 2 bars. Alt bars are entered thus for example 20 & 16. (With a gap between the number and &).
Min dia used is 10. If not required enter 0.

Bar spacing > 49 or nr < 50
See comment for Face 1. A value < 50 will be taken as the exact number.

Cover to F2 main bars
The distance from F2 bars to F2 concrete face.

Extra φ or φ1 & φ2 for alt bars
This gives the facility for Extra bars in a third layer L3 or bundled.
Alt bars are entered thus, 20 & 16 (with a gap between the number and &) Min bar size is 10. Or enter 0 if not required.

Bnr, BEnr, Lgap, S1, >3 =Tors
The Type of Extra bars.
B1 = Bundled once with the main F1 bars. BE1 = Bundled once with the main F1 & F2 bars.
B2 = Bundled twice with the main F1 bars BE2 = Bundled twice with the main F1 & F2 bars
Lgap = Bars in 3rd Layer (L3) with a gap in mm. L25 means a 25mm gap. Min is (largest bar or 2/3 Agg Size) x 1.1
S1 = Bars placed at mid depth, one each side. Use in Columns to give 8 bars.
>3 = This adds additional longitudinal bars evenly around the perimeter for Torsion Only

Cont.

INFORMATION FROM COMMENT BOXES

Shear or Torsion or Punching Shear

Shear Type

Normal Shear = S. Punching Shear = P and i for internal, e for edge, c for outer corner, r for re-entrant corner. Torsion = T

Legs - φ or nxφ or φ1 & φ2

Shear Leg dia. If used in longitudinally bundled pairs enter 2xdia if in 3s enter 3xdia. i.e. no gaps. Min dia is 10. For EC2 Punching Shear there is the option of specifying a smaller dia for the alternate dias for the radial bars. This is relevant if additional radials are needed to satisfy %As and tangential spacing rules. The first dia φ1 is for the main shear resisting legs which must satisfy the requirements at 2.0D from the support. The other criteria can usually be met by providing intermediate radials of a smaller dia i.e. φ2. The savings can be worthwhile. If only one dia is entered the intermediate radials will be the same dia as the main radials. For BS enter a single dia which will apply to both failure zone perimeters.

Legs - long or radial ctrs (≤0.75D)

Leg centres measured in direction away from the support = longitudinal for normal shear or BS punching shear or radial for EC2 punching shear. Sr notation is used for both cases. Ensure spacing is not more than 0.75D. If it is, the value of D in the output will say < 1.33Sr. For BS Punching shear the centres must be 0.75D to suit the 0.75D outward interval of failure checks.

Legs - long or radial start (≤0.5D)

Longitudinal or radial distance from support to the first leg. For EC2 this is 0.3D to 0.5D. For BS it must be 0.5D.

Legs - transv ctrs ≥ 50 or nr < 50

Leg Transverse centres or number. For a beam or column or EC2 punching, a number is used. For a slab or BS punching shear, spacing is used. A value > 50 = centres. For EC2 punching, this is the nr to satisfy STRUCTURAL requirements at 2D from the support. Note this is the number of Legs i.e. a link has 2 legs. For BS it is nr or spacing of the inner failure zone

For Punching Shear Only - Legs2 - EC2 - additional transv nr ≤48 or centres > 49

EC2 - nr of additional radials to satisfy min %As and tangential spacing rules. i.e. as the distance from the support increases the spacing increases. For BS it is the nr or spacing of the outer failure zone perimeter (can differ from inner perimeter).

Punch X dim or Strut Angle

For Normal Shear enter Strut Angle in degrees. For EC2 this can be varied between 45 and 21.8 but is usually set at 21.8. It has no effect in BS analysis but a value of 21.8 is suggested to ease switching to and from EC2 and to assist in the detailed comparison sheet. A higher value will reduce the EC2 capacity but will reduce the shear shift value (i.e. the tension reinforcement projection beyond flexure requirements will be less). Therefore for nominal / low shear requirements a higher value is worth considering. This is not adjustable (by EC2) in Punching shear. Reference to EC2 6.4.1 indicates that a value of 26.6 degrees is inferred in the design. This should be used for assessing spread through the section and column heads. see figs 6.17 and 6.18. The shear shift requirement does not apply to punching shear.. For Punching Shear enter Support Dimension X (L to R on dwg) dim or circular support Dia in mm.

Punch Y dim, Dia or Leg Angle

For Normal Shear enter the inclination of the vertical legs. This is used by EC2 but ignored in BS. The usual value is 90 but if the leg is leaned back to the support the value is reduced.. This is not adjustable (within this program) for Punching shear and a value of 90 is used. For Punching Shear enter Y Dim. If a circular support is used type Dia (not the value but the letters Dia).

(V between xD & 2D) / VED = Vratio

EC2 Only. For xD values less than 2.0. EC2 factors normal shear between 2D & xD by a maximum of 0.25 or xD / 2D. This is useful for corbels and pilecap design where the ratio will often be 1.0. For punching shear, it allows the program to assess how much of V is outside 2D so the 2vc at 2D capacity ratio limit can be modified. If not applicable or for BS, enter N/A or 0.

Nr of Effective Depths from Support

xD = Multiples of effective depths from the support to shear check. For Punching Shear, it is generally used to check outward perimeters. The normal shear default is 2.0 but a higher shear cap value (BS only see below for EC2) can be found if the load is closer to the support and a lower xD is used. The value is used in punching shear to check the values outwards or inwards from the control perimeter values (2.0 for EC2 and 1.5 for BS). In both codes the concrete punching shear stress is enhanced within the control perimeter. Note. EC2 deals with normal shear loads within 2D of the support by reducing the load whereas BS enhances the capacity. This program enhances the capacity within 2D for BS. For an EC2 design, if an xD value less than 2.0 is entered, the program uses the Vratio to calculate the Shear between 2D and xD from the support and factors it by a max of 0.5D /2D (i.e. 0.25) or xD / 2D. This is very useful for corbels and pile caps where Vratio = 1.

Cont.

INFORMATION FROM COMMENT BOXES

Shear or Torsion or Punching Shear Cont.

Punch udl w (kN/m²) or EC2 Teff
UDL on slab for punching shear. This value x the area within the perimeter being checked is removed from the applied punching shear load when checking at specified multiples of effective depths from the support. This is particularly useful for a flat slab supporting a head of water or heavy super loading.

Punch MED X - X (kNm) or N/A
Enter an MEDxx value > 2 and the β value is calculated according to BS8110 Cl 3.7.6.2 Equ 25 or EC2 Cl 6.4.3 or Enter Def to make the program use the Default β values according to the location of the columns as per the table on the Main sheet i.e. if Pi is entered β =1.15. or Define a β value <= 2.0 yourself or Enter N/A for normal shear or to set β = 1

Punch MED Y - Y (kNm) or N/A
Column MEDyy Moments. Follow similar procedure to Mxx moments.

Forces

Shr V or Pun (kN) or Tors T (kNM)
Applied Shear, Punching Shear or Torsion Value.
The program calculates and applies the appropriate β value automatically.

Axial Force N (kN) Tens is neg.
Axial Force acting in centre of section.

Primary Moment M (kNm)
The Primary Moment acting about the primary axis causing tension to occur in Face1. A negative value may be entered to demonstrate which side of the element is face 1. In EC2 Biaxial, this value is adjusted until the Cap is 1.0 about each axis. This is also the maximum column moment (MC2) in a slender design.

Bi-Axial, Slender Col MC1 or Redistribution

Bi-Ax or Mc1 (kNm) or 0.7 < δ < 1
If N/A is entered for Leff (effective length) and N = 0 and a δ value > 0.7 or < 1 is entered here it is assumed to be a redistribution factor. If the section is subjected to axial forces (tension or compression), leave blank to ensure the centre line equilibrium method is used. If a value is entered for Leff, the value here will be taken as the lesser end moment value for slender design (MC1). If Bi-Ax is entered for Leff, the value here will be Bi-Axial. If not required leave blank.

Results

Shear - Pun / Capacity at xD or Ult (S or P or T) / Capacity at xD
The applied ultimate value / the ultimate capacity value for Normal Shear or Punching Shear or Torsion. If the input is in Service (S) it is automatically converted to Ultimate by the program using the specified load factor. The Capacity is calculated at a distance of xD (multiple of Effective Depths) from the support. This is particularly relevant for punching shear since the perimeter and hence concrete capacity will increase as xD increases. Normal shear will usually be checked at 2.0D using the full shear value. BS allows an enhancement on the normal shear capacity within 2D but EC2 does not (it reduces the value of loads applied within 2D). See comment about loads within 2.0D for EC2 design in the Effective Depth Multiplier Input box.
For Punching Shear, the capacity is also calculated on the perimeter at the face of the support (Uo) based on the maximum shear stress values displayed in the global output (approx 5 N/mm2 depending on concrete grade). The displayed capacity factor will be based on the minimum of the capacity at Uo or the chosen perimeter, usually U1 (2.0D for EC2 and 1.5D for BS). As a further guide, the output will display Uo Fail if the capacity exceeds 1.0 due to failure at the column head. This is done because this type of failure is catastrophic and also it enables the user to find this value by increasing the shear value until this message appears. Also, if the section fails because of this, no amount of extra reinforcement will help and the slab thickness needs to be increased or a column head is needed or a larger support is needed. This situation can occur with small section driven piles. Also note, EC2 uses the circumference of a circular support as opposed to the enclosing square. The drop in capacity can be seen by switching between Dia and a Y dim value = X dim value.
It is also recommended (by the author) that the capacity factor against failure at the column head for BS designs based on 40 N/mm2 or higher should not exceed 0.90. This is because for BS designs the maximum cube strength that can be used for shear is 40 N/mm2, so if your design is based on 40 N/mm2 you will not be able to use evidence of higher strength on site to improve the situation if you find the design requires any more capacity. This does not come up as an alert.
Note also, that in EC2 punching shear with leg reinforcement, 75% of the concrete without legs resistance is included in assessing the capacity. This is different to normal shear where no contribution is allowed once legs are added.

Cont.

INFORMATION FROM COMMENT BOXES

Results Cont.

Ult (Axial & Moment) / Capacity

The applied ultimate moment / ultimate moment capacity (Mx / Mu) assuming the ultimate capacity ratio of N to M is the same as the applied ratio. It is fully appreciated that a different factor may be found if either N or M are increased separately but as the ratio becomes closer to 1 this is less relevant. This is the only practical way the factor can be displayed in one cell.
This involves projecting the N - M line until it strikes the N - M capacity curve. It is similar in concept to the Unity Value method used in steelwork design. It enables compliance to be demonstrated without a diagram (although a diagram is available to the user as the data is entered).
This method uses the principle that all of the key points where the reinforcement stress is locked (because the strain x Es value is beyond Fsmax) at either max compressive or max tension stress values can be defined by the anticlockwise increasing angle made between the N - M ratio line and the Origin (M = 0 and N= 0). This is called the Polar Angle and this is 0 when N =0 and M = Neg and 90 when N = Neg and M = 0 and 180 when N = 0 and M = positive etc. These points can be seen clearly in colour on the large scale N - M diagram. If the large scale Ult Stress and N - M diagrams are viewed and examined together, the procedure is quite clear.
The ratio of N / M is defined by the input so the Polar angle is therefore easily calculated by the program. The program calculates the Polar angle for all of the key stress lock points as well as the rebar start and finish points (to calculate displaced concrete adjustment). The program is therefore able to compare the applied N/M angle with these pre-defined angles and assess whether the reinforcement stress is locked or relates to the strain diagram in order to fix the variables in the master cubic equation. The program then solves the cubic equation using complex number theory. It filters the three results to display and use the correct value.
Where redistribution is used, i.e. $0.7 \leq \delta \leq 1$ with Axial (N) = 0, the value of Mu used is the lesser of the compression capacity (Mc) or Tension Capacity (Mt). If the balanced value of X (Xo) < maximum value of X (Xu), Xo is used and Mc = Mt. Since Xo self adjusts to ensure equilibrium about the centre line and no out of balance axial force, Fc = -Ft. Therefore, Mc = Fc x lever arm = Mt = Ft x lever arm. Therefore it is not possible for Mc > Mt unless Xo is locked when D - (0.5λX) > 0.95D or X < 0.1D/λ. Where λ is typically 0.9 for BS designs and 0.8 (if fck < 50 N/mm²) for EC2. This gives X < 0.111D for BS and X < 0.125D for EC2.
Where a slender column or strut analysis is performed. The program automatically calculates the moment at mid point including 2nd order effects. This value is displayed in the output so the user can see the effect and re-use the value in a bi-axial analysis if required. The capacity ratio is based on the maximum of that value or the original maximum end value. The charts update if required by shifting the ratio line to suit the revised moment.

Serv F1 Crack Width or Info

Face 1 crack width due to applied service forces. If the forces are entered as ultimate the service analysis is based on Forces / Load Factor. For both codes W = Crack Spacing x Strain (after deducting conc in tension stiffening) See detailed sheet. If the service reinforcement stress exceeds the maximum alowable (= k3 Fyk), the stress will be displayed (-ve = tension) instead.

Serv F2 Crack Width or Info

When redistribution is specified by inserting a value <1.0 & >0.7, W2 crack widths are not relevant and this cell is used to advise the designer if the Moment Capacity is controlled by failure in Tension or Compression. If Mt > Mc the section could fail in compression first which is not advisable as the failure will be sudden. It could also indicate more tension reinforcement than is required. See detailed sheet. If a slender column analysis is performed by entering a numerical value in the Leff cell and if the column is slender, SLEN will be displayed in this cell. If the service concrete compressive stress excedes the Design Value (k Fck), the value will be displayed in blue. If it exceedes the maximum value (k1 Fck) the value will be displayed in red.

X - serv or ult (depends on input)

This will display the service elastic value if Service i.e. S is selected as the Input type. It will display a negative value in high tension cases where the value of X is beyond Face 2

Values

Fs1 & Fs2 Stresses in N/mm²

The reinforcement stress in As1 and As2 which relates to the Input type (Ultimate or Service)

S transverse / D

The transverse spacing / D.

Sp/(Dx20xStr Sys)

Max Span / Eff Depth Ratio Factor (As BS8110) for fck and reinforcement %. For EC2, It can be converted to the appropriate span type by multiplying by 20 (the simply supported value) and by K (Appropriate Default Structural System Value).

Cont.

INFORMATION FROM COMMENT BOXES

Values Cont.

%AsLegs / BSr

Used in normal shear to check minimum AsL% on plan.

θ, EC2 Bi (Mb/Mr)ª or Med

EC2 ONLY Min θ Shear Angle allowing for tension (will be 33.7º for pure tension). Cell will display a red alert if angle is greater than the input angle or (Bi-Axial Moment / Moment of Resistance in Primary Direction when combined with Axial Load)ª. a is a coefficient or slender column mid span design moment including 2nd order effects.

% As1 Reinf / BH

0.01 x (Area of F1 and (F1+ or 50% of Column Side Bars)) / Full Cross Section Area

Lap Length x dia

Displays the Global minimum value unless factors such as top cover, bar spacing and use of lower steel or concrete stresses require a greater value. If the Thermal Reinforcement is equal to the critical ratio, the lap length will be 1.4 x code minimum which could also exceed the Global value. See display settings in Global Input Data.

EC2 Shear Shift

EC2 Only For Normal Shear, the moment envelope is shifted by this distance to increase the length of the tension reinforcement bars. In effect it increases the anchorage length. Increasing the strut angle will reduce this distance. See Shear.

St / D at Dria

Punching Shear Only EC2 Design Only

St / D Check at the inner start point for additional radials or the main radials start point if there are no intermediates. St / D = The Tangential Spacing / Effective Depth value at the entered xD distance from support. This must be <= 1D outside 2D from support and <= 0.75 D inside 2D from support and it is this value that often determines the need for the intermediate radials. These values are based on the main radials in order to demonstrate compliance.

St / D at Dro

Punching Shear Only. EC2 St / D check at outer perimeter of radials. St / D = The Tangential Spacing / Effective Depth value. This must be <= 2D outside 2D from support and it is this value that often determines the need for the intermediate radials. BS St / D check on a typical perimeter

AsL% at Dria

Punching Shear Only EC2 Design Only

%AsL check at the inner point of the additional radials or at the start point if they all go to the start point. The Area of a leg / (Tangential Spacing x Radial Spacing) This is based on the main radials only even though the additional radials will be present and must be > min value so that it demonstrates that the next ring inwards will comply without the additional radials. This criteria also determines the need and extent of additional radials.

AsL% at Dro

Punching Shear Only. EC2 %AsL check at outer perimeter of radials. The Area of a leg / (Tangential Spacing x Radial Spacing) must be = > min value. This criteria also determines the need and extent of additional radials.
BS %AsL check on a typical leg perimeter

xD at Dria

Punching Shear Only. EC2 Only. The number of Effective Depths from the face of the support to the inner (start) point of the additional / intermediate radials. Additional radials are often required to satisfy min %As or spacing rules so they will not normally be required from the start.

xD at Dro

Punching Shear Only. EC2 Design Only. The Number Effective Depths from the Support Face to the outermost radial leg. This must be within 1.5D of the point where the section is adequate without legs (Dout)

xD at Uout

Punching Shear Only. The nr of Effective Depths to Uout, where the concrete is alone is adequate for shear.

Perim at xD

Punching Shear Only. The shear perimeter length according to the entered xD value which is usually 2.0

Cont.

INFORMATION FROM COMMENT BOXES

Values Cont.

β Values

Program calculates the appropriate values according to the column moments M_{ED}. If no values ar entered for M_{ED} X - X and M_{ED} Y - Y the code defaults for nearly equal spans are used. The program multiplies the input VED x β.

Data

Reinf Area of F1 & Extra (mm²)

This includes all of the reinf in the Face 1 half of the section. It includes 50% of any column middle side bars.

Equiv or Avg Effective Depth

This is the equivalent value taking into account bars in the third layer. This is used in shear effective depth multiples and Span / Effective Depth calculations. It will equal D1 if no Layered or Side bars are specified.
For Punching Shear the reinforcement and cover is adjusted to reflect the average for each direction. This will cause the crack width for the section analysis to be different to the value when calculated individually.

EC2 Max Full Thickness Crack

This is based on the requirements of EC2 part 3 which takes into account tightness class, head of liquid and section depth H. This program considers Class 2 is satisfied by a maximum 0.05mm crack width (as opposed to a zero width) reducing to 0.025mm at a head ratio of 35 or more. (See CIRIA C660). The user and client must be satisfied with this approach.

Wk1 Strain Factor - Due to M & N

BS Strain Factor = 1 / (1+2(acr-Cover) / (H - X))
EC2 Strain Factor k2 (Only use Absolute Tensile Strain Values) = (Max Strain - Min Strain or Zero) / (2 x Max Strain). If X >=H, this value is Zero as crack width calculation is irrelevant. Cracking due to pure bending or 0 < X < H gives k2 = 0.5 and pure tension gives k2 = 1.

Min Direct Action % As1 B Z

EC2 The basic ρcrit% is multiplied by kc.
kc is the factor that varies between 0 for high compression and 0.4 for pure flexure or flexure and axial to 1.0 for pure tension.

σc is negative for tension and positive for compression

If σc is in tension kc = 0.4 (1 - σc / (2/3)(fcteff)) <= 1.0

If σc is in compression kc = 0.4 (1 - σc / (1.5)(H / H*)(fcteff)) <= 1.0

H* = Min of 1000mm or H

BS N / A is dsiplayed.

EC2 Bond Condition

The top part of ground slabs thicker than 250mm exhibit poor bond. The bond strength is then multiplied x 0.7.

Cont.

INFORMATION FROM COMMENT BOXES

Thermal & Drying & Creep

Zone Depth

Thermal Reinforcement Zone Depth Z. C660 and EC2 consider this differently to C91 & BS8007.

This is the depth used to calculate Min As for all methods.

For C660, this is based on Table 3.1

z = HAC Tension factor = 0.5 for End and Edge and N & M or 0.2 for Internal
For End and Edge Restraints and N & M
Z = (k = (1.0 for h <= 300 & 0.75 for h>= 800 & interpolated between)) x (z = 0.5) x H
For Internal Restraint
Z = (k = 1) x (z = 0.2) x H

Curing Temperature Drop

The Concrete Curing Temperature. This depends on the binder mix, formwork and Section Type.
This program automatically calculates T1 to C91 and C660. C660 gives higher values than C991 and BS8007 in many cases.

Drying Shrinkage μStrain

Influenced by Relative humidity and binder content. Based on the Equation in EC2 Annex B2
Rel humidity Factor βRH = 1.55 x (1- (RH / Rho)^3) RH = Rel Humidity Rho = 100
Basic Unrestrained Microstrain = εcd,o = 0.85 x ((220 + 110 x αds1) x Exp(-αds2 x fcm / fcmo)) x βRH
Final Drying Shrinkage microstrain after t days = εcd(t) = βds(t,ts) x kh x εcd,0
If t is taken as Design Life in days, t = Design Life L in yrs x 365 and ts is taken as 0 say
β(t,ts) = (365L -ts) / ((365L - ts) + 0.4 x ((ho)^1.5)) = t / (t + 0.4 x ((ho)^1.5))
Therefore β(t,ts) = 365L / (365L + 0.4 x ((ho) ^1.5)). The published values in C660 and EC2 relate to 70 yrs
ho = H if both sides are open to the atmosphere or 2h if only one surface is i.e. if cast against the ground or buried.
Note that the max value of ho is 500mm and increasing ho reduces the drying strain (as one would expect).
kh depends on ho and the values are below. The program interpolates between the values.

ho	kh
>= 500mm	0.7
400mm	0.71
300mm	0.75
200mm	0.85
100mm	1.00
< 100mm	1.00

Cont.

INFORMATION FROM COMMENT BOXES

Thermal & Drying & Creep Cont.

F1 Crack Width or Uncracked με

Face 1 thermal and shrinkage crack width. C660 gives similar results to C91 if the restraint type is set to Edge and similar restraint factors are used as the methods of calculating spacing and strain are broadly similar. Note how cover effects the C660 results. C660 End restraint strain calculation is based on the EC2 service forces crack width method and gives large cracks compared to C91 when the section is cracked which will be the norm unless the restraint factor is very low (slab cast on a sliding membrane on a power floated blinding and no restraining end walls etc).

Crack Width = Crack Spacing x Strain
End Restraint Crack spacing as per Equ 3.13 of C660
k1 = EC2 value is 0.8 but this is increased to 0.8 / 0.7 i.e. 1.14 to take into account less than perfect bond.
3.4 x cover + 0.425 k1 Dia / (As1 / (B (2.5 x (cover + Dia/2))))
Therefore spacing is reduced by:- Smaller bars at closer centres, Less cover, Good bond
End restraint Strain as per Equ 3.16 of C660. This is determined by the tensile strength of the concrete.
Ref Table 3.1 Kc = 1.0 for End restraint
k = 1.0 for h <= 300 and 0.75 for h >= 800 and interpolated in between
fctm = 3 or 28 day ult tensile strength Es = Steel modulus = 200 kN/mm²
αe = Modular Ratio = MR = Es / (Ec / (1 + creep ratio)) Act = B x 0.5H
Strain = (0.5 αe Kc k fctm / Es) (1 + (1 / (αe (As1 / Act))))
= (0.5 αe Kc k fctm / Es) (1 + (Act / (αe As1)))
For a 300 slab with 16 dia bars at 175 ctrs and MR = 12.2 say (for CR = 1) and fctm = 2.9 N/mm²
For B = 1000mm and Z = 150mm and As =1149mm²
= (1.45 x 12.2 / 200000) (1 + (150000 / (12.2 x 1149))
= (88.5 / 1000000) (1 + 10.7) = 1035 Microstrain
If Mr is based on 6.1 i.e. no creep allowed for
= (44.25 / 1000000)(1 +21.4) = 991 microstrain
Therefore doubling the value of MR to match the value used in flexural crack width analysis increases the strain by approx 5%.
Therefore strain is reduced by a lower value of fcm
One solution is to try and avoid cracks altogether - See Restraints Sheet.

If the drying shrinkage, restraints and temperature drop can be controlled it may be possible to keep the restrained strain within the strain capacity. This is a risky approach however because the margin for error is not very great and it only needs a small variation from the assumed parameters to push it over the limit and cause huge cracks. The spreadsheet can demonstrate this by displaying the restrained strain if it is less than the capacity. Increasing restraint will increase the strain to the point where it exceeds the capacity and then the crack width is displayed.

% As1 / BZ

0.01 x Area of F1 + L3 / Zone Depth x Section Width

EC2 Loaded Creep Coefficient

This is the creep due to constant loading which has the effect of reducing the effective Young's Modulus in concrete in the same way as the Creep Coefficient is used in the flexural crack analysis MR factor. Eeff = Ec28 / (1 + Creep Coeff). Ref EC2 3.14 and Annexe B
The value is influenced by:-
time of loading (to in days) - Early loading makes it worse. Time of assessment (t in days) - taken as life of the structure
Relative humidity - high humidity makes it better. The depth of the element - deeper is better
No of surfaces exposed - one is better than 2. The concrete strength - stronger concrete reduces the value
The type of cement S or R or N (which is normally specified)
the average curing temperature - assumed to be 20 deg - a lower temperature increases the value.

Since all of these parameters are within the spreadsheet it is possible to display this value which is immensely valuable because it affects the value of Eeff that must be used in calculating long term deflection. This allows the value to be calculated with a degree of confidence. The values agree closely with the results from fig 3.1 provided one uses the correct ho value. If the drying is only from one face ho = 2H otherwise ho = H. Therefore if the creep related deformation (or strain) due to sustained load = 1.5 x stress / Ec and the basic deformation due to load is stress / Ec. Total deformation = strain = 2.5 x stress / Ec. Therefore stress / strain = Ec / 2.5 i.e. Ec / (1 + Creep Coeff). It would appear that Ec / 2.5 is a good starting point.

These values are used in EC2 slender column analysis so it is particularly useful to have this information to hand.
The displayed values include any adjustment (increase) due to non linear effects caused by high service compressive stress.

ITEM	BS8110 & BS8007	EC2
Actions - Variation in Time	Dead Super Abnormal	**Permanent** G_{kj}, $G_{k,inf}$, G_{ksup} SW, Water & Earth **Variable** $Q_{k,i}$ Super, Snow, Wind, Thermal, Surch **Accidental** A_k Explosions, Fire, Impact, Overload
Actions - Other Criteria	N / A	**Origin** Direct or Indirect **Spatial Variation** Fixed or Free **Nature & Response** Nature & Static or Dynamic
Variable Factors	N / A	**Representative Factors Cl 1.5.3** Characteristic 1 Liquids Combination ψ_o 1 Frequent ψ_1 0.9 Quasi Permanent ψ_2 0.8
Ultimate Combinations & PSFs	**Generally** Dead Stability Unfav 1.50 Fav 0.90 Other Unfav 1.40 Fav 1.00 Super Unfav 1.60 Abnormal 1.10	**Tables NA A1.2(A) & (B)** Fundamental / Accidental **Permanent $\gamma_{G,j}$** Equ Unfav 1.10 / 1.00 Fav 0.90 / 1.00 Str Unfav 1.35 / 1.00 Fav 1.00 / 1.00 **Variables $\gamma_{Q,i}$** Lead 1.5 / 1.00 Accompanying Main ψ_{o1}1.5 / 1.00 Accompanying Other ψ_{oi} 1.5 / 1.00
Serviceability Combinations	Serv 1.0 Dead + 1.0 Super or worse combinations	**Table A1.4** Permanent **G**d (Unfav, Fav) / Variable **Q**d (Lead, Others) **Characteristic** G_{kjsup} G_{kjinf} Q_{k1} $\psi_{oi}Q_{ki}$ **Frequent** G_{kjsup} G_{kjinf} $\psi_{11}Q_{k1}$ $\psi_{2i}Q_{ki}$ **Quasi Permanent** G_{kjsup} G_{kjinf} $\psi_{21}Q_{k1}$ $\psi_{2i}Q_{ki}$
Concrete Specification	Based on 28 Day Cube Fcu	Based on 28 Day Cylinder Fck
Ultimate Design	Stress Block 0.9X Hinges about X = 0 throughout	Stress Block 0.8X If X > H, Stress Block Hinges about X = 0.5H
Crack Width Limits	No Head (ho) / H Limits General Use 0.3 - 0.4mm Water Retaining 0.2mm Appearance 0.1mm Special 0mm	At ho/H = 35, Wk = 0.05mm to at ho/H = 5, Wk = 0.2mm Class 0 0.3mm to 0.4mm according to exposure Class 1 Wk if X < 50mm or 0.2H else 0.3mm Class 2 0mm if X < 50mm or 0.2H else Wk Class 3 0mm
Crack Width Design	W>=0.1mm tens = 0 to 2/3 N/mm² W<=0.1mm tens= 0 to 1.0 N/mm² No Limit on Tension Stiffening Strain calculated at Face Spacing relates to cover and ctrs	Tens = 0.4 Fctm = 1.16 N /mm2 at 28D for Fck = 30 N/mm² Rectangular Tension Block Teff wide Tens Stiffening Strain Limited to 0.4 Fs / Es Strain calculated at Reinf Spacing = 3.4 x Cov + Constants x Dia / (As / Ateff)
Shear - Normal	45° Strut and Tie Method Can use conc cap with reinf Can increase cap if X < 2.0D No Shear Shift	Variable Angle (θ = 21.8° to 45°) Strut & Tie Method Cannot use conc cap with reinf cap Can only reduce values on loads within 2D Shear Shift extends tension bar anchorage length
Shear - Punching	Tested at 1.5D Orthogonal System Uses Conc Cap with Reinf Cap Rectangular Perimeter	Tested at 2.0D. Revised β Factors Radial System with Infill radials as required Uses 75% Conc with 75% Reinf based on 26.6 deg Perimeter is circular at corners
Flat Slab Moments	Column Strip -75% & +55% Middle Strip -25% & +45% 67% of Supp At in 0.125 panel	Column Strip -60% to -80% & +50% to +70% Middle Strip -20% to -40% & +30% to +50% 50% of Supp At to be in 0.125 panel over support.
Shrinkage	Edge Restraint Method T1 Curing & T2 Seasonal Min T1 values Uses Ciria 91 Single Restraint R 0.5 Creep incl in Restraints	End, Edge Internal (End crack relates to tens strength) T1 Curing, T2 Seasonal, Autogenous & Drying No minimum T1 values Uses Ciria C660 R1, R2 and R3 Restraint Factors 0.65 creep factor separate from Restraint values

The Design Of Liquid Retaining Structures To EC2

Basics

- The structures considered are of reinforced concrete and must hold or exclude water.
- Concrete has a tensile strength capacity of approximately 1 / 10 of its compressive strength.
- Concrete will normally crack in tension under Actions due to loading and or restrained shrinkage.
- Cracks must be of a small enough width so they will self heal.
- The categories of actions and combinations and partial safety factors are within EC0.
- Values of actions are specified within EC1.
- Element design is controlled by EC2 - 1 & EC2 - 3 & CIRIA C660.

Forces Actions Analysis

- Structures must be designed for any possible combination of internal or external load Actions.
- External loads cannot be used to assist in resisting internal loads and vice versa.
- Some simple structures can be analysed using charts and tables based on the theory of plates.
- Larger structures are best analaysed by computer using grillage or Finite Element techniques.
- The output results will include Shear or Punching Shear and combined Axial and Bending.

Shrinkage Actions Analysis

- Concrete shrinks due to curing and seasonal temperature drops, autogenous curing and drying.
- If the free shrinkage strain is restrained sufficiently the concrete will crack.
- Edge Restraint is along an edge of the element such as a slab restraining the base of a wall.
- End Restraint is where the element is restrained at the ends or along its length by piles or friction.
- Accurate assessment of End Restraint is complex and may require a computer analysis.
- The design rules are within EC2 - 3 with further guidance provided by CIRIA C660.

Autogenous Healing

- Cracks can self heal due to calcium hydroxide being conveted to calcium carbonate (limestone).
- Too much flow will flush through the deposits. Not enough flow will not create enough deposits.
- Cracks of 0.3mm can self heal within a few weeks but will leave an unsightly residue.
- Cracks of 0.2mm can self heal in days and will be noticeable but less so than the 0.3mm cracks.
- Cracks less than 0.1mm will self heal almost immediately and may not be noticed.

Reinforcement Requirements

- Reinforcement is required to resist ultimate forces in the same manner as normal structures.
- It must also limit crack widths due to crack inducing strain from loads or restrained shrinkage.
- Crack width = Crack Spacing x Crack Inducing Strain.
- The procedures for compliance are complex and the use of a spreadsheet and tables is worthwhile.

Relevant Eurocodes and UK National Annexes

BS EN 1990:2002 + A1:2005	Eurocode 0. (EC0) Basis of structural design UK National Annex to BS EN 1990:2002 + A1:2005
BS EN 1991-1-1:2002	Eurocode 1. (EC1 - 1) Actions on Structures Part 1-1: General actions - Densities, self-weight, imposed loads for buildings UK National Annex to BS EN 1991-1-1-2002
BS EN 1991-4:2006	Eurocode 1. (EC1 - 4) Actions on structures. Part 4: Silos and tanks UK National Annex to BS EN 1991-4-2006
BS EN 1991-5:2006	Eurocode 1. (EC1 - 5) Actions on structures. Part 5: Thermal Actions UK National Annex to BS EN 1991-5-2006
BS EN 1992-1-1:2004	Eurocode 2. (EC2 - 1) Design of concrete structures. Part 1 - 1: General rules and rules for buildings UK National Annex to BS EN 1992-1-1-2004
BS EN 1992-3-2006	Eurocode 2. (EC2 - 3) Design of concrete structures. Part 3: Liquid retaining and containing structures UK National Annex to BS EN 1992-3-2006

Non Contradictory Supporting Document

CIRIA Report C660	Early-age thermal crack control in concrete - published 2007

EC2 DESIGN TOOL

CRACK WIDTH CALCULATIONS

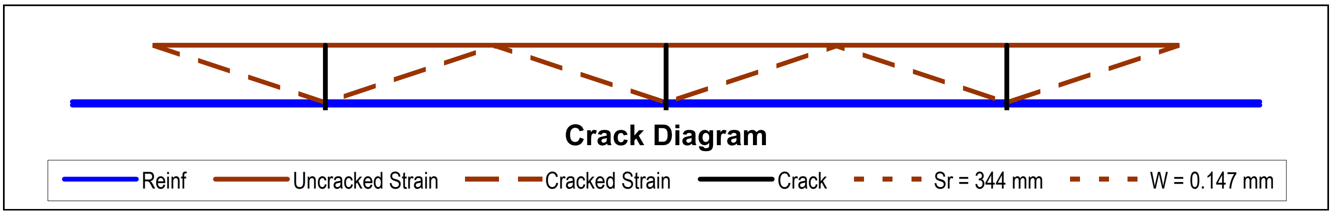
HAC-PRO 1 - 5 - 2 CRACK 1

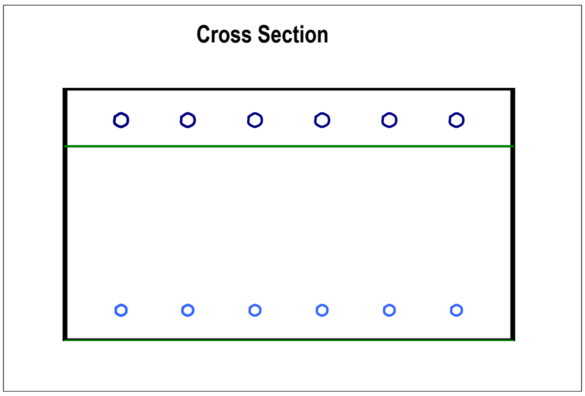
Howes Atkinson Crowder LLP

Service Crack Width Analysis See Sheet 3 For Criteria and Width Limits C **30** / **37**

BS Crack Calculation & Creep Coefficient (CC)	**EC2 Crack Calculation**
W = Crack Spacing x (Basic Strain - Conc Stiffening Strain)	W = Crack Spacing x (Basic Strain - Conc Stiffening & Mean Strains)
3 acr / (1 + (2 x (acr - cov) / (H - X))) x	$((k_3 * Cov) + (k_1 * k_2 * k_4 * \varphi / \rho_{p,eff}))$ x
((Fs1 x R / Es) - (Fct x 0.5 x B x (H - X) x R / As1) / Es))	((Fs1 / Es) - $(((K_t * f_{ct,eff} / \rho_{p.eff}) / Es) + (K_t * f_{ct,eff} * MR / Es)))$

Strains are calculated at surface of Face 1		Strains are calculated at the centre of As1	
R = (H - X)/(d1 - X) converts strain at As1 to strain at Face 1		Ref UK Nat Annex	k_3 = 3.4 ; k_4 = 0.425
acr = ((Cov + φ/2)² + (Ctrs/2)²)½ - φ/2	B = Section Width	k_1 = Bond Factor. Good = 0.8, Poor = 1.14	k_1 = 0.80
Auto CC due to age & exposure 1.523	CC Specified 1.50	Strain Factor k2 (below) k_2 = 0.50	φ = 32.0
Strain Factor (below) = 0.868	CC Used 1.500	kt = 0.4 Long Term or 0.6 Short Term.	kt = 0.4
Fct = 1 N/mm² for W =0.1mm or 2/3 N/mm² for w = 0.2mm		Conc in tension fct,eff = fctm,(t crack)	= 2.90 N/mm²
Es = 200000 N/mm²	Ec = 27.4 N/mm²	Es = 200000 N/mm²	Ec = 32.8 kN/mm²
MR = Es / (Ec / (1 + CC))	= 18.25	MR = Es / (Ec / (1 + CC))	= 15.23

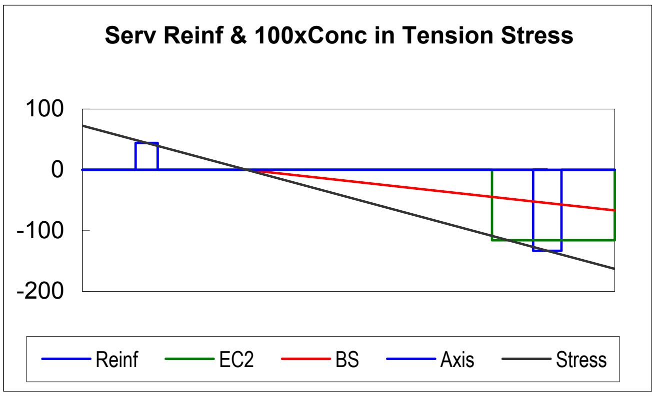




Load at **28** Days

Creep Age **60** Yrs

Crack W at **28** Days



H	B	F1	φ1	Sp, nr	Cov	Exp	φ2	Sp, nr	Cov	φE	Fact	Diag	L or S	CC	Ns	Ms	K1
600	1000	int	32	150	60	1 & 85	25	150	60			EC2	L	1.50	-137	296	0.80

Basic Strain **BS** W1 =	0.158	mm	**Basic Strain** **EC2** W1 =	0.147	mm
Neutral Axis Dist from Face 2 to Face 1 X =	195	mm	Neutral Axis Dist from Face 2 to Face 1 X =	185	mm
Reinforcement Stress Fs1	-134	N/mm²	Reinforcement Stress Fs1	-133	N/mm²
Strain at Reinf Due to Forces εs = Fs1 / Es	-669	με	Strain at Reinf Due to Forces εs = Fs1 / Es	-666	με
Stiffening Strain ε2			**Stiffening Strain (εc) & Mean Conc Strain (εcm)**		
Effective Depth to As1 = d1	524	mm	Kt x fct,eff = Kt x Fctm(t = time at crack)	1.159	N/mm²
fct at Face 1	-0.67	N/mm²	A = (H - X) / 3	138	mm
fct at Face 2 or X = Min(0 or - fct1 X / (H - X))	0.00	N/mm²	B = 2.5 x (Cov + Dia / 2)	190	mm
Fct = 0.5B(fct1+fct2)(H - Max(X or 0))	-135	kN	C = H / 2	300	mm
Fct1 = Fct Fs1 As1 / (Fs3s1 + Fs3As3 + Fs2As2)	-135	kN	T,eff = Min of A, B or C	138	mm
Fct3 = Fct Fs3 As3 / (Fs3s1 + Fs3As3 + Fs2As2)	0	kN	ρp,eff = As1 / (Aceff = B x T,eff)	0.039	
Fct2 = Fct Fs2 As2 / (Fs3s1 + Fs3As3 + Fs2As2)	0	kN	Stiffening εc = (kt x fctm,t / (ρp,eff)) / Es	-149	με
Stiffening Strain at As1 = Fct1 / As1/ Es	-126	με	Mean Conc Strain εcm = kt x fctm,t x MR / Es	-88	με
Stiffening Strain at Face 1 Surface = ε2,F1	-155	με	Stiffening & Mean Conc Strain = εc + εcm	-238	με
Average Strain εm			**Average Strain εm**		
Strain ε1,F1 = εs (H - X) / (d1 -X)	-824	με	Average (εm) = Mean (εsm = εs - εc) - εcm	-428	με
Strain ε1,F2 = Min of:- 0 or - εs X / (d1 - X)	0	με	F1 Limiting Strain = 0.6 * εs	-400	με
Average Strain at Face 1 εm = ε1,F1 - ε2,F1	-669	με	F1 εm = Min of (εsm - εcm) & (0.6 * εs)	-428	με
Crack Spacing Smax			**Crack Spacing Srmax**		
acr = ((((Cover+φ/2)^2+(ctrs/2)^2)^0.5)-φ/2)	91	mm	Strain ε1 = εs (H - X) / (d1 -X)	-815	με
1 + 2(acr -Cover) / (H - X)	1.152		Strain ε2 = Min of:- 0 or - εs X / (d1 - X)	0	με
Strain Factor = 1 / (1+2(acr-Cover) / (H - X))	0.868		Strain Factor K2 = (ε1 + ε2) / (2ε1)	0.500	
3acr = Pure Tension Smax where Fs1 = Fs2	272	mm	K1 * K2 * 0.425 * φ / ρp,eff	140	mm
Smax=3acr / (1+2(acr-cmin) / (H - X))	236	mm	Sr,max = 3.4*Cov + K1*K2*0.425*φ/ρp,eff	344	mm
Crack Width W1			**Crack Width W1**		
F1 Crack Width = - εm x Smax	0.158	mm	**F1 Crack Width = - εm x Sr,max**	0.147	mm

Calculation of Minimum Face 1 Reinforcement to Control Cracking

Criteria

Reinf Stress σs must <= fyk when new cracks form
σs = Conc Strength at Cracking x kc k Act / As1
Concrete Strength will be greater for cracks at later age
Stronger Concrete requires greater % As1 at cracking
Strength Age used for Min % As1 (3D or 28D or LT) for:-
Note. Min Restraint Age is specified on MAIN sheet
Edge = **3D**
End = **28D**
Reduction factor (k) if H > 300mm (for Int Restr k = 1)
Depth of Tension Zone Factor (z), (See C660 Table 3.1)
The effective area of concrete in the tensile zone (Act)
Stress Distribution Factor kc For Shrinkage Restraint
Stress Distribution Factor kc For Forces
The Mean Concrete Axial Stress (σc = N / BH), (-ve in Tens)
Adjustment of fct,eff factor (k1 (h / h*)) for Tens or Comp
(h / h*) values if Axial Force is Compressive

Guidance

Generally	Full crack pattern forms at first cracking and later greater strain increases crack widths	
End Restr	Cracks are formed individually. If later strain > conc cap, a new crack will form with a higher σs	
Forces	At First Cracking	Normally at 28 Days
Int Restr	At First Cracking	Always at 3 Days
Edge Restr	At First Cracking	Calculate but >= Min Age
End Restr	At Latest Crack	Calculate but >= Min Age

k varies from 1.0 at H ≤ 300 to 0.75 at H ≥ 800
z = 0.5 except for Int Restraint where z = 0.2
Act = Z B, where Z = k z H (= 0.2H for Int Restr)
For Edge and End = 1.0, For Internal = 0.5
kc = 0 (High Comp), 0.4 (N = 0), 1.0 (High Tens)
Value and if in Tension or Compression
k1 (h / h*) = 2/3 (Tens) or 1.5 (h / h*) (Comp)
h = H and h* = Min of H or 1000mm

Procedure Ref EC2 Cl 7.3.2 and CIRIA C660 Section 3.3.1 incl Table 3.1

Asmin σs = kc k σct fct,eff Act ρcrit% is the default unadjusted Asmin% = 100 x fctm,t / fyk

fct,eff = fctm at time t in days σs = fyk = 500 N/mm² = kc k fctm,t Act / Asmin

A Surface Zone Depth Factor (z) is introduced where z = 0.5 generally except for Internal Restraint where z = 0.2.
As is taken as Face 1 Reinforcement (As1) and Act = Z x B, where Z = k z H . For Internal Restraint k = 1 so Z = 0.2H

Equation is re-arranged to read in % terms As1min = %(fctm,t / fyk) x kc x Z x B / 100

For fck = 30 N/mm² fctm 3Day = 1.733 N/mm² fctm 28Day = 2.896 N/mm²

ρcrit % = 100 x fctm,t / fyk 3Day = 0.347 % 28Day = 0.579 %

Section Depth Reduction Factor k BS Method uses a k value appropriate to BS8007 Zone Depth

If H <= 300, k = 1 or If H >= 800, k = 0.75 else, k = 0.75 + (0.25 x (800 - H) / 500) For Internal Restraint, k = 1.0

Stress Distribution Factor kc BS Method Uses 1.0 for Shrinkage and is N/A for Forces

Shrinkage For End and Edge Restraint, kc = 1.0. For Internal Restraint kc = 0.5.

Forces A Forces Zone Adjustment factor (n) is introduced to allow the use of the Shrinkage Z value in all cases
n = (Forces Z / Shrinkage Z) = 1 generally, except for Internal Restraint where n = 2.5 k (forces)

Axial Force is 0 or Tensile n kc = n x 0.4 x (1 - (σc / ((2/3) (fct,eff))))
Axial Force is Compressive n kc = n x 0.4 x (1 - (σc / ((1.5) (h / h*) (fct,eff)))) h = H & h* = Min 1000 or H

Example

H = 600 mm B = 1000 mm N = -137 kN BS or EC2 EC2

Shrinkage Restraint Edge k = 0.850 z = 0.500 k z = 0.425

Age 3 Days fct,eff 1.73 N/mm² ρcrit % 0.347 kc = 1.000 Z = k z H = **255** mm

%As1min = kc x ρcrit% = 1.000 x 0.347 = **0.347** % As1 req = %As1min x BZ / 100 = **884** mm²

Forces at 28 Days σc = -0.23 N/mm² k = 0.850 z = 0.500 n = 1.000

ρcrit % = 0.579 fct,eff 2.90 N/mm² σc/fct,eff = -0.08 kc = 0.447 n kc = 0.447

%As1min = n kc x ρcrit% = 0.447 x 0.579 = **0.259** % As1 req = %As1min x BZ / 100 = **661** mm²

As1 provided must be >= the larger value whilst also checking against :- 0.151 % x B x d1 = **789** mm²

EC2 Maximum Leakage Criteria **Ref BS EN - 3 - 2006 Clause 7.3**

Class	Acceptable Leakage	Criteria to be Met
0	Some degree of leakage acceptable or not relevant.	Adopt the provisions of 7.3.1 of EN 1992 - 1 - 1 Note that widths are affected by exposure class.
1	Limited to a small amount. Some surface staining or damp patches acceptable.	Full thickness cracks must be <= wk1 or If X >= 50mm or 0.2H based on a quasi permanent combination of actions and strain range is < 150 με Adopt the provisions of 7.3.1 of EN 1992 - 1 - 1
2	Minimal Appearance not to be impaired by staining.	Avoid full thickness cracks by ensuring X >= 50mm or 0.2H based on a quasi permanent combination of actions and strain range is < 150 με Any partial depth cracks must be <= wk1
3	None at all.	Use Liners or Pre-stress or Post-tension

Class 1 is the minimum class for Liquid Retaining Structures. This is considered to be appropriate for a utility structure and is closest to BS8007 0.2mm criteria.

Class 2 can exceed the BS8007 0.1mm crack width limit and will result in a significant increase in reinforcement over Class 1 and will be impossible to achieve in respect of full depth thermal or direct tension cracks.

Provisions of 7.3.1 of EN 1992 - 1 - 1

Exposure Class	Quasi Permanent Load Combination Wmax mm
X0, XC1	0.4
XC2, XD2, XS1, XS2, XS3	0.3

Water at a consistent level for most of the time with SW is considered to be a quasi permanent combination. Therefore in certain circumstances a 0.3mm crack width would be permissible in a non full thickness crack.

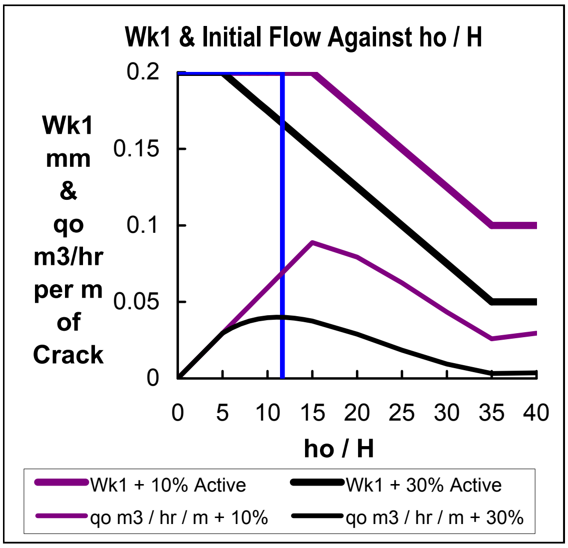
Wk1 **Active ΔWk1 % =** 30 or 20 or 10 **10** % **ho / H Limit of Wk1 = 0.2mm** **15**

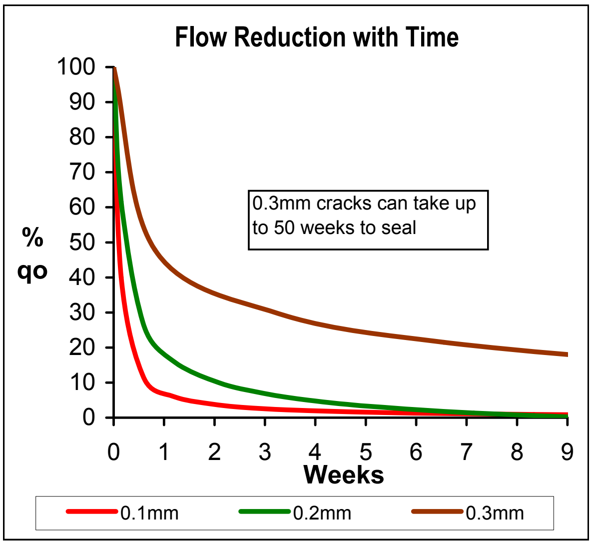
If ho / H < = 15 wk1 = 0.2 mm
If ho / H >= 35 wk1 = 0.1 mm Otherwise Wk1 = 0.1 + 0.1 * (35 - (ho / H)) / 20 mm

ho **7000** mm H **600** mm ho/H **11.67** Wk1 = **0.200** mm

qo = 0.740 (ho / H) Wk ^ 3 m³ / hr / m at 20° **% qt/qo = 65 (Wk^-1.05)(t^(-1.3+4Wk)) - (10^5)(Wk^5.8)**

Ref Edvardsen Water Permeability and Autogenous Healing of Cracks in Concrete ACI Materials Journal 1999





EC2 DESIGN TOOL

CRACK WIDTH CALCULATIONS

HAC-PRO 1 - 5 - 2 CRACK 4

Howes Atkinson Crowder LLP

Comparison between BS8007 & EC2 Crack Width Calculations **F1 = Face 1 (Tens)** **F2 = Face 2 (Comp)**

BS Crack Calculation	Case	1	2	3	4	5	6	7	8	9	10	11	12
F1 Conc in Tension Stiffening Stress N/mm²		-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667
F2 Conc in Tension Stiffening Stress N/mm²		-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667
Conc in Tension Stiffening Force kN		-135	-149	-149	-200	-67	-139	-149	-147	-160	-146	-54	-33
F1 Neutral Axis X, from Face 2 towards Face 1 mm		195	152	152	-154939	98	183	152	159	120	162	178	137
F1 Reinforcement Stress N/mm²		-134	-102	-98	-112	-170	-46	-126	-67	-118	-1	-300	-281
F1 Strain at Surface Due to Forces Є1 μStrain		-824	-587	-566	-561	-1267	-269	-726	-407	-661	-6	-2003	-2330
F1 Conc in Tension Stiffening Strain Є2 μStrain		-155	-412	-412	-209	-238	-250	-412	-166	-426	-611	-113	-129
F1 Average Strain Єm = Є1- Є2 μStrain	**Єm1**	**-669**	**-175**	**-154**	**-351**	**-1028**	**-19**	**-315**	**-241**	**-234**	**605**	**-1890**	**-2201**
F1 3acr=3*((((cover+φ/2)^2+(ctrs/2)^2)^0.5)-φ/2) mm		272	258	258	245	270	255	258	272	240	243	261	267
F1 Strain Dist Factor = 1 / (1+2(acr-cmin)/(H-X))		0.868	0.861	0.861	0.999	0.748	0.856	0.861	0.877	0.857	0.842	0.796	0.687
F1 Crack Spacing Srmax=3acr/(1+2(acr-cmin)/(H-X))mm	**Sr1**	**236**	**222**	**222**	**244**	**202**	**219**	**222**	**239**	**206**	**205**	**208**	**184**
F1 Crack Width = - Єm1 x Sr1 mm	**W1**	**0.158**	**0.038**	**0.034**	**0.085**	**0.207**	**0.004**	**0.069**	**0.057**	**0.048**	**0.000**	**0.392**	**0.404**
F2 Neutral Axis X, from Face 1 towards Face 2 mm		405	448	448	155239	202	417	448	441	480	438	272	163
F2 Reinforcement Stress N/mm²		50	24	23	-112	46	16	30	16	19	0	170	209
F2 Strain at Surface Due to Forces Є1 μStrain		0	0	0	-560	0	0	0	0	0	0	0	0
F2 Conc in Tension Stiffening Strain Є2 μStrain		0	0	0	-209	0	0	0	0	0	0	0	0
F2 Average Strain Єm = Є1- Є2 μStrain	**Єm2**	**0**	**0**	**0**	**-351**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
F2 3acr=3*((((cover+φ/2)^2+(ctrs/2)^2)^0.5)-φ/2) mm		275	258	258	244	274	258	258	278	240	243	267	267
F2 Strain Dist Factor = 1 / (1+2(acr-cmin)/(H-X))		0.754	0.678	0.678	0.999	0.582	0.718	0.678	0.710	0.600	0.664	0.705	0.649
F2 Crack Spacing Srmax=3acr/(1+2(acr-cmin)/(H-X))mm	**Sr2**	**208**	**175**	**175**	**244**	**160**	**185**	**175**	**197**	**144**	**162**	**189**	**174**
F2 Crack Width = - Єm2 x Sr2 mm	**W2**	**0.000**	**0.000**	**0.000**	**0.085**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
EC2 Crack Calculation													
F1 Neutral Axis X, from Face 2 towards Face 1 mm		185	143	143	-154939	93	173	143	150	113	152	169	133
F1 Reinforcement Stress N/mm²		-133	-101	-97	-112	-168	-45	-125	-67	-118	-1	-298	-272
F1 Strain Distribution Factor K2		0.500	0.500	0.500	0.999	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
F1 Kt x Concrete Tensile Stress fcteff = 0.4 x Fctm N/mm²		-1.159	-1.159	-1.159	-1.159	-1.159	-1.159	-1.159	-1.159	-1.159	-1.159	-1.159	-1.159
F1 Concrete Tensile Stress Width mm		138	150.0	150	119	69	142	150	150	125	120	94	56
F1 Aceff = width of section x tensile stress width mm²		138315	150000	150000	119211	69080	142440	150000	150112	125000	120000	56256	33351
F1 3.4 * Cover mm		204	170	170	136	190	170	170	204	136	136	177	177
F1 Ppeff = As1 / Aceff		0.039	0.014	0.014	0.020	0.030	0.024	0.014	0.036	0.017	0.011	0.057	0.074
F1 φ Equiv - Where alt bars of Diff Dia Ref Equ 7.11		32.0	20.0	20.0	15.2	20.0	25.0	20.0	32.0	20.0	16.0	32.0	25.0
F1 K1 = Bond factor. Good = 0.8, Poor = 1.14		0.80	1.14	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
F1 K1 * K2 * 0.425 * Dia / Ppeff mm		140	347	243	258	112	180	242	152	203	244	95	58
F1 Sr max = 3.4*Cov + K1*K2*0.425*Dia/Ppeff mm	**Sr1**	**344**	**517**	**413**	**394**	**303**	**350**	**412**	**356**	**339**	**380**	**272**	**235**
F1 Applied Forces Reinforcement Strain εs μStrain		-666	-505	-487	-561	-842	-227	-626	-336	-590	-6	-1491	-1362
F1 Concrete in Tension Stifffening Strain εc μStrain		-149	-415	-415	-289	-191	-252	-415	-162	-346	-519	-101	-79
F1 Mean Strain Between Cracks εcm =fcteffxMR/Es μStrain		-88	-88	-88	-88	-88	-88	-88	-88	-88	-88	-88	-88
F1 Average Microstrain = (εsm = εs - εc) - εcm μStrain		-428	-2	16	-183	-563	113	-123	-85	-156	601	-1301	-1196
F1 Limiting Strain = 0.6 * εs μStrain		-400	-303	-292	-336	-505	-136	-375	-201	-354	-3	-894	-817
F1 εm1 = Min of (εsm - εcm) & (0.6 * εs) = Max μstrain	**εm1**	**-428**	**-303**	**-292**	**-336**	**-563**	**-136**	**-375**	**-201**	**-354**	**-3**	**-1301**	**-1196**
F1 Crack Width = - εm1 x Sr1 mm	**W1**	**0.147**	**0.157**	**0.121**	**0.132**	**0.170**	**0.048**	**0.155**	**0.072**	**0.120**	**0.001**	**0.354**	**0.280**
F2 Neutral Axis X, from Face 1 towards Face 2 mm		415	457	457	155239	207	427	457	450	487	448	281	167
F2 Reinforcement Stress N/mm²		44	21	20	-112	37	14	26	14	17	0	149	183
F2 Strain Distribution Factor K2		0.000	0.000	0.000	0.999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F2 Kt x Concrete Tensile Stress fcteff = 0.4 x Fctm N/mm²		0.000	0.000	0.000	-1.159	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F2 Concrete Tensile Stress Width mm		0	0	0	119	0	0	0	0	0	0	0	0
F2 Aceff2 = width of section x Stress Width mm²		0	0	0	119211	0	0	0	0	0	0	0	0
F2 3.4 * Cover mm		0	0	0	136	0	0	0	0	0	0	0	0
F2 Ppeff2 = As2 / Aceff2		0.001	0.001	0.001	0.020	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
F2 φ Equiv - Where alt bars of Diff Dia Ref Equ 7.11		25.0	20.0	20.0	15.2	12.0	20.0	20.0	20.0	20.0	16.0	20.0	25.0
F2 K1 * K2 * 0.425 * Dia / Ppeff2 mm		0	0	0	258	0	0	0	0	0	0	0	0
F2 Sr max = 3.4*Cov + 0.8*K2*0.425*Dia/Ppeff2 mm	**Sr2**	**0**	**0**	**0**	**394**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
F2 Applied Forces Reinforcement Strain εs μStrain		0	0	0	-560	0	0	0	0	0	0	0	0
F2 Concrete in Tension Stifffening Strain εc μStrain		0	0	0	-289	0	0	0	0	0	0	0	0
F2 Mean Strain Between Cracks εcm = fcteff x MR / Es μStrain		0	0	0	-88	0	0	0	0	0	0	0	0
F2 Average Microstrain = (εsm = εs - εc) - εcm μStrain		0	0	0	-182	0	0	0	0	0	0	0	0
F2 Limiting Strain = 0.6 * εs μStrain		0	0	0	-336	0	0	0	0	0	0	0	0
F2 εm2 = Min of (εsm - εcm) & (0.6 * εs) = Max μstrain	**εm2**	**0**	**0**	**0**	**-336**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
F2 Crack Width = - εm2 x Sr2 mm	**W2**	**0.000**	**0.000**	**0.000**	**0.132**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

EC2 DESIGN TOOL

CRACK WIDTH CALCULATIONS

HAC-PRO 1 - 5 - 2 CRACK 5

Howes Atkinson Crowder LLP

Comparison between BS8007 & EC2 Crack Width Calculations **F1 = Face 1 (Tens)** **F2 = Face 2 (Comp)**

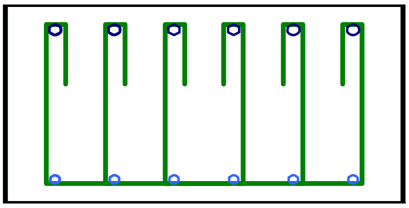
BS Crack Calculation	Case	13	14	15	16	17	18	19	20	21	22	23	24
F1 Conc in Tension Stiffening Stress N/mm²		-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667
F2 Conc in Tension Stiffening Stress N/mm²		-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667	-0.667
Conc in Tension Stiffening Force kN		-135	-64	-49	0	-46	-46	-44	-6	-6	-86	-86	-167
F1 Neutral Axis X, from Face 2 towards Face 1 mm		194	129	206	5893	270	327	335	245	236	170	170	-610
F1 Reinforcement Stress N/mm²		-110	-309	-194	112	-221	-229	-203	1	-12	-1	-1	-49
F1 Strain at Surface Due to Forces Є1 µStrain		-653	-1914	-1378	0	-1571	-1523	-1365	-360	-454	-7	-7	-261
F1 Conc in Tension Stiffening Strain Є2 µStrain		-205	-317	-69	0	-135	-126	-123	0	-155	-527	-527	-153
F1 Average Strain Єm = Є1- Є2 µStrain	**Єm1**	**-449**	**-1597**	**-1309**	**0**	**-1435**	**-1397**	**-1242**	**-360**	**-300**	**520**	**520**	**-109**
F1 3acr=3*((((cover+φ/2)^2+(ctrs/2)^2)^0.5)-φ/2) mm		231	272	254	365	355	293	293	280	280	679	679	237
F1 Strain Dist Factor = 1 / (1+2(acr-cmin)/(H-X))		0.890	0.806	0.789	0.977	0.633	0.750	0.744	0.342	0.376	0.564	0.564	0.921
F1 Crack Spacing Srmax=3acr/(1+2(acr-cmin)/(H-X))mm	**Sr1**	**206**	**219**	**200**	**357**	**225**	**219**	**218**	**96**	**105**	**383**	**383**	**218**
F1 Crack Width = - Єm1 x Sr1 mm	**W1**	**0.092**	**0.350**	**0.262**	**0.000**	**0.323**	**0.306**	**0.270**	**0.034**	**0.031**	**0.000**	**0.000**	**0.023**
F2 Neutral Axis X, from Face 1 towards Face 2 mm		406	321	244	-5443	230	273	265	55	64	430	430	910
F2 Reinforcement Stress N/mm²		42	82	162	118	277	289	276	245	254	0	0	-38
F2 Strain at Surface Due to Forces Є1 µStrain		0	0	0	0	0	0	0	0	0	0	0	-175
F2 Conc in Tension Stiffening Strain Є2 µStrain		0	0	0	0	0	0	0	0	0	0	0	-102
F2 Average Strain Єm = Є1- Є2 µStrain	**Єm2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-73**
F2 3acr=3*((((cover+φ/2)^2+(ctrs/2)^2)^0.5)-φ/2) mm		233	274	264	365	355	293	293	280	280	679	679	237
F2 Strain Dist Factor = 1 / (1+2(acr-cmin)/(H-X))		0.790	0.620	0.740	0.977	0.670	0.782	0.786	0.696	0.688	0.339	0.339	0.921
F2 Crack Spacing Srmax=3acr/(1+2(acr-cmin)/(H-X))mm	**Sr2**	**184**	**170**	**196**	**357**	**238**	**229**	**230**	**195**	**193**	**230**	**230**	**218**
F2 Crack Width = - Єm2 x Sr2 mm	**W2**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.015**

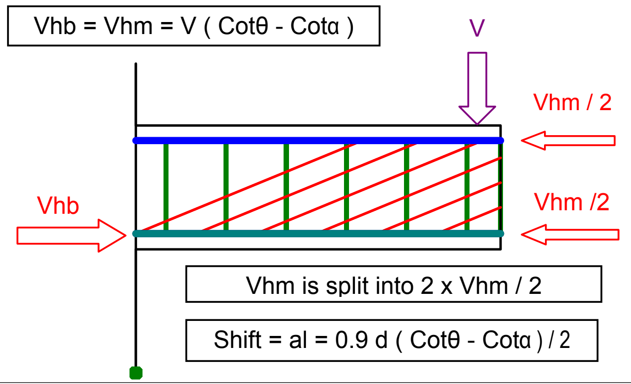
EC2 Crack Calculation	Case	13	14	15	16	17	18	19	20	21	22	23	24
F1 Neutral Axis X, from Face 2 towards Face 1 mm		183	121	196	5849	263	317	326	243	233	160	160	-611
F1 Reinforcement Stress N/mm²		-109	-307	-193	93	-214	-223	-197	-2	-13	-1	-1	-49
F1 Strain Distribution Factor K2		0.500	0.500	0.500	0.000	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.835
F1 Kt x Concrete Tensile Stress fcteff = 0.4 x Fctm N/mm²		-1.159	-1.159	-1.159	0.000	-1.159	-1.159	-1.159	-1.159	-1.159	-1.159	-1.159	-1.159
F1 Concrete Tensile Stress Width mm		139	110	85	0	79	94	91	19	22	147	147	131
F1 Aceff = width of section x tensile stress width mm²		138992	65764	50791	0	47445	47133	45690	5747	6661	87973	87973	131250
F1 3.4 * Cover mm		177	177	177	0	177	177	177	136	136	204	204	136
F1 Ppeff = As1 / Aceff		0.028	0.019	0.099	0.001	0.068	0.068	0.073	0.280	0.241	0.011	0.011	0.025
F1 φ Equiv - Where alt bars of Diff Dia Ref Equ 7.11		25.0	20.0	40.0	16.0	32.0	32.0	32.0	32.0	32.0	25.0	25.0	25.0
F1 K1 = Bond factor. Good = 0.8, Poor = 1.14		1.14	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	1.14	0.80	0.80
F1 K1 * K2 * 0.425 * Dia / Ppeff mm		214	178	69	0	80	80	75	19	23	543	372	285
F1 Sr max = 3.4*Cov + K1*K2*0.425*Dia/Ppeff mm	**Sr1**	**391**	**355**	**246**	**0**	**257**	**257**	**251**	**155**	**159**	**747**	**576**	**421**
F1 Applied Forces Reinforcement Strain εs µStrain		-546	-1533	-964	0	-1071	-1114	-986	-9	-67	-6	-6	-246
F1 Concrete in Tension Stifffening Strain εc µStrain		-205	-303	-59	0	-85	-85	-82	-21	-24	-519	-519	-232
F1 Mean Strain Between Cracks εcm =fcteffxMR/Es µStrain		-88	-88	-88	0	-88	-88	-88	-88	-88	-88	-88	-88
F1 Average Microstrain = (εsm = εs - εc) - εcm µStrain		-253	-1141	-817	0	-898	-941	-816	100	45	601	601	74
F1 Limiting Strain = 0.6 * εs µStrain		-328	-920	-578	0	-643	-668	-592	-5	-40	-3	-3	-148
F1 εm1 = Min of (εsm - εcm) & (0.6 * εs) = Max µstrain	**εm1**	**-328**	**-1141**	**-817**	**0**	**-898**	**-941**	**-816**	**-5**	**-40**	**-3**	**-3**	**-148**
F1 Crack Width = - εm1 x Sr1 mm	**W1**	**0.128**	**0.405**	**0.201**	**0.000**	**0.231**	**0.241**	**0.207**	**0.001**	**0.006**	**0.003**	**0.002**	**0.062**
F2 Neutral Axis X, from Face 1 towards Face 2 mm		417	329	254	-5399	237	283	274	57	67	440	440	911
F2 Reinforcement Stress N/mm²		38	70	142	99	247	259	247	218	226	0	0	-38
F2 Strain Distribution Factor K2		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.835
F2 Kt x Concrete Tensile Stress fcteff = 0.4 x Fctm N/mm²		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-1.159
F2 Concrete Tensile Stress Width mm		0	0	0	0	0	0	0	0	0	0	0	131
F2 Aceff2 = width of section x Stress Width mm²		0	0	0	0	0	0	0	0	0	0	0	131250
F2 3.4 * Cover mm		0	0	0	0	0	0	0	0	0	0	0	136
F2 Ppeff2 = As2 / Aceff2		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.025
F2 φ Equiv - Where alt bars of Diff Dia Ref Equ 7.11		20.0	16.0	20.0	16.0	32.0	32.0	32.0	32.0	32.0	25.0	25.0	25.0
F2 0.8 * K2 * 0.425 * Dia / Ppeff2 mm		0	0	0	0	0	0	0	0	0	0	0	285
F2 Sr max = 3.4*Cov + 0.8*K2*0.425*Dia/Ppeff2 mm	**Sr2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**421**
F2 Applied Forces Reinforcement Strain εs µStrain		0	0	0	0	0	0	0	0	0	0	0	-190
F2 Concrete in Tension Stifffening Strain εc µStrain		0	0	0	0	0	0	0	0	0	0	0	-232
F2 Mean Strain Between Cracks εcm = fcteff x MR / Es µStrain		0	0	0	0	0	0	0	0	0	0	0	-88
F2 Average Microstrain = (εsm = εs - εc) - εcm µStrain		0	0	0	0	0	0	0	0	0	0	0	130
F2 Limiting Strain = 0.6 * εs µStrain		0	0	0	0	0	0	0	0	0	0	0	-114
F2 εm2 = Min of (εsm - εcm) & (0.6 * εs) = Max µstrain	**εm2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-114**
F2 Crack Width = - εm2 x Sr2 mm	**W2**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.048**

Shear Design **BS & EC2 Compared**

BS Cap 0.219 **EC2 Cap** 0.173

Cross Section





Common Data		
Ultimate Applied Shear kN	Vu	297
Ultimate Axial Load kN	Nu	-185
Ultimate Moment kNm	Mu	400
Effective Depth d	d	524

BS increases vc when closer than 2d from support.
EC2 applies a reduction factor on loads closer than 2d.

EC2 Shear Calculation C 30 / 37

Cl 6.2.2 Without Shear Legs

VRd,c = (CRd,c k (100 ρ1 fck)$^{1/3}$ + (k1 σcp)) bw d
≥ (vmin + k1 σcp) bw d (k1 = 0.15)

Cl 6.2.3 With Shear Legs - Min of

VRd,s = (Asw / s) z fywd (cotθ + cotα) sinα
VRd,max = αcw bw z v1 fcd (cotθ + cotα) / (1 + cot²θ)

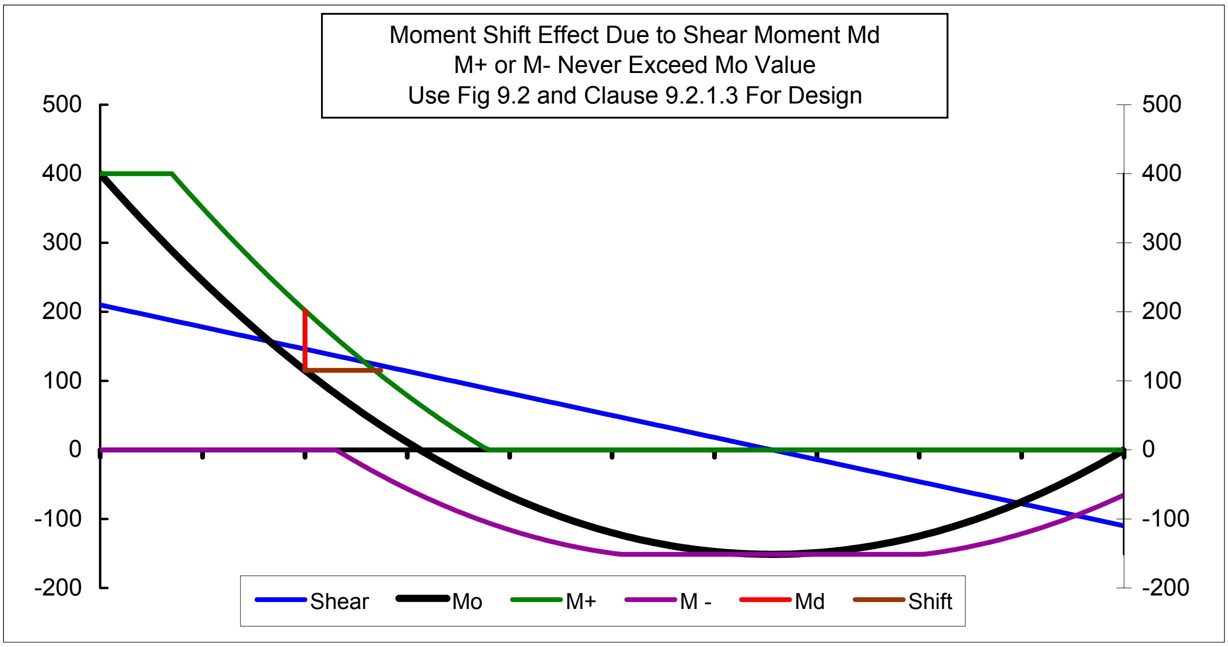
H	B	φ1	Sp, nr	Cov	φ2	Sp, nr	Cov	φE	Fact	N	M	Input
600	1000	32	150	60	25	150	60	0	0	-185	400	U

Type	φ	Long	Start	Trans	θ°	α°	xD	Vratio	Sect	F1	V	VEC2	LF	Min θ°
S	16	300	150	150	21.8	90	2.0	0.1	Wall	int	297	297	1.35	21.8

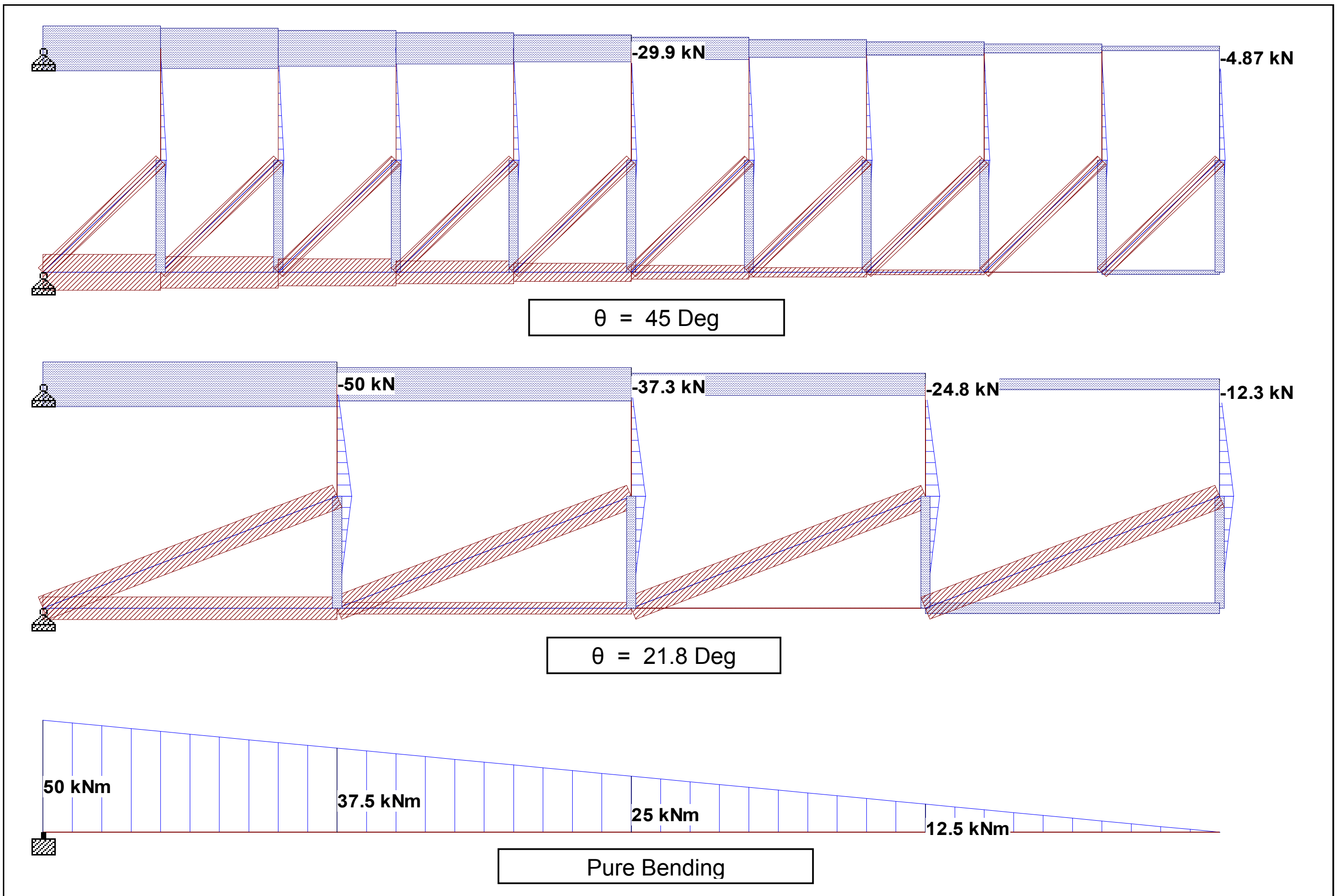
BS Without Shear Reinforcement			EC2 Without Shear Reinforcement Cl 6.2.2		
Ultimate Applied Shear Stress N/mm²	v	0.567	CRd,c = 0.18 / (γm = 1.5) Factor	CRd,c	0.12
			k = Min of 2.0 or 1 + (200 / d)$^{1/2}$ Factor	k	1.618
Tension Reinf As / Bd	ρ1	0.010	ρ1 = Min of 0.02 or As1 / b d Ratio	ρ1	0.010
Tension Reinf %As / Bd Max usable = 3	As1%	1.023	(100 x ρ1 x fck)$^{1/3}$		3.131
			Fatigue Adjustment Factor (fck / fck,fat)$^{1/3}$	fat	1
Min of (% As / Bd)$^{1/3}$ or (3)$^{1/3}$ = 1.422	A	1.008	National Annex k1 = EC2 recommended	k1	0.15
(400 / d)$^{1/4}$ >= 0.67 If No legs, >=1.0 If Legs	B	1.000	NEd / Ac = Axial / Area of Section N/mm²		-0.31
0.79 x A x B / (γm = 1.25) N/mm²	.79AB/γ	0.637	National Annex Value for α for shear	α	1.0
(fcu / 25)$^{1/3}$ but not > (40 / 25)$^{1/3}$ = 1.1696	Factor	1.140	fcd = α fck / (γm = 1.5) N/mm²	fcd	20
Ult Concrete vc N/mm²	vc	0.726	0.2 x fcd N/mm²	0.2fcd	4.0
Axial Adj = 0.6 (Nu / Ac) x Vu h / Mu N /mm²	vcax	-0.08	σcp = Min of: NEd / Ac or 0.2 fcd N/mm²	σcp	-0.31
Ult vc incl axial adjust or enhancement N/mm²	vc'	0.643	VRd,c = (CRd,c k(100ρ1 fck)$^{1/3}$ + k1σcp) bw d kN	VRd,c	294.3
Fatigue Adjustment Factor (fcu / fcu,fat)$^{1/3}$	fat	1.000	vmin = 0.035 k$^{3/2}$ fck$^{1/2}$ N/mm²	vmin	0.394
			Fatigue Adjustment Factor (fck / fck,fat)$^{1/2}$	fat	1
Distance From Support in Effective Depths	xd	2.00	VRd,c min = (vmin + k1 σcp) bw d kN	VRd,c	182.5
			Red Factor v = 0.6 (1-(fck/250))	v	0.528
Max Shear Stress at Support Face N/mm²	vc max	4.866	Max shear stress at support 0.5 v fcd N/mm²	0.5vfcd	5.28
			VED max value at Support = 0.5 bw d v fcd kN	VED	2767
			Shear Shift Distance a1 = d mm	mm	524
Shear Capacity Due to Concrete Only kN	**Vc**	**337**	**Unreinforced Shear Resistance kN**	**Vc**	**294.3**
BS With Shear Legs (> 0.092 %)			**EC2 With Shear Legs Cl 6.2.3 (> 0.088 %)**		
			Concrete Strut Angle	θ	21.8
% AsL / BSr = Asv / bSv	Ratio	0.447	Verticle Leg Angle	α	90
			Asw / s mm (where s = longitudinal spacing)	Asw / s	4.468
0.87 Fyv N/mm²	Fywd	435	z = 0.9d mm	z	471.6
			Fatigue Factor x fywd = fyk / (γm = 1.15) N/mm²	fywd	434.8
Bent Bars Fatigue Factor (fyd,fat / fyd)	fat	1.000	VRd,s = (Asw / s) z fywd (cotθ + cotα) sinα kN	VRd,s	2291
			σcp / fcd = (NEd / Ac) / fcd or 0 If Tension	σcp/ fcd	0
0.87 Fyv x Fatigue factor N/mm²		435	αcw = 1 or (1+ σcp /fcd) or 1.25 or 2.5(1 -σcp/fcd)	αcw	1
			v1 = v x (1 - 0.5Cosα)	v1	0.528
v-vc N/mm²	v-vc	1.944	VRd,max=αcw bw z v1 fcd (cotθ+cotα)/(1+cot²θ)	VRd,mx	1717
			Shear Shift Distance = z (cot θ - cot α) / 2	mm	589.5
Shear Capacity Due To Legs kN	**VL**	**1018**	**With Shear Legs Resistance kN**	**VL**	**1717**
BS Shear Capacity			**EC2 Shear Capacity**		
Total Shear Capacity = Conc + Shear Legs kN	**Vc+VL**	**1356**	**ValueUsed For calculating Capacity**	**V**	**1717**
Shear Capacity Ratio	**Ratio**	0.219	Shear Capacity Ratio	**Ratio**	0.173

Moment (Md) Due to Shear θ **Md = 0.9 x d1 x V x 0.5 x Cotθ** **Shift = al = 0.9 x d1 x 0.5 x Cot θ**

Beam, Cant	Beam		Length	8	m	W	320	kN	FEM L (RH Pinned)	320	
Legs Y or N	Y		Check at	0.200	x L	M+ or M-	M+		FEM	N/A	
θ =	21.8	Deg	Dia+	25	mm	Cov+	60	mm	V at Check	146	
H =	600	mm	Dia -	20	mm	Cov -	60	mm	0.5 Cotθ	1.250	
TDL or UDL or P at L/2 for Beam or at L for Cant							UDL		d1	527.5	mm
L End Fixity Moment or 0 For Simple Supp or Cant for Cantilever							400	kNm	Md at Check	87	kNm
R End Fixity Moment or 0 For Simple Supp or Free for Cantilever							0	kNm	Shift at Check	593	mm



Strut Action Force Shift for a 5m x 1m dp Cantilever Truss with 10kN at the end.



EC2 DESIGN TOOL

GENERAL SHEAR

HAC-PRO 1 - 5 - 2 SHEAR 3

Howes Atkinson Crowder LLP

Shear Design 1

Code	EC2	Conc	30	/	37 H	600 bw	1000 fyk	500 θ	21.8 d1	528 fywd 434.8
Shear kN		Dia1	25	Ctrs or Nr (< 50)		150 Cov 1	60 As1	3272 S < Smax = 0.75d1 =		396
V	600	Leg	12	Ctrs or Nr (< 50)		300 S	300 Asw	377 % =	0.126 Min % =	0.088

Concrete	K	=	Min of 1 + (200 / d1) ^ 0.5 or 2.0	=	0		
	ρ1	=	Min of As1 / bw d1 or 0.02	=	0.000		
	vrdc	=	Max of 0.035 K^1.5 fck^0.5 or 0.12 x K x (100 x ρ1 x fck)^(1/3)	=	0	N/mm²	
Shear Force Shift		=	d1	=	0	mm	
	Vrdc	=	(Min of (0.5 (0.6 (1 - fck / 250)) fck / 1.5) or vrdc) x bw x d1 / 1000	=	**0**	kN	
Legs		=	Asw / S	=	1.257	mm	
Transv Leg Ctrs		=	Ctrs or (bw / nr)	=	300	mm	
Max Transv Ctrs		=	Min of 0.75d1 or 600mm	=	396	mm	
Shear Force Shift		=	0.9 d1 x 0.5 x Cot θ	=	593	mm	
Vrds		=	(Asw / S) x 0.9 d1 x fywd x Cot θ / 1000	=	**648.5**	kN	OK
Vrd,max		=	(bw 0.9 d1 (0.6 (1 - (fck / 250)) fck / 1.5) / (Cotθ + Tanθ)	=	1729	kN	OK

Shear Design 2

Code	BS	Conc	30	/	37 H	600 bw	1000 fyk	500 θ	45 d1	528 fywd 434.8
Shear kN		Dia1	25	Ctrs or Nr (< 50)		150 Cov 1	60 As1	3272 S < Smax = 0.75d1 =		396
V	600	Leg	12	Ctrs or Nr (< 50)		300 S	300 Asw	377 % =	0.126 Min % =	0.088

Concrete	A	=	(400 / d) ^ 1/4 >= 0.67 If No legs, >=1.0 If Legs	=	1		
	B	=	Min of (100 As1 / bw d1) ^ 1/3 or 1.422	=	0.853		
	vc	=	(Min fcu or 40 / 25) ^ 1/3 x 0.79 x A x B / 1.25	=	0.614	N/mm²	
Shear Force Shift		=	N/A	=	N/A	mm	
	Vc	=	(Min of (0.8 (fcu^1/2) or 5 or vc) x bw x d1 / 1000	=	**324**	kN	
Legs		=	Asw / bw S Min = 0.0009	=	0.001		
Transv Leg Ctrs		=	Ctrs or (bw / nr)	=	300	mm	
Max Transv Ctrs		=	Min of 0.75d1 or 600mm	=	396	mm	
Shear Force Shift		=	N/A	=	N/A	mm	
Vrds		=	(Asw / bw S) x fywd x bw x S and Add to Vc	=	**288.2**	kN	
Total		=	Total BS Capacity	=	**612.2**	kN	OK

Shear Design 3

Code	BS	Conc	30	/	37 H	600 bw	1000 fyk	500 θ	21.8 d1	528 fywd 434.8
Shear kN		Dia1	25	Ctrs or Nr (< 50)		6 Cov 1	60 As1	2945 S < Smax = 0.75d1 =		396
V	600	Leg	0	Ctrs or Nr (< 50)		0 S	0 Asw	0 % =	0 Min % =	0.000

Concrete	A	=	(400 / d) ^ 1/4 >= 0.67 If No legs, >=1.0 If Legs	=	0.933		
	B	=	Min of (100 As1 / bw d1) ^ 1/3 or 1.422	=	0.823		
	vc	=	(Min fcu or 40 / 25) ^ 1/3 x 0.79 x A x B / 1.25	=	0.553	N/mm²	
Shear Force Shift		=	N/A	=	N/A	mm	
	Vc	=	(Min of (0.8 (fcu^1/2) or 5 or vc) x bw x d1 / 1000	=	**291.9**	kN	
Legs		=	Asw / bw S Min = 0.0009	=	0.000		
Transv Leg Ctrs		=	Ctrs or (bw / nr)	=	0	mm	
Max Transv Ctrs		=	Min of 0.75d1 or 600mm	=	0	mm	
Shear Force Shift		=	N/A	=	N/A	mm	
Vrds		=	(Asw / bw S) x fywd x bw x S and Add to Vc	=	**0**	kN	
Total		=	Total BS Capacity	=	**291.9**	kN	< V

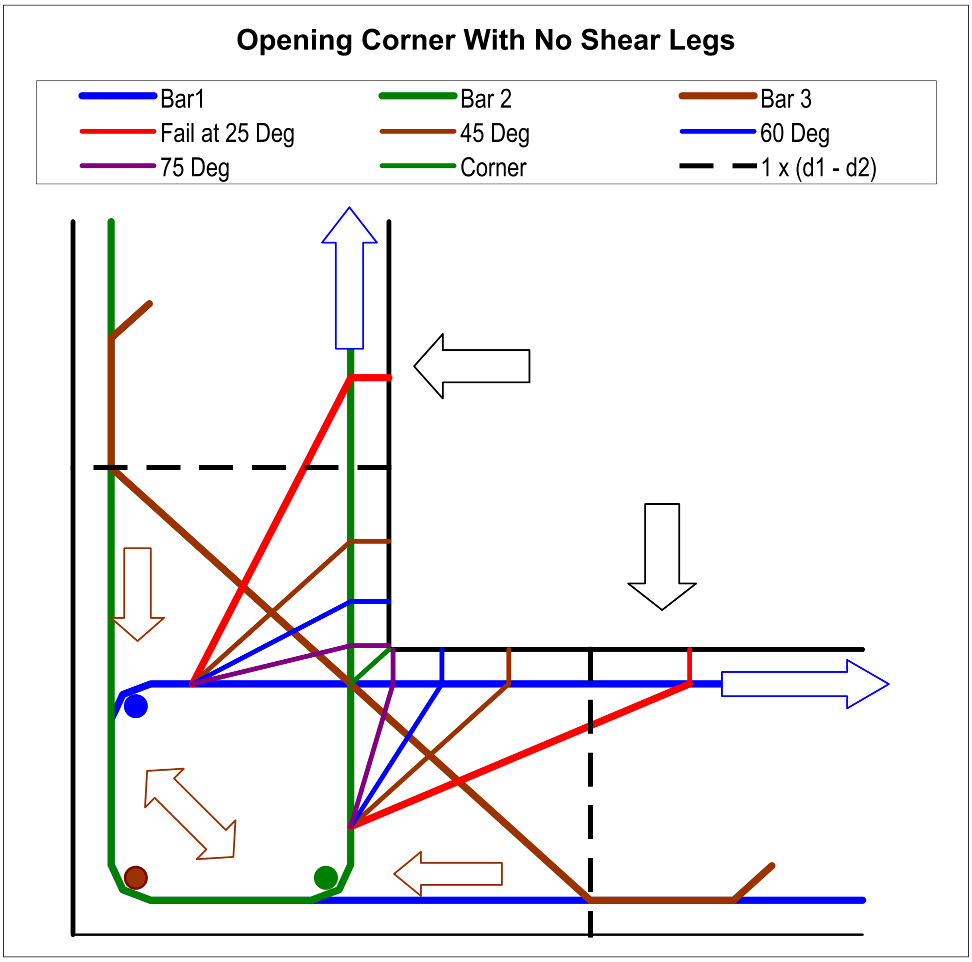
Shear Design 4

Code	EC2	Conc	30	/	37 H	600 bw	1000 fyk	500 θ	21.8 d1	528 fywd 434.8
Shear kN		Dia1	25	Ctrs or Nr (< 50)		6 Cov 1	60 As1	2945 S < Smax = 0.75d1 =		396
V	600	Leg	0	Ctrs or Nr (< 50)		0 S	0 Asw	0 % =	0 Min % =	0.000

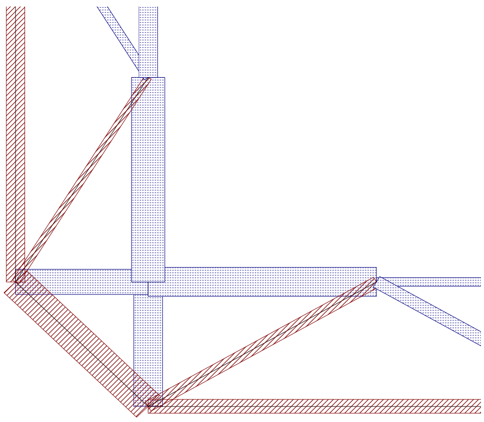
Concrete	K	=	Min of 1 + (200 / d1) ^ 0.5 or 2.0	=	1.616		
	ρ1	=	Min of As1 / bw d1 or 0.02	=	0.006		
	vrdc	=	Max of 0.035 K^1.5 fck^0.5 or 0.12 x K x (100 x ρ1 x fck)^(1/3)	=	0.496	N/mm²	
Shear Force Shift		=	d1	=	528	mm	
	Vrdc	=	(Min of (0.5 (0.6 (1 - fck / 250)) fck / 1.5) or vrdc) x bw x d1 / 1000	=	**261.7**	kN	< V
Legs		=	Asw / S	=	0.000	mm	
Transv Leg Ctrs		=	Ctrs or (bw / nr)	=	0	mm	
Max Transv Ctrs		=	Min of 0.75d1 or 600mm	=	0	mm	
Shear Force Shift		=	0.9 d1 x 0.5 x Cot θ	=	593	mm	
Vrds		=	(Asw / S) x 0.9 d1 x fywd x Cot θ / 1000	=	**0**	kN	
N/A		=	N/A	=	**N/A**	kN	

Forces in an Opening Corner Without Shear legs

DATA	
Section Depth H	600
Length x H	2.5
Cover	60
Bar Dias	25
R of U Bars x D	3
Diagonal Bar	Y
Corner Crack	Y
1st Shear Angle	75
2nd Shear Angle	60
3rd Shear Angle	45
Shear Failure Angle	25
d1-d2 Intersect Fact	0.66
d1-d2 Fact From Rebar	1.00



Strut and Tie Model



From QSE Analysis of a 16m x 12m Box Loaded Internally

Blue Denotes Tension **Brown Denotes Compression**

Note how shear compressive struts contribute to the force that passes around the corner

EC2 DESIGN TOOL

STEP BY STEP SHEAR CALCULATIONS

HAC-PRO 1 - 5 - 2 SHEAR 5

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Comparison between BS8110 & EC2 For Normal Shear Calculations **Note Min Ult Axial Load = + or -1**

Common Data	Case	1	2	3	4	5	6	7	8	9	10	11	12
Ultimate Applied Shear kN	V_{ED}	**297**			**14**	**127**	**1382**		**61**	**120**	**1**	**387**	**50**
Ultimate Axial Load kN	N_{ED}	**-185**			**-722**	**14**	**1**		**-270**	**-120**	**1**	**1**	**965**
Effective Depth d	d	524			252	234	538		524	550	552	382	207
Distance From Support in Multiple of Effective Depths	xd	2.00			2.00	2.00	2.00		2.00	2.00	2.00	2.00	2.00
Concrete Strut Angle - not used in BS analysis	θ	21.8			0.0	0.0	21.8		0.0	0.0	0.0	21.8	21.8
Verticle Leg Angle - not used in BS analysis	α	90			0	0	90		0	0	0	90	90
BS Design													
Ultimate Applied Shear Stress N/mm²	v	0.567			0.054	0.542	2.571		0.116	0.218	0.002	1.688	0.403
Tension Reinforcement %As / BD - Max usable = 3	As1%	1.023			0.946	0.895	0.609		1.023	0.381	0.243	1.404	1.976
Min of (% As / BD) $^{1/3}$ or (3) $^{1/3}$ = 1.422	A	1.0077			0.9818	0.9637	0.8476		1.0077	0.7248	0.6239	1.1196	1.2549
(400 / D) $^{0.25}$ > 0.67 If No legs, >1.0 If Design Legs	B	1			1.1221	1.1434	1		0.9347	0.9235	0.9226	1.0116	1.179
0.79 x A x B / (γm = 1.25) N/mm²	.79AB/γ	0.6369			0.6962	0.6964	0.5357		0.5953	0.423	0.3638	0.7158	0.9351
(fcu / 25) $^{1/3}$ but not > (40 / 25)1/3 = 1.1696	Factor	1.140			1.140	1.140	1.140		1.140	1.140	1.140	1.140	1.140
Ult vc incl axial adjust or enhancement N/mm²	vc'	0.643			0.001	-3.240	0.611		0.618	0.410	0.415	0.817	1.189
Maximum Shear Stress at Support Face N/mm²	vc max	4.866			4.866	4.866	4.866		4.866	4.866	4.866	4.866	4.866
Shear Capacity Due to Concrete Only kN	**Vc**	**337**			**0**	**-758**	**329**		**324**	**226**	**229**	**187**	**148**
AsL / BSr = Asv / bSv	Ratio	0.0045			0.0000	0.0000	0.0045		0.0000	0.0000	0.0000	0.0025	0.0017
0.87 Fyv N/mm²	Fywd	435			435	435	435		435	435	435	435	435
v-vc N/mm²	v-vc	1.944			0.000	0.000	1.944		0.000	0.000	0.000	1.093	0.759
Shear Capacity Due To Legs kN	**VL**	**1018**			**0**	**946**	**1045**		**0**	**0**	**0**	**251**	**94**
Total Shear Capacity = Conc + Shear Legs kN	**Vc+VL**	**1356**			**0**	**188**	**1373**		**324**	**226**	**229**	**438**	**242**
Shear Capacity Ratio	**Ratio**	**0.2191**			**53.504**	**0.6743**	**1.0063**		**0.1877**	**0.532**	**0.0059**	**0.8841**	**0.2067**
EC2 Design													
Without Shear Reinforcement Cl 6.2.2													
$C_{Rd,c}$ = 0.18 / (γm) Factor	$C_{Rd,c}$	0.12			0.12	0.12	0.12		0.12	0.12	0.12	0.12	0.12
k = Min of 2.0 or 1 + (200 / d)$^{1/2}$ Factor	k	1.6178			1.8903	1.9245	1.61		1.6178	1.603	1.6019	1.7236	1.9829
ρ1 = Min of 0.02 or As1 / b d Ratio	ρ1	0.0102			0.0095	0.0090	0.0061		0.0102	0.0038	0.0024	0.0140	0.0198
28 Day Cylinder Strength f_{ck} N/mm²	f_{ck}	30			30	30	30		30	30	30	30	30
(100 x ρ1 x f_{ck}) $^{1/3}$		3.1311			3.0506	2.9945	2.6335		3.1311	2.2522	1.9385	3.479	3.8992
Natonal Annex Value for k1 = EC2 recommended	k1	0.15			0.15	0.15	0.15		0.15	0.15	0.15	0.15	0.15
National Annex Value for α for shear	α	1.00			1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00
f_{cd} = α f_{ck} / $γ_m$ N/mm²	f_{cd}	20.0			20.0	20.0	20.0		20.0	20.0	20.0	20.0	20.0
0.2 x f_{cd} N/mm²	0.2f_{cd}	4.00			4.00	4.00	4.00		4.00	4.00	4.00	4.00	4.00
N_{ED} / Ac = Axial / Area of Section N/mm²	N_{ED}/Ac	-0.31			-2.41	0.05	0.00		-0.45	-0.20	0.00	0.00	5.36
$σ_{cp}$ = Min of:- N_{ED} / Ac or 0.2 f_{cd} N/mm²	$σ_{cp}$	-0.31			-2.41	0.05	0.00		-0.45	-0.20	0.00	0.00	4.00
$V_{Rd,c}$ = ($C_{Rd,c}$ k(100ρ1 f_{ck})$^{1/3}$ + k1 $σ_{cp}$) bw d kN	$V_{Rd,c}$	294			83	163	274		283	222	206	165	190
vmin = 0.035 k $^{3/2}$ f_{ck} $^{1/2}$ N/mm²	v_{min}	0.39			0.50	0.51	0.39		0.39	0.39	0.39	0.43	0.54
$V_{Rd,c}$ min = (v_{min} + k1 $σ_{cp}$) bw d kN	$V_{Rd,cmin}$	182			35	121	211		171	197	215	100	141
Shear Resistance of Concrete without Shear Legs kN	$V_{Rd,c}$	294			83	163	274		283	222	215	165	190
Red Factor v = 0.6 (1 - (f_{ck} / 250))	v	0.528			0.528	0.528	0.528		0.528	0.528	0.528	0.528	0.528
VED max value at Support = 0.5 bw d v f_{cd} kN	VED	2767			1332	1236	2838		2767	2904	2915	1210	656
Unreinforced Shear Resistance kN	**Vc**	**294**			**83**	**163**	**274**		**283**	**222**	**215**	**165**	**190**
Shear Shift Distance a1 = d mm	mm	524			252	234	538		524	550	552	382	207
With Shear Legs Cl 6.2.3													
A_{sw} / s mm	A_{sw}/s	4.468					4.468					1.508	1.0472
z = 0.9d mm	z	471.6					483.75					343.8	186.3
f_{ywd} = f_{yk} / $γ_m$ N/mm²	f_{ywd}	435					435					435	435
$V_{Rd,s}$ = (A_{sw} / s) Z f_{ywd} (cot θ + cot α) Sin α kN	$V_{Rd,s}$	2291					2350					564	212
$σ_{cp}$ / f_{cd} = (N_{ED} / Ac) / f_{cd} or 0 If Tension	$σ_{cp}$/ f_{cd}	0.00					0.00					0.00	0.27
$α_{cw}$ = 1 or (1+ $σ_{cp}$ /f_{cd}) or 1.25 or 2.5(1 -$σ_{cp}$/f_{cd})	$α_{cw}$	1.00					1.00					1.00	1.25
Red Factor = v1 = v x (1 - 0.5Cosα)	v1	0.528					0.528					0.528	0.528
$V_{Rd,max}$ = $α_{cw}$ bw z v1 f_{cd} (cot θ+cot α)/(1 + cot ^{2}θ)	$V_{Rd,max}$	1717					1762					751	509
With Shear Legs Resistance	**VL**	1717					1762					564	212
Shear Shift Distance = z (cot θ - cot α) / 2	mm	590					605					430	233
ValueUsed For calculating Capacity	**V**	**1717**			**83**	**163**	**1762**		**283**	**222**	**215**	**564**	**212**
Shear Capacity Ratio	**Ratio**	**0.17**			**0.16**	**0.78**	**0.78**		**0.21**	**0.54**	**0.01**	**0.69**	**0.24**

EC2 DESIGN TOOL

STEP BY STEP SHEAR CALCULATIONS

HAC-PRO 1 - 5 - 2 SHEAR 6

HAC

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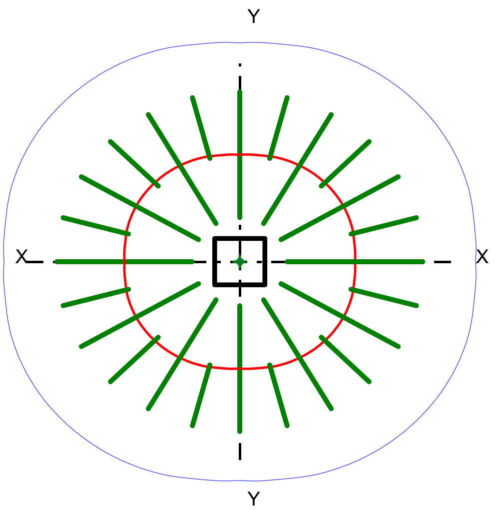
Comparison between BS8110 & EC2 For Normal Shear Calculations **Note Min Ult Axial Load = + or -1**

Common Data	**Case**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Ultimate Applied Shear kN	V_{ED}	**393**	**397**	**387**	**50**	**275**	**337**	**275**	**50**	**50**	**150**	**150**	**400**
Ultimate Axial Load kN	N_{ED}	**1**	**1**	**1**	**1600**	**2500**	**2500**	**2500**	**1500**	**1500**	**1**	**1**	**-400**
Effective Depth d	d	536	388	378	390	359	439	439	244	244	528	528	248
Distance From Support in Multiple of Effective Depths	xd	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Concrete Strut Angle - not used in BS analysis	θ	21.8	21.8	21.8	21.8	21.8	21.8	45.0	21.8	45.0	45.0	45.0	29.8
Verticle Leg Angle - not used in BS analysis	α	90	90	90	90	90	90	90	90	90	90	90	90
BS Design													
Ultimate Applied Shear Stress N/mm²	v	0.734	1.705	1.706	0.366	1.276	1.535	1.252	0.683	0.683	0.474	0.474	1.616
Tension Reinforcement %As / BD - Max usable = 3	As1%	0.733	0.540	2.216	0.295	1.493	1.465	1.465	2.197	2.197	0.310	0.310	1.322
Min of (% As / BD) $^{1/3}$ or (3) $^{1/3}$ = 1.422	A	0.9018	0.8142	1.3038	0.6654	1.1428	1.1357	1.1357	1.3001	1.3001	0.6769	0.6769	1.0976
(400 / D) $^{0.25}$ > 0.67 If No legs, >1.0 If Design Legs	B	1	1.0076	1.0142	1.0063	1.0273	1	1	1.1315	1.1315	1	1	1.1275
0.79 x A x B / (γm = 1.25) N/mm²	.79AB/γ	0.5699	0.5185	0.8357	0.4232	0.742	0.7178	0.7178	0.9297	0.9297	0.4278	0.4278	0.7821
(fcu / 25) $^{1/3}$ but not > (40 / 25)1/3 = 1.1696	Factor	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140
Ult vc incl axial adjust or enhancement N/mm²	vc'	0.643	0.526	0.701	0.001	-3.240	0.611	0.976	0.618	0.410	0.415	0.817	1.189
Maximum Shear Stress at Support Face N/mm²	vc max	4.866	4.866	4.866	4.866	4.866	4.866	4.866	4.866	4.866	4.866	4.866	4.866
Shear Capacity Due to Concrete Only kN	**Vc**	**344**	**123**	**159**	**0**	**-698**	**134**	**214**	**45**	**30**	**131**	**258**	**294**
AsL / BSr = Asv / bSv	Ratio	0.0010	0.0017	0.0017	0.0022	0.0013	0.0016	0.0016	0.0026	0.0026	0.0035	0.0035	0.0035
0.87 Fyv N/mm²	Fywd	435	435	435	435	435	435	435	435	435	435	435	435
v-vc N/mm²	v-vc	0.456	0.759	0.759	0.976	0.569	0.683	0.683	1.139	1.139	1.518	1.518	1.518
Shear Capacity Due To Legs kN	**VL**	**248**	**192**	**229**	**1031**	**1209**	**446**	**331**	**210**	**219**	**504**	**377**	**104**
Total Shear Capacity = Conc + Shear Legs kN	**Vc+VL**	**592**	**315**	**388**	**1031**	**511**	**581**	**545**	**255**	**249**	**635**	**635**	**398**
Shear Capacity Ratio	**Ratio**	**0.6636**	**1.2611**	**0.9964**	**0.0485**	**0.5381**	**0.5803**	**0.5047**	**0.196**	**0.2007**	**0.2361**	**0.2361**	**1.004**
EC2 Design													
Without Shear Reinforcement Cl 6.2.2													
$C_{Rd,c}$ = 0.18 / (γm) Factor	$C_{Rd,c}$	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
k = Min of 2.0 or 1 + (200 / d) $^{1/2}$ Factor	k	1.6111	1.718	1.7274	1.7161	1.7462	1.6748	1.6748	1.9054	1.9054	1.6157	1.6157	1.8989
ρ1 = Min of 0.02 or As1 / b d Ratio	ρ1	0.0073	0.0054	0.0200	0.0029	0.0149	0.0146	0.0146	0.0200	0.0200	0.0031	0.0031	0.0132
28 Day Cylinder Strength f_{ck} N/mm²	f_{ck}	30	30	30	30	30	30	30	30	30	30	30	30
(100 x ρ1 x f_{ck}) $^{1/3}$		2.802	2.53	3.9149	2.0675	3.5511	3.529	3.529	3.9149	3.9149	2.1034	2.1034	3.4104
Natonal Annex Value for k1 = EC2 recommended	k1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
National Annex Value for α for shear	α	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
f_{cd} = α f_{ck} / $γ_m$ N/mm²	f_{cd}	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
0.2 x f_{cd} N/mm²	0.2f_{cd}	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
N_{ED} / Ac = Axial / Area of Section N/mm²	N_{ED}/Ac	0.00	0.00	0.00	10.16	8.33	8.33	8.33	16.67	16.67	0.00	0.00	-1.33
$σ_{cp}$ = Min of:- N_{ED} / Ac or 0.2 f_{cd} N/mm²	$σ_{cp}$	0.00	0.00	0.00	4.00	4.00	4.00	4.00	4.00	4.00	0.00	0.00	-1.33
$V_{Rd,c}$ = ($C_{Rd,c}$ k(100ρ1 f_{ck}) $^{1/3}$ + k1 $σ_{cp}$) bw d kN	$V_{Rd,c}$	290	122	184	140	290	288	288	109	109	129	129	143
vmin = 0.035 k $^{3/2}$ f_{ck} $^{1/2}$ N/mm²	v_{min}	0.39	0.43	0.44	0.43	0.44	0.42	0.42	0.50	0.50	0.39	0.39	0.50
$V_{Rd,c}$ min = (v_{min} + k1 $σ_{cp}$) bw d kN	$V_{Rd,cmin}$	210	101	99	141	225	223	223	81	81	125	125	75
Shear Resistance of Concrete without Shear Legs kN	$V_{Rd,c}$	290	122	184	141	290	288	288	109	109	129	129	143
Red Factor v1 = 0.6 (1 - (f_{ck} / 250))	v	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528
VED max value at Support = 0.5 bw d v f_{cd} kN	VED	2827	1229	1198	721	1138	1159	1159	386	386	1671	1671	1307
Unreinforced Shear Resistance kN	**Vc**	**290**	**122**	**184**	**141**	**290**	**288**	**288**	**109**	**109**	**129**	**129**	**143**
Shear Shift Distance a1 = d mm	mm	536	388	378	390	359	439	439	244	244	528	528	248
With Shear Legs Cl 6.2.3													
A_{sw} / s mm	A_{sw}/s	1.0472	1.0472	1.0472	0.7854	0.7854	0.7854	0.7854	0.7854	0.7854	2.0944	2.0944	3.4907
z = 0.9d mm	z	481.95	349.2	340.2	351	323.28	395.28	395.28	219.6	219.6	474.75	474.75	222.75
f_{ywd} = f_{yk} / $γ_m$ N/mm²	f_{ywd}	434.78	434.78	434.78	434.78	434.78	434.78	434.78	434.78	434.78	434.78	434.78	434.78
$V_{Rd,s}$ = (A_{sw} / s) Z f_{ywd} (cot θ + cot α) Sin α kN	$V_{Rd,s}$	548.62	397.51	387.26	299.67	276	337.47	134.98	187.48	74.988	432.31	432.31	590.29
$σ_{cp}$ / f_{cd} = (N_{ED} / Ac) / f_{cd} or 0 If Tension	$σ_{cp}$/ f_{cd}	8E-05	0.0002	0.0002	0.5079	0.4167	0.4167	0.4167	0.8333	0.8333	0.0001	0.0001	0
$α_{cw}$ = 1 or (1+ $σ_{cp}$ /f_{cd}) or 1.25 or 2.5(1 -$σ_{cp}$/f_{cd})	$α_{cw}$	1.0001	1.0002	1.0002	1.2302	1.25	1.25	1.25	0.4167	0.4167	1.0001	1.0001	1
Red Factor = v1 = v x (1 - 0.5Cosα)	v1	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528
$V_{Rd,max}$ = $α_{cw}$ bw z v1 f_{cd} (cot θ+cot α)/(1 + cot ^{2}θ)	$V_{Rd,max}$	1755	763.04	743.38	550.28	882.84	899.56	1304.4	99.951	144.94	1504.2	1504.2	1014.4
With Shear Legs Resistance	**VL**	548.62	397.51	387.26	299.67	276	337.47	134.98	99.951	74.988	432.31	432.31	590.29
Shear Shift Distance = z (cot θ - cot α) / 2	mm	602.48	436.53	425.28	438.78	404.13	494.14	197.64	274.52	109.8	237.38	237.38	194.47
ValueUsed For calculating Capacity	**V**	**549**	**398**	**387**	**300**	**276**	**337**	**135**	**100**	**75**	**432**	**432**	**590**
Shear Capacity Ratio	**Ratio**	**0.72**	**1.00**	**1.00**	**0.17**	**1.00**	**1.00**	**2.04**	**0.50**	**0.67**	**0.35**	**0.35**	**0.68**

Punching Shear See Sheet 3 For Method

Punching Shear



Control Perimeter at xD from Support Face is shown in Red
No Legs Capacity Perimeter Uout is shown in Blue if Uout > U1
Note:- If Uout is not displayed, no legs are required.
BS Circular Col Perimeter as a Square or Circle **Circle**
At Supp Face vRDmax = 0.5 (0.6 (1 - fck /250))1.0 fck / 1.5

EC2 Ult Punching Shear Stress N/mm²

Without Legs vRD,c ref Equ 6.47

= $C_{RD,c}$ k ((100ρ1 fck) ^ 1/3) + k1σcp
≥ vmin + k1 σcp

This is the stress part of equs 6.2a & 6.2b
where ρ1 is (ρx.ρy)^0.5 ≤ 0.2
based on a width of Col + 6D
σcp = (σcy + σcz) / 2 & k1 = 0.1
vmin = 0.035 (k ^ 3/2) (fck ^ 1/2)

With Shear Legs vRD,cs ref Equ 6.52

θ is fixed at 26.6° Cot θ = 2 See below
α is fixed at 90° Sin α = 1

$$= 0.75\ vRD,c + 0.75\ \frac{Asw\ fywd,ef\ (Cot\ \theta=2)\ d}{u1 \times d} / sr$$

Asw = Area of one perimeter of primary legs
fywd,e = 250 + 0.25d ≤ fyd
sr = Primary radial leg spacing
u1 = Control perimeter at xd from face

Default β Values	EC2	BS
Pi = Internal	**1.15**	**1.15**
Pe = Edge	**1.40**	**1.40**
Pc = Corner	**1.50**	**1.25**
Pr = Re-entrant	**1.30**	**1.30**
Basic Control Perim U1 dist =	**2.0D**	**1.5D**

H	B	D	φ1	Ctrs	Cov	φE	Fact	β or $M_{ED}X$	$M_{ED}Y$	M Per B	N	Des	fyk	fywd	fck / fcu		
600	1000	540	20	150	50			Def	N/A	140	0	U	500	385	30	37	EC2

Type	φ Leg	Sr	Start	Nr	Nra	X	Y	Sect	F1	FOS	Vratio	V_{ED}	udl	β	V kN	xD
Pi	20	405	270	12	12	600	600	Slab	Top	1.35	0	3750	0	1.150	4313	2.000

Ult Stress Capacity	**vRD,c**	As1 / B mm²	**2094**	**0.75 vRD,s**
CRD,c	0.120	As per Leg mm²		314
k = Min (2, (1+200/d)^0.5)	1.609	Asw per Ux mm²		3770
(ρ1fck)1/3	2.266	Sr mm		405
k1σcp = 100Nu / H B	0.000	U mm		9186
vmin + k1σcp	0.280	2 Asw fywd,ef / (Sr Ux)		0.780
vRD,c	0.438	1.5 Asw fywd,ef / (Sr Ux)		0.585

Vcap at Face Ult	**6843**	kN
vRD at Face Ult	**5.28**	N/mm²
vED at Face Ult	**3.33**	N/mm²
	Main Sheet	
U1vc Cap Ratio	**0.99**	**Displayed**
U1 Cap Ratio	**0.99**	
U Cap Ratio	**0.99**	

Ult EC2 Concrete Stress Capacity **0.75** x (If xD < 2D, 2D / xD else 1.0) x vRD,c **0.328** N/mm²
Ult EC2 Concrete Stress Capacity Limit at 2D 2vRD,c **0.875** N/mm²
Ult EC2 Conc & Reinf Stress Cap at xD = vRD,cs Using equations = **0.328** + **0.585** **0.913** N/mm²

Perimeter at Uout = 1000 x (4313 - 0 = 4313) / (0.438 x 540) **18251** mm
U1 = Basic Control Perimeter 2400 + ((2.0 x 3.142) x 540) x 2.00 **9186** mm
U = Check Control Perimeter at xD 2400 + ((2.0 x 3.142) x 540) x 2.00 **9186** mm

EC2 Capacity at U1using 2vRD,c or if no legs vRD,c Uvc Cap **4341** kN
EC2 Capacity at U1 based on Min of equations or 2vRD,c (or vRD,c if no legs) limit U1 Cap **4341** kN
EC2 Capacity at U based on Min of equations or 2vRD,c (or v,RD,c if no legs) limit U Cap **4341** kN

xD From Uout to Dro (Must be <= 1.5D) xD at Uout - xD at Dro **1.172** **632.7** mm
xD at Uout = (18251 - 2400) / (2.0 x 3.142 x 540) = **4.672** **2523** mm
xD & Distance From Face to U1 - Basic Control Perimeter xD at U1 **2.0** **1080** mm
xD & Distance From Face to Start of Main Radials xD at Drim **0.500** **270** mm
xD & Distance From Face to Start of Additional Radials Dri xD at Dria **2.000** **1080** mm
xD & Distance From Face to Outermost Radials Perimeter Dro xD at Dro **3.500** **1890** mm

% Area of Legs Min = **0.088** % AsL% at Dro **0.109** % AsL% at Dria **0.136** %
Tangential Spacing / D at Perimeter St / D at Dro **1.323** St / D at Dria **1.059**
Number of Legs in a longitudinal direction per Radial Main **5** Secondary **3**

Calculation of β Values

Where moments occur in the columns or piles that support a flat slab, the punching shear around the support will not be even. The β values take account of this by applying a factor to the analysis value.

Default values are shown adjacent for the general flat slab case where the spans are nearly equal. Where the exact method gives very low β values, consider using the default values.

	EC2	BS
Pi = Internal	1.15	1.15
Pe = Edge	1.4	1.4
Pc = Corner	1.5	1.25
Pr = Re-entrant (suggested)	1.3	1.3

Where the spans are not even or the arrangement is irregular, the β Value depends on the Shear Eccentricity. This is defined as Column Moment / Shear Force = M_{ED} / V_{ED} (EC2) and Mt / Vt (BS8110) and is in mm. xD is the number of effective depths from the support to Perimeter. Control Perimeter = 1.5D (BS) & 2.0D (EC2).

β due to MEDxx or MEDyy or both Pi **N/A** Pr **N/A** Pe **N/A** Pc **N/A**

BS8110 Ref Cl 3.7.6.2 x = Col Dim + (xD)d(2 if Pi, 1.5 if Pr or 1 if Pe)

			X - X x	X - X β	Y - Y x	Y - Y β	β
Pi	β =	Max of (1 + 1.5 (Mt / Vt) / x about each axis	2220	N/A	2220	N/A	N/A
Pr	β =	Max of (1.25 + 1.5 (Mt / Vt) / x about each axis	1815	N/A	1815	N/A	N/A
Pe	β =	Max of 1.25 & 1.25 + 1.5 (Mtxx / Vt) / x	1410	N/A		N/A	N/A
Pc	β =	1.25 Vt					N/A

EC2 Ref Cl 6.4.3

Pi = Internal
Fig 6.19
c1 & c2 relate to axis of bending

	c1	c2	k	M_{ED} / V_{ED}	u1	W1	β
M_{XX}	600	600	0.60	N/A	9186	8537352	N/A
M_{YY}	600	600	0.60	N/A	9186	8537352	N/A
Bi - Axial	600	600					N/A

Pr = Re-entrant
c1 & c2 relate to axis of bending

	c1	c2	k	M_{ED} / V_{ED}	u1	W1	β
M_{XX}	600	600	0.60	N/A	7489	6802014	N/A
M_{YY}	600	600	0.60	N/A	7489	6802014	N/A
Bi - Axial	600	600					N/A

k = Depends on c1 / c2 ratio

c1 / c2	<=0.5	1	2	>=3
K =	0.45	0.6	0.7	0.8

β = 1 + k (M_{ED} / V_{ED}) x (u1 / W1)

W1 = Pi $c1^2 / 2 + c1c2 + (2)(xD)C2d + (4)(xD)^2d^2 + (xD)\pi dc1$
Pr $c1^2 / 3 + c1c2 + (2)(xD)C2d + (3)(xD)^2d^2 + (0.75)(xD)\pi dc1$

β Circ = Pi $1 + 0.6\pi (M_{ED} / V_{ED}) / (Dia + (2)(xD)d)$
Pr $1 + 0.6\pi (M_{ED} / V_{ED}) / (Dia + (1.5)(xD)d)$

xD = 2, gives value at u1
This allows the β Value at smaller xD values including 0 for col face
xD must not exceed 2.0

If Bi-Axial EC2 states that formula applies to a rectangular column, If circular, conservatively, set c2 = c1

β = Pi $1 + 1.8 (((M_{EDxx} / V_{ED}) / (c1 + 2(xD)d))^2 + ((M_{EDyy} / V_{ED}) / (c2 + 2(xD)d))^2) ^{0.5}$
Pr $1 + 1.8 (((M_{EDxx} / V_{ED}) / (c1 + 1.5(xD)d))^2 + ((M_{EDyy} / V_{ED}) / (c2 + 1.5(xD)d))^2) ^{0.5}$

Pe = Edge
Fig 6.20 a
c1 & c2 are fixed

	c1	c2	k	M_{ED} / V_{ED}	u1	W1	β
M_{XX}	600	600	0.70	N/A	5193	5096676	N/A
M_{YY}	600	600			5193		N/A
Bi - Axial		=		Constant Myy part + (Mxx part -1)		=	N/A

k = Depends on c2 / c1 ratio where c1 = 0.5 x actual to give 2c2 / c1 (not c1 / 2c2 as in EC2)

β = Myy part (Always Present) + Mxx part -1 = u1 / u1* + k (M_{EDYY} / V_{ED}) x (u1 / W1)

u1* = u1 - c1 W1 = $c2^2 / 4 + c1c2 + (2)(xd)C1d + (2)(xd)^2d^2 + 0.5(xd)\pi dc2$

Pc = Corner

	c1	c2	u1	β
M_{XX}	600	600	2896	N/A

Fig 6.20 b
c1 & c2 are fixed β = u1 / u1* u1* = u1 - c1 / 2 - c2 / 2

EC2 Punching Shear Design

Principles

The method is based on multiples of the Average Effective Depth (D) from support face.
Capacity is calculated on the basic number of legs around the basic control perimeter (U1) at 2.0D.
Additional smaller dia radials may be added to satisfy spacing and minimum %As requirements.

Perimeter spacing must be (≤2.0D outside and ≤1.5D inside and on U1).
Minimum area of leg per (transverse x radial) area must be > 0.088 % for Fck = 30 N/mm²
Radial (outwards) spacing of the legs must not exceed 0.75D. Capacity is increased with closer spacing.
Where legs are required, a minimum of 2 perimeters are provided.
All radials finish at Dro at a spacing interval that is within 1.5D of the Outer Perimeter Uout.
Main (capacity design) radials must start between 0.3D & 0.5D from the support face.
Additional intermediate radials may start at Dri if they are not required closer to the support.

Tangential Spacing / D (St/D) and %As are displayed according to Dro and Dri and non compliance is shown.
The shear value is automatically adjusted according to the udl load (w) within the perimeters considered.
Note: EC2 punching shear fixes the strut angle at 26.6º and Cot 26.6º = 2. This program fixes the leg angle at 90º.

Without Shear Legs

Enter average element section data over the support. Note: average cover will be basic cover + 0.5 x bar dia.
Enter the appropriate Punching Shear Type, Pi, Pe, Pc or Pr to enable Punching Shear Output.
Enter the Punching Shear Value the program will multiply the value by the appropriate Beta.
Enter Px and Py Support Dimensions. If circular, type Dia instead of the Py value.

The program checks the support perimeter Uo and displays **Uo Fail** if Cap Ratio is > 1.
If Uo check is unsatisfactory, increase the slab thickness or add a column head.

Set leg dia, radial (outward) spacing (Sr) and transverse (perimeter) nrs (nr and nra) to 0.
The diagram will show the support, U1 perimeter in red and Uout perimeter(if > U1) in blue.
The xD factor (Dout) where the concrete is sufficient without shear legs (Uout) is displayed in the output.
You can check that the Cap Ratio = 1.0 when this value is entered into the xD data field.
If Dout is ≤ 2.0 (which sets Control Perimeter U1), no legs are required, section is satisfactory.

With Shear Legs

Set xD factor to 2.0 and enter primary radial leg dia φ1 and basic nr of legs. Keep to rules below.
Note: basic nr of legs = nr of spaces + 1 for Pc, Pe, and Pr. Spaces = nr for Pi.
Spaces must be a whole number (≤12) per quadrant. i.e. typically, for Pr, nr = (3 x 3) + 1 = 10.
Enter radial spacing at 0.75D or less and start by making additional radials number (nra) equal to 0.
Enter radial distance from support to 1st Leg (Sr1) ensuring that it is between 0.3D and 0.5D.
Check capacity, transverse St/D and %As at Dro and Dri and adjust dia, radial spacing and nrs to comply.
If required, add additional intermediate radials φ2 to satisfy %AsL & St / D .
Note: nr of additional radials will be basic nr -1 for Pc, Pe and Pr. i.e. typically, for Pr, nr = 10 and nra = 9.

The output displays the xD factor for the maximum (outer) leg perimeter (Dro) and %AsL & St / D values.
It displays the xD factor for the minimum (inner) intermediate leg perimeter (Dri) and %AsL & St / D values.
The Dri %Asl & St / D values apply to the main radials to demonstrate compliance without the intermediates.

The output displays the perimeter U appropriate to the entered xD factor for info and for checking purposes.
It also allows a direct comparison with the equivalent BS design. Enter spacing instead of nr.
Full code compliance and leg radials geometry can be displayed in one column without the need for a diagram.
The whole EC2 procedure is quite complex at first but with practice this method is quite practical.

Amendment No. 1 of The National Annex was published in Dec 2009 and limits the shear stress v_{ED} at the first control perimeter (i.e. at 2.0D or closer if chosen) to 2 x the unreinforced stress capacity v_{Rdc}.
This restriction has been incorporated into the program.

Example

See following sheet for an example that links to the graphics from the MAIN sheet.
The example can also display the results for a BS design in order to show the differences.

Derivation of Code formula for Lever Arm Z where As2 = 0 or is ignored

Mrc = Moment of Resistance of Concrete acting about As1 Excel maths notation is used.

BS 8110 Clause 3.4.4.4 Fact = 0.67 γm = 1.5 normally

Conc = (Fact) * (1 / γm) * Fcu λ = 0.9 z = d - (0.9 / 2) X So X = (d - z) / 0.45

Mrc = b * (Fact / γm) * Fcu * 0.9 * X * z = b * (Fact / γm) * Fcu * 0.9 * ((d - z) / 0.45) * z

= b * (Fact / γm) * Fcu * 2 * (d - z) * z

= b * (2 * Fact / γm) * Fcu * d * z - b * (2 * Fact / γm) * Fcu * z^2

So b * (2 * Fact / γm) * Fcu * z^2 - b * (2 * Fact / γm) * Fcu * d * z + Mrc = 0

Divide through by bd²Fcu and set 2 * Fact / λm = J and Mrc / bd²Fcu = K to give:-

(J / d²) z^2 + (- J / d) z + K = 0

Divide through by J / d to give:-

(1 / d) z^2 + (- 1) z + (d K / J) = 0 This is a quadratic equation a z^2 + b z + c = 0

z = (1 + (1 - 4 (1 / d) (d K / J)) ^ 0.5) / (2 / d)

Replace the 1 term within the square root by 4 (0.25) and cancel the d terms

z = (1 + (4 (0.25) - 4 (K / J)) ^ 0.5) / (2 / d)

4 ^ 0.5 = 2. So this can be brought outside of the square root term

z = (1 + (2)((0.25) - (K / J)) ^ 0.5) / (2 / d)

Multiply top and bottom by d / 2

= d (0.5 + (0.25 - K / J) ^ 0.5)

= d (0.5 + (0.25 - (K / (2 * Fact / γm))) ^ 0.5)

Fact = 0.67 and if γm = 1.5 this becomes Z = d (0.5 + (0.25 - (K / 0.893)) ^ 0.5)

Code Formula is approximated to Z = d (0.5 + (0.25 - (K / 0.9)) ^ 0.5)

EC2 αcc = 0.85 (NA value) γm = 1.5 normally

Conc = (αcc / γm) * Fck λ = 0.8 z = d - (0.8 / 2) X So X = (d - z) / 0.4

Mrc = b * (αcc / γm) * Fck * 0.8 * ((d - z) / 0.4) * z = b * (αcc / γm) * Fck * 2 * (d - z) * z

= b * (αcc / γm) * 2 * Fck * d * z - b * (αcc / γm) * 2 * Fck * z^2

So b * (2 * αcc / γm) * Fck * z^2 - b * (2 * αcc / γm) * Fck* d * z + Mrc = 0

Divide through by bd²Fck and set 2 * αcc / λm = Je and Mrc / bd²Fck = Ke and solve as above to give:-

z = d (0.5 + (0.25 - (Ke / (2 * αcc / γm))) ^ 0.5)

αcc = 0.85 and if γm = 1.5 this becomes = d (0.5 + (0.25 - (Ke / 1.133)) ^ 0.5)

Formula can be approximated to Z = d (0.5 + (0.25 - (Ke / 1.13)) ^ 0.5)

	EC2 DESIGN TOOL **STEP BY STEP FOR FLEXURE ONLY** HAC-PRO 1 - 5 - 2 FLEX 2	**Howes Atkinson Crowder LLP** **Copyright © 2009 HAC**

Calculation of K' = Max M / Bd² fcu and M / bd² fck without considering As2

Mrc = b * (Fact / γm) * Fcu * 0.9 * X * Z   X = d * (δ - 0.4)   δ = βb = Mred / M or 1

Mrc / fcu = b * (Fact / γm) * 0.9 * d * (δ - 0.4) * d * (1 - (0.45 * (δ - 0.4)))

Mrc / b d² fcu = K' = (Fact / γm) * 0.9 * (δ - 0.4) * (1 - (0.45 * (δ - 0.4)))

Mrc / b d² fck = Ke' = (αcc / γm) * 0.8 * (δ - 0.4) * (1 - (0.4 * (δ - 0.4)))

Equates to K' or Ke' = (J /2) * λ * (δ - 0.4) - (J /2) * (λ² / 2) * (δ - 0.4)^2

BS	Fact	γm	J	λ	Redistribution δ					
	0.67	1.5	0.893	0.9	1.0	0.9	0.85	0.8	0.75	0.7
			Max M / bd² fcu =		0.176	0.156	0.144	0.132	0.119	0.104

EC2	αcc	γm	Je	λ	Redistribution δ					
	0.85	1.5	1.133	0.8	1.0	0.9	0.85	0.8	0.75	0.7
			Max M / bd² fck =		0.207	0.181	0.167	0.152	0.136	0.120

When Z = 0.95d   Min M / bd² fcu = 0.042   Min M / bd² fck = 0.054

If M / bd²(fcu or fck) < K' or Ke'   As1 = M (kNm) x 10⁶ / Z mm²

If As2 is Taken into Account   If Fs2 < 0 it is in tension and is ignored

Calculation of Balanced Neutral Axis Distance (Xo) where Fs1 = Fyd and As1 and As2 are known.

Fyd = Fyk / γs   Conc = (BS) 0.67 x Fcu / γc   or (EC2) αcc x Fck / γc   If As1 only, set As2 = 0

1. If Fs2 = Fyd   Xo1 = (As1 x Fyd - As2 x (Fyd - Conc)) / (B x λ x Conc)

If Xo1 > d1 / (1 + Fyd / 700) = T d1   (= 0.617 d1 if Fyd = 434.8)   Solution is Invalid, Fs1 < Fyd
If Xo1 < d2 * 700 / (700 - Fyd) = C d2   (= 2.639 d2 if Fyd = 434.8)   Solution is Invalid, Try Xo2a

2. If Fs2 is Variable and Displaced As2 Concrete Stress Adjustment = DC2 = - Conc

Xo2a = (- (As1*Fyd+As2*(700+DC2)) - (((As1*Fyd+As2*(700+DC2))^2 - (4 * - B * λ * Conc * As2 * 700 * d2))^0.5))

Divided By   2 * - B * λ * Conc

If Xo1 > d1 / (1 + Fyd / 700) = T d1   (= 0.617 d1 if Fyd = 434.8)   Solution is Invalid, Fs1 < Fyd
If Xo2a < d2 / λ, As2 is outside Concrete Compression Block. Solution is Incorrect. Recalculate with DC2 = 0 to give Xo2b

Xo will be the valid solution from Xo1 or Xo2a or Xo2b. The section is balanced and Mrc = Mrt
If Xu Due to Redistribution ((δ - 0.4) * d1) < Xo then Xu is used to calculate Mrc & Mrt and Mrt > Mrc
If X < Min X (0.1 * d1 / λ) then Z > 0.95 * d1, and Mrt is calculated using Z = 0.95d1 and Mrt < Mrc

Fconc = B * Conc * λ * X / 1000   F2 = Fs2 * As2 / 1000   F1a = Fyd * As1 / 1000 - F2   F1b = F2
If Fs2 < 0, F2 = 0

Mrc (a + b) = Fconc * Z + F2 * (d1 - d2)
Mrt (a + b) = F1a * Z + F1b * (d1 - d2)
Mr = Min of Mrc & Mrt   Cap = Mu / Mr

Fs2 includes displaced concrete adjustment
Z = Min of (0.95 * d1) or (d1 - (0.5 * λ * X))
If As2 = 0, X = Xo1 = Xo2a = Xo2b

Input				**Shear**	V	400	θ	21.8	Red	App	Max		Face 1			Face 2	
Code	Fck /	Fcu	B	H	γc	αcc	Fyk	γs	δ	Mu	z / d1	φ1	Ctr, nr	Cov	φ2	Ctr, nr	Cov
EC2	30	37	1000	600	1.5	0.85	500	1.15	0.85	1196	0.95	32	130	60	16	300	60
					ΔFtd = 0.5 * V * Cotθ kN					**a1 = 0.5 * Z * Cotθ mm**			**Md = ΔFtd * Z kNm**				
Output		**Shear Shift or Md**			ΔFtd	500	a1	566.4	or	Md	226.5	Mu + Md <= Mmax for Span or Supp					
λ	Conc	Fyd	Cd2	d2 / λ	Xo1	Xo2a	Xo2b	Xo	Xu	X	Fs2	As1	d1	DC1	As2	d2	DC2
0.8	17.0	434.8	179	85	177	177	177	177	236	177	415	6187	524	0	670	68	-17.0
Fconc	F2	F1a	F1b	d1-d2	.95d1	Mrta	Mrtb	Mrt	Mrca	Mrcb	Mrc	Mr	Cap	Z	Ke	Info	
2412	277.9	2412	277.9	456	498	1093	126.7	**1219**	1093	126.7	**1219**	**1219**	0.981	453.1	0.145	Mrt = Mrc	

EC2 DESIGN TOOL

GENERAL FLEXURE

HAC-PRO 1 - 5 - 2 FLEX 3

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Flexure Case 1

Code	EC2	Mu	1196	Conc	30	/	37	H	600	bw	1000	fyk	500	0.7 > δ <= 0.85			0.85
Dia1	32	Ctrs or	Nr (< 50)		130	Cov 1	60	As1	6187	% =	1.181	d1	524			fyd	434.8
Dia2	16	Ctrs or	Nr (< 50)		300	Cov 2	60	As2	670	% =	0.128	d2	68	d1-d2	456	Min%	0.151

As1	Ke'	=	0.453 * (δ - 0.4) - 0.18 * (δ - 0.4)^2	=	0.167	Ratio	
	Ke	=	M / bw d1^2 fck	=	0.145	Ratio	
	Mr	=	Ke' x bw x d1^2 x fck = Mr ignoring As2	=	1378	kNm	
Z (Max = 0.95d1)		=	d1 (0.5 + (0.25 - (Min of Ke or Ke') / 1.13)) ^ 0.5)	=	445	mm	
As1 Req		=	M / (Z fyd) If As2 req Mr / Z fyd + (M - Mr) / ((d1 - d2) fyd)	=	6186	mm^2	<Prov
As2		=	Neutral axis X = (d1 - Z) / 0.4	=	N/A	mm	
Fs2 Status		=	As2 stress limited at X > 2.64 d2 Limit is at	=	N/A	mm	N/A
Fs2		=	(If Lim, fyd, If Var, 700 x (X - d2) / X) - (fck x 0.85 / 1.5)	=	N/A	N/mm^2	
As2 Req		=	(M - Mr) / (d1 - d2) x Fs2	=	N/A	mm^2	N/A

Flexure Case 2

Code	BS	Mu	1196	Conc	30	/	37	H	600	bw	1000	fyk	500	0.7 > δ <= 0.9			0.85
Dia1	32	Ctrs or	Nr (< 50)		130	Cov 1	60	As1	6187	% =	1.181	d1	524			fyd	434.8
Dia2	16	Ctrs or	Nr (< 50)		300	Cov 2	60	As2	670	% =	0.128	d2	68	d1-d2	456	Min%	0.13

As1	K'	=	0.402 * (δ - 0.4) - 0.18 * (δ - 0.4)^2	=	0.144	Ratio	
	K	=	M / bw d1^2 fcu	=	0.118	Ratio	
	Mr	=	K' x bw x d1^2 x fcu = Mr ignoring As2	=	1466	kNm	
Z (Max = 0.95d1)		=	d1 (0.5 + (0.25 - (Min of K or K') / 0.9)) ^ 0.5)	=	443	mm	
As1 Req		=	M / (Z fyd) If As2 req Mr / Z fyd + (M - Mr) / ((d1 - d2) fyd)	=	6211	mm^2	>Prov
As2		=	Neutral axis X = (d1 - Z) / 0.45	=	N/A	mm	
Fs2 Status		=	As2 stress limited at X > 2.64 d2 Limit is at	=	N/A	mm	N/A
Fs2		=	(If Lim, fyd, If Var, 700 x (X - d2) / X) - (fcu x 0.67 / 1.5)	=	N/A	N/mm^2	
As2 Req		=	(M - Mr) / (d1 - d2) x Fs2	=	N/A	mm^2	N/A

Flexure Case 3

Code	EC2	Mu	1500	Conc	30	/	37	H	600	bw	1000	fyk	500	0.7 > δ <= 0.85			0.85
Dia1	32	Ctrs or	Nr (< 50)		10	Cov 1	60	As1	8042	% =	1.535	d1	524			fyd	434.8
Dia2	16	Ctrs or	Nr (< 50)		5	Cov 2	60	As2	1005	% =	0.192	d2	68	d1-d2	456	Min%	0.151

As1	Ke'	=	0.453 * (δ - 0.4) - 0.18 * (δ - 0.4)^2	=	0.167	Ratio	
	Ke	=	M / bw d1^2 fck	=	0.182	Ratio	>Ke'
	Mr	=	Ke' x bw x d1^2 x fck = Mr ignoring As2	=	1378	kNm	
Z (Max = 0.95d1)		=	d1 (0.5 + (0.25 - (Min of Ke or Ke') / 1.13)) ^ 0.5)	=	429	mm	
As1 Req		=	M / (Z fyd) If As2 req Mr / Z fyd + (M - Mr) / ((d1 - d2) fyd)	=	7998	mm^2	<Prov
As2		=	Neutral axis X = (d1 - Z) / 0.4	=	237	mm	
Fs2 Status		=	As2 stress limited at X > 2.64 d2 Limit is at	=	180	mm	Lim
Fs2		=	(If Lim, fyd, If Var, 700 x (X - d2) / X) - (fck x 0.85 / 1.5)	=	418	N/mm^2	
As2 Req		=	(M - Mr) / (d1 - d2) x Fs2	=	641	mm^2	<Prov

Flexure Case 4

Code	BS	Mu	1500	Conc	30	/	37	H	600	bw	1000	fyk	500	0.7 > δ <= 0.9			0.85
Dia1	32	Ctrs or	Nr (< 50)		10	Cov 1	60	As1	8042	% =	1.535	d1	524			fyd	434.8
Dia2	16	Ctrs or	Nr (< 50)		5	Cov 2	60	As2	1005	% =	0.192	d2	68	d1-d2	456	Min%	0.13

As1	K'	=	0.402 * (δ - 0.4) - 0.18 * (δ - 0.4)^2	=	0.144	Ratio	
	K	=	M / bw d1^2 fcu	=	0.148	Ratio	>K'
	Mr	=	K' x bw x d1^2 x fcu = Mr ignoring As2	=	1466	kNm	
Z (Max = 0.95d1)		=	d1 (0.5 + (0.25 - (Min of K or K') / 0.9)) ^ 0.5)	=	419	mm	
As1 Req		=	M / (Z fyd) If As2 req Mr / Z fyd + (M - Mr) / ((d1 - d2) fyd)	=	8220	mm^2	>Prov
As2		=	Neutral axis X = (d1 - Z) / 0.45	=	233	mm	
Fs2 Status		=	As2 stress limited at X > 2.64 d2 Limit is at	=	180	mm	Lim
Fs2		=	(If Lim, fyd, If Var, 700 x (X - d2) / X) - (fcu x 0.67 / 1.5)	=	418	N/mm^2	
As2 Req		=	(M - Mr) / (d1 - d2) x Fs2	=	180	mm^2	<Prov

EC2 DESIGN TOOL

STEP BY STEP FOR FLEXURE ONLY

HAC-PRO 1 - 5 - 2 FLEX 4

Howes Atkinson Crowder LLP

Ultimate Flexure Only Calculation - Out of Balance Check When Redistribution Factor Forces X < Xo
Comparison between Centre Line Equilibrium Method and Lever Arm Equilibrium Method

1 Centre Line Method which checks equilibrium about Centre Line
Using Xo This is the value of X when δ is not applied

		Case	1	2	3	4	5	6	7	8	9	10	11	12
	Xo	mm		63	61								121	
	X / D	Ratio		0.12	0.11								0.32	
	Fs1	N /mm²		-435	-435								-435	
	Fs3	N /mm²		-435	-435								-435	
	Fs2	N /mm²		29	4								325	
	Ult Axial Capacity	kN		0	0								0	
Mo	Ult Moment Capacity	kNm		467	467								461	

Using Min of Xu or Xo If 0.7 < δ < 1.0. If Xo < Xu, Xo is used and there will be no out of balance.

			1	2	3	4	5	6	7	8	9	10	11	12
	Min of Xu or Xo	mm		63	61								115	
	X / D	Ratio		0.12	0.11								0.30	
	Fs1	N /mm²		-435	-435								-435	
	Fs3	N /mm²		-435	-435								-435	
	Fs2	N /mm²		29	4								304	
	Ult Axial Capacity	kN		0	0								-81	
	Ult Moment Capacity	kNm		467	467								449	
	Out of balance force	kN		0	0								-81	
	At an Eccentricity of	mm		240	240								157	
	M Out of Bal about Centre Line	kNm		0	0								-13	
Mb	If O / B Force is removed Mb =	kNm		467	467								437	

2 Lever Arm Method which is based on a couple about Tension and Compression Centroids
Using Min of Xu or Xo If 0.7 < δ < 1.0. If Xo < = Xu results will be the same as above.
If X < 0.1D / λ then Lever Arm Z > 0.95D. A maximum value of Z = 0.95D is used below.

			1	2	3	4	5	6	7	8	9	10	11	12
	Min of Xu or Xo	mm		63	61								115	
	X / D	Ratio		0.12	0.11								0.30	
	Fs1	N /mm²		-435	-435								-435	
	Fs3	N /mm²		-435	-435								-435	
	Fs2	N /mm²		29	4								304	
	F conc in comp	kN		851	903								935	
	F Reinf in Comp allowing for displ conc	kN		60	7								382	
	F Reinf in Tension	kN		-911	-911								-1399	
	Lever Arm Z Conc Block to Tens Reinf	mm		513	513								336	
	Lever Arm Comp Reinf to Tens Reinf	mm		480	480								320	
	Mr Concrete Block about Tens Reinf	kNm		436	463								314	
	Mr Comp Reinf about Tens Reinf	kNm		29	4								122	
Mc	Mr Comp Total	kNm		465	467								437	
	F Ten Reinf acting against conc block	kN		-851	-903								-1016	
	F Ten Reinf acting against Comp Reinf	kN		-60	-7								-382	
	Mr Ten Reinf acting about Conc Block	kNm		-436	-463								-342	
	Mr Ten Reinf acting about Comp Reinf	kNm		-29	-4								-122	
Mt	Mr Tens Reinf Total	kNm		-465	-467								-464	
	If T is reduced by	kN		0	0								-81	
	F ten reinf about Conc Block becomes	kN		-851	-903								-935	
	Mr Ten Reinf about conc block becomes	kNm		-436	-463								-314	
Mr =	Mr Tens total becomes	kNm		-465	-467								-437	

Mc = Mb

Therefore, if the out of balance tensile force is removed the section
can be in equilibrium about the centre line or by the lever arm method.
This is best done by reducing the tension reinforcement if Mrt > Mrc
It can also be done by increasing the compression reinforcement if M > Mrc

The main purpose of redistributing moments is to reduce tension reinforcement.
The purpose of limiting X is also to ensure Mrc > Mrt so it fails in tension first.

Ultimate Flexure Only Calculation - Out of Balance Check When Redistribution Factor Forces X < Xo
Comparison between Centre Line Equilibrium Method and Lever Arm Equilibrium Method

1 Centre Line Method which checks equilibrium about Centre Line
Using Xo This is the value of X when δ is not applied

		Case	13	14	15	16	17	18	19	20	21	22	23	24
	Xo	mm	89	63	203									
	X / D	Ratio	0.17	0.16	0.54									
	Fs1	N /mm²	-435	-435	-435									
	Fs3	N /mm²	-435	-435	-435									
	Fs2	N /mm²	197	37	418									
	Nu	kN	0	0	0									
Mo	Mu	kNm	840	197	658									

Using Min of Xu or Xo If 0.7 < δ < 1.0. If Xo < Xu, Xo is used and there will be no out of balance.

			13	14	15	16	17	18	19	20	21	22	23	24
	Min of Xu or Xo	mm	89	63	113									
	X / D	Ratio	0.17	0.16	0.30									
	Fs1	N /mm²	-435	-435	-435									
	Fs3	N /mm²	-435	-435	-435									
	Fs2	N /mm²	197	37	300									
	Nu	kN	0	0	-883									
	Mu	kNm	840	197	562									
	Out of balance force	kN	0	0	-883									
	At an Eccentricity of	mm	236	163	153									
	M Out of Bal about Centre Line	kNm	0	0	-135									
Mb	If O / B Force is removed Mb =	kNm	840	197	427									

2 Lever Arm Method which is based on a couple about Tension and Compression Centroids
Using Min of Xu or Xo If 0.7 < δ < 1.0. If Xo < Xu results will be the same as above.
If X < 0.1D / λ then Lever Arm Z > 0.95D. A maximum value of Z = 0.95D is used below.

			13	14	15	16	17	18	19	20	21	22	23	24
	Min of Xu or Xo	mm	89	63	113									
	X / D	Ratio	0.17	0.16	0.30									
	Fs1	N /mm²	-435	-435	-435									
	Fs3	N /mm²	-435	-435	-435									
	Fs2	N /mm²	197	37	300									
	F conc in comp	kN	1213	517	925									
	F Reinf in Comp allowing for displ conc	kN	494	30	377									
	F Reinf in Tension	kN	-1707	-546	-2185									
	Lever Arm Concrete Block to Tens Reinf	mm	500	363	333									
	Lever Arm Comp Reinf to Tens Reinf	mm	474	328	316									
	Mr Concrete Block about Tens Reinf	kNm	606	187	308									
	Mr Comp Reinf about Tens Reinf	kNm	234	10	119									
Mc	Mr Comp Total	kNm	840	197	427									
= Mb	F Ten Reinf acting against conc block	kN	-1213	-517	-1808									
	F Ten Reinf acting against Comp Reinf	kN	-494	-30	-377									
	Mr Ten Reinf acting about Conc Block	kNm	-606	-187	-601									
	Mr Ten Reinf acting about Comp Reinf	kNm	-234	-10	-119									
Mt	Mr Tens Reinf Total	kNm	-840	-197	-721									
	If T is reduced by	kN	0	0	-883									
	F ten reinf about Conc Block becomes	kN	-1213	-517	-925									
	Mr Ten Reinf about conc block becomes	kNm	-606	-187	-308									
Mr =	Mr Tens total becomes	kNm	-840	-197	-427									

Mc = Mb

Therefore, if the out of balance tensile force is removed the section can be in equilibrium about the centre line or by the lever arm method.
This is best done by reducing the tension reinforcement if Mrt > Mrc
It can also be done by increasing the compression reinforcement if M > Mrc

The main purpose of redistributing moments is to reduce tension reinforcement.
The purpose of limiting X is also to ensure Mrc > Mrt so it fails in tension first.

EC2 DESIGN TOOL

STEP BY STEP FOR SLENDER COLUMNS

HAC-PRO 1 - 5 - 2 SLEN 1

Howes Atkinson Crowder LLP

Comparison between BS8110 & EC2 Slender Columns

		Case											
Common Data		1	2	3	4	5	6	7	8	9	10	11	12
Ultimate Applied Axial Load kN	N_{Ed}												965
Ultimate Applied Maximum End Moment kNm BS , EC2	M_2,M_{c2}												50
Ultimate Applied Minimum End Moment kNm BS , EC2	M_1,M_{c1}												30
Effective Length Leff, BS = le , EC2 = lo	le , lo												9000
Unbraced (U) or Braced (B)	U or B												B
Primary Loading - Transverse (T) or Vertical (V)	T or V												V
BS Design													
le / h limit - determines if slender	le/h lim												20
le / h - where h = depth H & b = width B	le/h												30
Status - Slender or Short	Status												SLEN
Total Area of reinf = As1 + As1a + As2 mm²	Asc												4909
Ult Axial Only Cap = 0.45 fcu*h*b + Asc*0.87*fy kN	Nuz												5132
Nbal = Axial Load at max moment resistance kN	Nbal												1040
K = (Nuz - N_{Ed}) / (Nuz - Nbal) < 1	K												1.000
βa = (1 / 2000) x (Le / h)²	βa												0.450
αu = β K h mm	au												135
Mi = 0.4M_1 + 0.6M_2 >= 0.4M_2 kNm	Mi												60
Madd = N_{Ed} x au kNm	Madd												130
Design Moment = M_{Ed} = Mi + Madd kNm	M_{Ed}												190
EC2 Design - First Order & Imperfections													
φef = creep x ratio of Mperm / Mdesign = 0.75φ(∞,to)	φef												1.178
ω = As fyd / Ac fcd	ω												0.697
n = N_{Ed} / (Ac fcd)	n												0.315
rm = If Unbraced or Transverse = 1, else M_{c1} / M_{c2}	rm												0.600
A = 1 / (1 + 0.2 φef)	A												0.809
B = √ (1 + 2ω)	B												1.548
C = 1.7 - rm	C												1.100
√n	√n												0.562
λ lim = 20 x A x B x C / √ n - determines if slender	λ lim												49
λ = lo / (0.2887 x H)	λ												104
Status - Slender or Short	Status												Slender
M_{oE} = 0.4M_{c1} + 0.6M_{c2} >= 0.4M_{c2} kNm	M_{oE}												60
ei = Accidental Eccentricity = H / 400 mm	ei												23
Mi = (N) x (ei) kNm	Mi												22
M_{oEd} = Total First Order Moments M_{oE} + Mi kNm	M_{oEd}												82
Second Order - Nominal Curvature Method													
β = 0.35 + fck / 200 - λ / 150	β												0.000
Kφ = 1 + βφef >= 1	Kφ												1.000
εyd = fyd / Es = 434.7 / 200000	εyd												0.002
1 / ro x 10E3 = (εyd / 0.45d) x 10E3 / mm	1/ro												0.021
nu = 1 + ω	nu												1.697
nbal = Nbal / N and is taken by EC2 as 0.4	nbal												0.400
Kr = (nu - n) / (nu - 0.4) = axial load correction	Kr												1.000
1 / r x 10E3 = Kr Kφ (1 / ro) x 10E3	1 / r												0.021
C = curve distribution constant	C												10
e2 = Deflection = (1 / r) (1o²) / C mm	e2												166
M_2 = Additional Moment N_{Ed} x e_2 kNm	M_2												160
Design Moment = M_{Ed} = M_{oEd} + M_2 kNm	M_{Ed}												242
Second Order - Nominal Stiffness Method													
K1 = √ (fck / 20)	K1												1.225
K2 = n λ / 170	K2												0.193
Ecd = Ecm / 1.2 = 32836 / 1.2 N/mm²	Ecd												27364
Ic x 10E4 = B x H³ / 12 mm4	Ic												135000
Isx10E4=As1(d1-H/2)²+As1a(d1a-H/2)²+As2(H/2-d2)²	Is												2871
EI x 10E9 =((K1)(K2)(Ecd)(Ic)/(1 + φ)) + (Is)(Es) Nmm²	EI												9747
Nb = Buckling Load = π² EI / lo² kN	Nb												1188
β = π² / 8	β												1.234
Design Moment M_{Ed} = M_{oEd} (1+β / ((Nb/N_{Ed}) -1)) kNm	M_{Ed}												519

EC2 DESIGN TOOL

STEP BY STEP FOR SLENDER COLUMNS

HAC-PRO 1 - 5 - 2 SLEN 2

Howes Atkinson Crowder LLP

Comparison between BS8110 & EC2 Slender Columns

		1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
		Case											
Common Data		**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Ultimate Applied Axial Load kN	**N_{Ed}**								1500	1500			
Ultimate Applied Maximum End Moment kNm BS , EC2	**M_2,M_{c2}**								80	80			
Ultimate Applied Minimum End Moment kNm BS , EC2	**M_1,M_{c1}**								-50	-50			
Effective Length Leff, BS = le , EC2 = lo	**le , lo**								5670	6050			
Unbraced (U) or Braced (B)	**U or B**								B	B			
Primary Loading - Transverse (T) or Vertical (V)	**T or V**								V	V			
BS Design													
le / h limit - determines if slender	**le/h lim**								20	20			
le / h - where h = depth H & b = width B	**le/h**								19	20			
Status - Slender or Short	**Status**								Short	SLEN			
Total Area of reinf = As1 + As1a + As2 mm²	**Asc**									3217			
Ult Axial Only Cap = 0.45 fcu*h*b + Asc*0.87*fy kN	**Nuz**									2898			
Nbal = Axial Load at max moment resistance kN	**Nbal**									587			
K = (Nuz - N_{Ed}) / (Nuz - Nbal) < 1	**K**									0.605			
βa = (1 / 2000) x (Le / h)²	**βa**									0.203			
αu = β K h mm	**au**									37			
Mi = 0.4M_1 + 0.6M_2 >= 0.4M_2 kNm	**Mi**									32			
Madd = N_{Ed} x au kNm	**Madd**									55			
Design Moment = M_{Ed} = Mi + Madd kNm	**M_{Ed}**									87			
EC2 Design - First Order & Imperfections													
φef = creep x ratio of Mperm / Mdesign = 0.75φ(∞,to)	**φef**								1.178	1.178			
ω = As fyd / Ac fcd	**ω**								0.914	0.914			
n = N_{Ed} / (Ac fcd)	**n**								0.980	0.980			
rm = If Unbraced or Transverse = 1, else M_{c1} / M_{c2}	**rm**								-0.625	-0.625			
A = 1 / (1 + 0.2 φef)	**A**								0.809	0.809			
B = √ (1 + 2ω)	**B**								1.682	1.682			
C = 1.7 - rm	**C**								2.325	2.325			
√n	**√n**								0.990	0.990			
λ lim = 20 x A x B x C / √ n - determines if slender	**λ lim**								64	64			
λ = lo / (0.2887 x H)	**λ**								65	70			
Status - Slender or Short	**Status**								Slender	Slender			
M_{OE} = 0.4M_{c1} + 0.6M_{c2} >= 0.4M_{c2} kNm	**M_{OE}**								32	32			
ei = Accidental Eccentricity = H / 400 mm	**ei**								14	15			
Mi = (N) x (ei) kNm	**Mi**								21	23			
M_{OEd} = Total First Order Moments M_{OE} + Mi kNm	**M_{OEd}**								53	55			
Second Order - Nominal Curvature Method													
β = 0.35 + fck / 200 - λ / 150	**β**								0.064	0.034			
Kφ = 1 + βφef >= 1	**Kφ**								1.075	1.040			
εyd = fyd / Es = 0 / 200000	**εyd**								0.002	0.002			
1 / ro x 10E3 = (εyd / 0.45d) x 10E3 / mm	**1/ro**								0.020	0.020			
nu = 1 + ω	**nu**								1.914	1.914			
nbal = Nbal / N and is taken by EC2 as 0.4	**nbal**								0.400	0.400			
Kr = (nu - n) / (nu - 0.4) = axial load correction	**Kr**								0.617	0.617			
1 / r x 10E3 = Kr Kφ (1 / ro) x 10E3	**1 / r**								0.013	0.013			
C = curve distribution constant	**C**								10	10			
e2 = Deflection = (1 / r) (1o²) / C mm	**e2**								42	46			
M_2 = Additional Moment N_{Ed} x e_2 kNm	**M_2**								63	70			
Design Moment = M_{Ed} = M_{OEd} + M_2 kNm	**M_{Ed}**								117	124			
Second Order - Nominal Stiffness Method													
K1 = √ (fck / 20)	**K1**								1.225	1.225			
K2 = n λ / 170	**K2**								0.200	0.200			
Ecd = Ecm / 1.2 = 0 / 1.2 N/mm²	**Ecd**								27364	27364			
Ic x 10E4 = B x H³ / 12 mm4	**Ic**								67500	67500			
Isx10E4=As1(d1-H/2)²+As1a(d1a-H/2)²+As2(H/2-d2)²	**Is**								2843	2843			
EI x 10E9 =((K1)(K2)(Ecd)(Ic)/(1 + φ)) + (Is)(Es) Nmm²	**EI**								7763	7763			
Nb = Buckling Load = π² EI / lo² kN	**Nb**								2383	2093			
β = π² / 8	**β**								1.234	1.234			
Design Moment M_{Ed} = M_{OEd} (1+β / ((Nb/N_{Ed}) -1)) kNm	**M_{Ed}**								165	225			

EC2 DESIGN TOOL

STAAD PRO OUTPUT CONVERTER

HAC-PRO 1 - 5 - 2 STAAD 1

Howes Atkinson Crowder LLP

STAAD PRO OUTPUT ASSEMBLER **Includes Wood and Armer Mxy Adjustment**

The following method allows STAAD output to be copied in one operation and arranged to be suitable for copying and pasting into the MAIN spreadsheet. Section dimensions are in mm.

Note:- **v is always an Absolute (+ve) value of SQ and n = - S so that N is negative if in Tension**
SQ, S, v & n are in N / mm² **Output M is in kNm per width B**
Shear Force V = v x H x B / 1000 kN **Axial Force N = n x H x B / 1000 kN**

Results For All 4 Nodes

Load Case 2 FTB

1	W & A	Y	Plate		Node	SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy		Dir	X	Y
Panel 1	Type	Wall	48		39	-0.22	-0	0.197	-0.03	0.006	-184	-21	-12				
Mh at	Loc	int			40	-0.22	0.11	0.244	0.052	0.003	-277	-73	-1				
Corner	H	600			57	-0.22	0.11	0.271	0.055	-0.04	-267	-18	-40		v	0.222	0.11
48	B	1000			56	-0.22	-0	0.224	-0.03	-0.04	-173	-35	-51		n	-0.271	-0.055
Direction		X & Y	Node Ref		57	-0.222	0.11	0.271	0.055	-0.044	-267	-18	-40		V kN	133	66
Wood and Armer			Mx1	-227	My1	22	Mx2	-180	My2	-12	Mxd	0	Myd	-12	N kN	-163	-33
Moments			Mx1	-307	My1	-58	Mx2	-354	My2	-24	Mxd	-307	Myd	-58	M kNm	-307	-58

Basic Procedure

Copy the loadcase plate values from STAAD output.
Paste into the shaded cell which will vary in position according to the data type selected.
Plate and Load Case values will only display for the first node in a group. Otherwise, enter missing data manually.
Enter Design Description. Plate number is inserted automatically. This can be copied and pasted into MAIN sheet.
Enter Section Data. This can be copied and pasted into MAIN sheet.
Enter Direction of results, X or Y or X & Y.
Enter Node Ref for the All 4 Nodes case.
Select if Wood and Armer analysis is required to include Mxy values or delete Mxy. See below.
The values will automatically fill up and arrange the data at the right so V is always +ve and N is -ve if in Tension.
Copy the V N M values and Paste into the MAIN sheet. **Use Paste Special & Values Only**
The centre or single node or summary table is more compact and is usable for most cases.

Wood and Armer Procedure

It is undertaken twice as the results depend on the sign of Mx and My. +ve M denotes tension on the +ve Z face.
The method produces one appropriate result for each direction. These are selected automatically by the program.

A
Mx1 = Mx + abs(Mxy) If both Mx1 and My1 are positive, Mxd = Mx1 and Myd = My1.
My1 = My + abs(Mxy) If both Mx1 and My1 are negative, Mxd = 0 and Myd = 0.
Mx2 = Mx + abs(Mxy² / My) If Mx1 is negative and My1 positive, Mxd = 0 and Myd = My2.
My2 = My + abs(Mxy² / Mx) If My1 is negative and Mx1 positive, Mxd = Mx2 and Myd = 0.

B
Mx1 = Mx - abs(Mxy) If both Mx1 and My1 are positive, Mxd = 0 and Myd = 0.
My1 = My - abs(Mxy) If both Mx1 and My1 are negative, Mxd = Mx1 and Myd = My1.
Mx2 = Mx - abs(Mxy² / My) If Mx1 is negative and My1 positive, Mxd = Mx2 and Myd = 0.
My2 = My - abs(Mxy² / Mx) If My1 is negative and Mx1 positive, Mxd = 0 and Myd = My2.

The procedure can be disabled by entering N after the W & A cell or setting Mxy = 0.

Centre or Node or Summary **Mx1, My1, Mx2, My2, Mxd, Myd are Wood and Armer** X Y

Ref	1	Centre		Dir	X & Y	Load Case	2 FTB								v	0.221	0.053
Panel 1	Type	Wall		Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy		n	-0.234	-0.013
Mh at	Loc	int		48		-0.221	0.053	0.234	0.013	-0.019	-225	-37	-26		V kN	133	32
Corner	H	600	Mx1	-199	My1	-11	Mx2	-207	My2	-34	Mxd	0	Myd	0	N kN	-140	-8
48	B	1000	Mx1	-251	My1	-63	Mx2	-243	My2	-40	Mxd	-251	Myd	-63	M kNm	-251	-63

Ref	2	Node		Dir	X	Load Case	=	2 FTB							v	0.221	
Panel 1	Type	Wall	Plate		Node	SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy		n	-0.234	
Mh at	Loc	int	48		40	-0.221	0.053	0.234	0.013	-0.019	-277	-73	-1		V kN	133	
Corner	H	600	Mx1	-276	My1	-72	Mx2	-277	My2	-73	Mxd	0	Myd	0	N kN	-140	
48	B	1000	Mx1	-278	My1	-74	Mx2	-277	My2	-73	Mxd	-278	Myd	-74	M kNm	-278	

Ref	3	Summary		Dir	Y	Load Case	12 1.35(SW) + 1.2(FTB)								v		0.053
Panel 1	Type	Wall	Val	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy		n		-0.013
Mv at	Loc	int	Min My	136		-0.221	0.053	0.234	0.013	-0.019	-41	-294	1		V kN		32
Base	H	600	Mx1	-39	My1	-293	Mx2	-41	My2	-294	Mxd	0	Myd	0	N kN		-8
136	B	1000	Mx1	-42	My1	-296	Mx2	-41	My2	-294	Mxd	-42	Myd	-296	M kNm		-296

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Centre or Node or Summary **Mx1, My1, Mx2, My2, Mxd, Myd are Wood and Armer**

X	Y

Ref	1	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

Ref	2	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

Ref	3	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

Ref	4	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

Ref	5	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

Ref	6	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

Ref	7	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

Ref	8	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

Ref	9	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

Ref	10	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

Ref	11	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

Ref	12	Centre	Dir	X	Load Case								v		
Panel 1	Type	Wall	Plate		SQx	SQy	Sx	Sy	Sxy	Mx	My	Mxy	n		
Mh at	Loc	int											V kN		
Corner	H	600	Mx1	My1		Mx2		My2		Mxd		Myd	N kN		
	B	1000	Mx1	My1		Mx2		My2		Mxd		Myd	M kNm		

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Centre or Node or Summary **Mx1, My1, Mx2, My2, Mxd, Myd are Wood and Armer**

X	Y

Ref	**13**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

Ref	**14**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

Ref	**15**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

Ref	**16**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

Ref	**17**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

Ref	**18**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

Ref	**19**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

Ref	**20**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

Ref	**21**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

Ref	**22**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

Ref	**23**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

Ref	**24**	**Centre**	**Dir**	X	**Load Case**								**v**	
Panel 1	**Type**	Wall	**Plate**		**SQx**	**SQy**	**Sx**	**Sy**	**Sxy**	**Mx**	**My**	**Mxy**	**n**	
Mh at	**Loc**	int											V kN	
Corner	**H**	600	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	N kN	
	B	1000	**Mx1**	**My1**	**Mx2**			**My2**		**Mxd**		**Myd**	M kNm	

EC2 DESIGN TOOL

CAPACITY CHARTS AND TABLES

HAC-PRO 1 - 5 - 2 Tables 1

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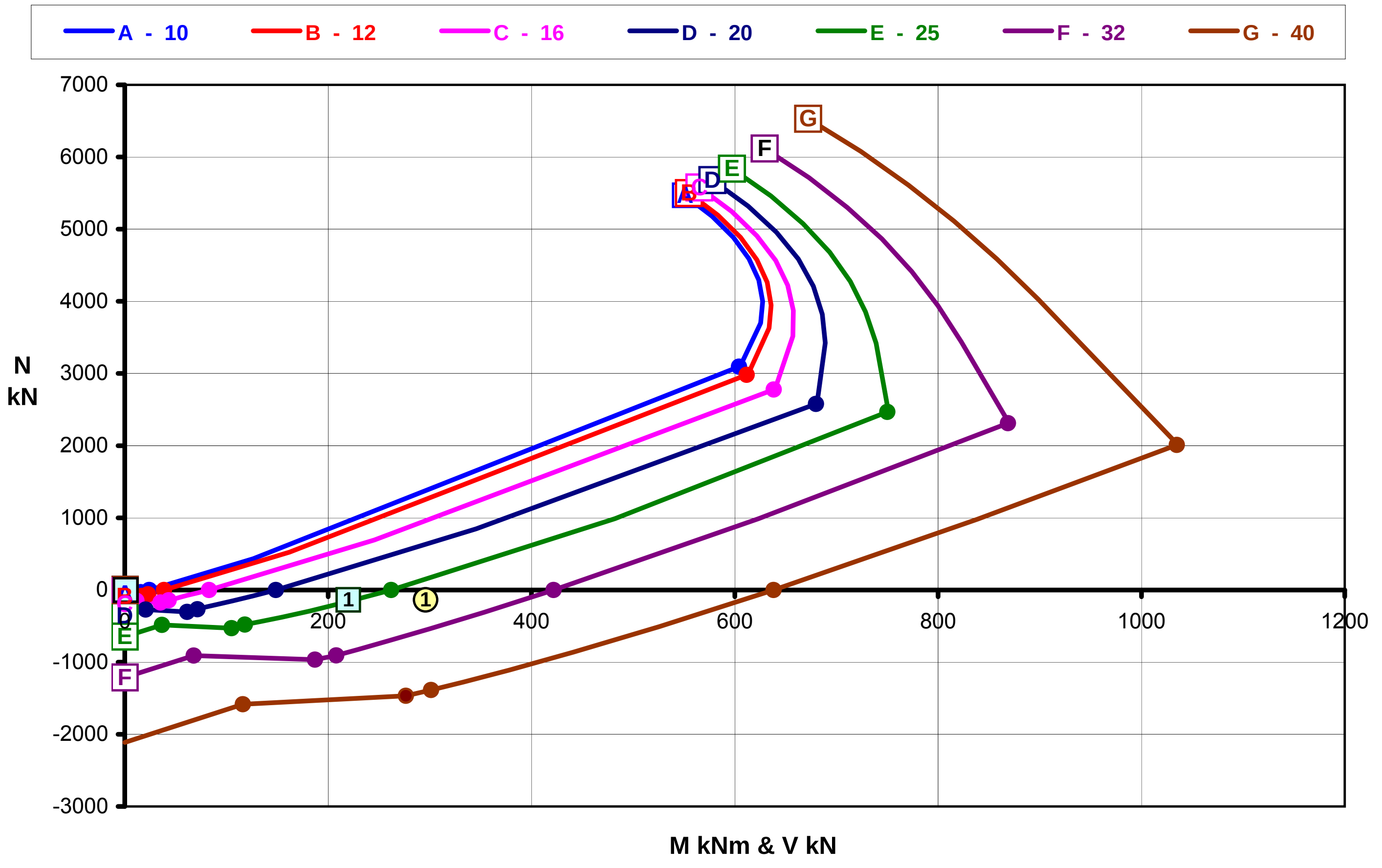
Capacity Charts and Tables **Chart Service Capacity is based on Wmax = 0.2 mm**

The chart shows crack width limits and stress limits or shear limits. Reinforcement data is entered so that the chart curves show increasing capacity. The markers show where X = -∞, X = 0, X = Min 50mm or 0.2H, N = 0 & X = 0.45fck limit. Values are based on Design Age. Load & Creep Age and RH% control Auto Creep Coefficient (CC).

Reinf f_{yk}	500	Gain	N	Depth H mm	600	Ambient T °C	15	$f_{ck,cyl}$ N/mm²	40	Linear CC	1.5
Bond - k1	0.800	Conc PSFγc	1.5	Width B mm	1000	Load Age d	28	$f_{ctm,t}$ N/mm²	3.509	Linear MR	14.2
Reinf PSF γs	1.15	CC or Auto	1.5	RH %	85	Creep Age Yr	Max	Ec,t kN/mm²	35.22	CC at kfck	1.5
28 Day Cube	50	Ult / Serv LF	1.35	ExpFaces	1	LT or ST	LT	ho	1200	MR at kfck	14.2
Design Age	28	Agg	Default	fck k factor	0.45	fyk k3 factor	0.7	k factor x f_{ck}	18	k3 x f_{yk}	350

Ref	F1 Bars	Equiv φ1	Cov1	Ctrs	d1	As1		Ref	F2 Bars	Equiv φ2	Cov2	Ctrs	d2	As2
A	10	10	60	150	535	524	Equiv φ	A					65	262
B	12	12	60	150	534	754	is used to	B					66	377
C	16	16	60	150	532	1340	allow for	C					68	670
D	20	20	60	150	530	2094	different alt	D					70	1047
E	25	25	60	150	527.5	3272	bar dias in	E					73	1636
F	32	32	60	150	524	5362	Srmax	F					76	2681
G	40	40	60	150	520	8378	Equ 7.11	G					80	4189

Chart Values					
Service		Crack Control & Elastic Method	Y	Limit State Method	N
		Show Beyond Balance Point	Y	Shear Capacity	N
Auto As2 / As1	0.50	Show Beyond X = 0.2H or 50mm	Y	Linear after 0.45fck	N



Combined Forces Capacity Limits

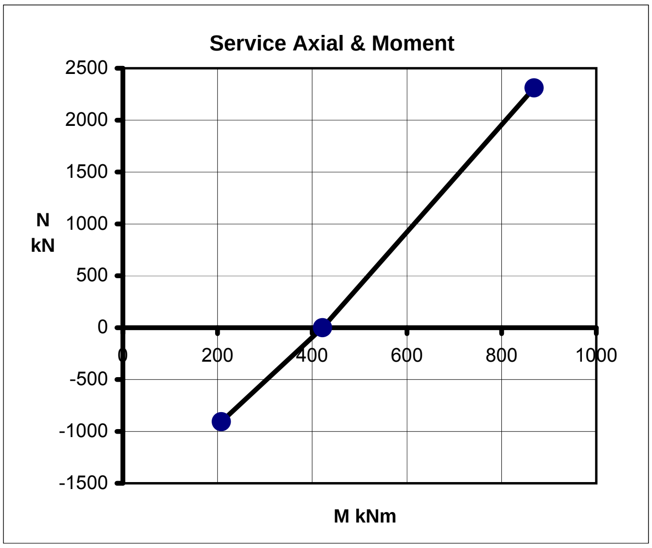
DESIGN VALUES	S	Notation:- N & M are within a yellow circle			N & V are within a blue square				
Ref	Description	M kNm	N kN	V kN	Ref	Description	M kNm	N kN	V kN
1	Drives Stress Diagrams	296	-137	220	5				
2	Design 2				6				
3	Design 3				7				
4	Design 4				8				

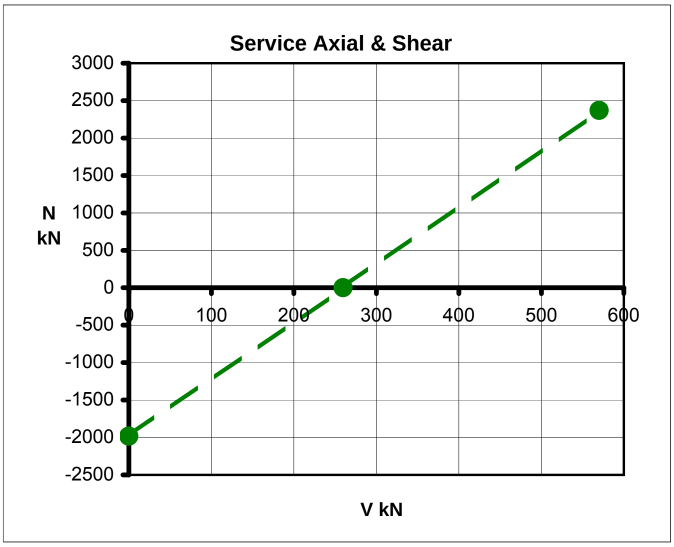
Capacity Charts and Tables Cont.

Service N & M capacity values are taken as linear between the values at X = 0, N = 0 and fc = kfck.
Minimum value of X = 50mm or X = 0.2X. Maximum value is where crack limit capacity is limited by kFck.

Service N & V capacity is linear between Min & Max. Max beneficial axial stress is 0.2 Fck / γc (typically 0.133 Fck).
Nu = N x Load Factor. Nu at Vu = 0, Vu at Nu = 0 and Vu at Numax are calculated and then divided by LF.

NOTE Sheets 1 & 3 can be edited and printed to pdf or a printer to create your own reference document





Tabular Format Verification Example

Note: **Cells with Bold Green Text can be adjusted to update the values in the block**
Cells with Bold Blue Text read the values at the head of sheet NMV 1

The values are grouped together as in the block below and automatically inserted. The block can be used for verification.

W =	0.2	Ctrs =	150 mm			As2 =	0.50	As1	Fck	40	H	600	CC	1.5	LF	1.35

Dia	Cov	60			
		M	N	N	V
32	Max	869	2310	2370	570
	N = 0	422	0	0	260
	Min	208	-907	-1982	0

Xcub	309.1
kFck	18.00
X	309.1
fc	18.00

If X cub does not give fc = kFck,
Use Goal Seek on X-goal & fc-goal

X-goal = 309.1 fc-goal = 18.00

SERVICE CAPACITY TABLE

Axial (N kN) with Moment (M kNm) or Shear (V kN)

k1	0.800
	Default

Note **This table cannot be edited directly. It reads values from the first table on the next sheet**

W =	0.2	Ctrs =	150 mm			As2 =	0.50	As1	Fck	40	H	600	CC	1.5	LF	1.35	
Dia	**Cov**	**40**				**50**				**60**				**70**			
		M	N	N	V	M	N	N	V	M	N	N	V	M	N	N	V
12	Max	616	2903	2370	512	614	2947	2370	504	612	2981	2370	496	609	3006	2370	487
	N = 0	59	0	0	184	47	0	0	182	39	0	0	179	36	0	0	177
	Min	36	-86	-1328	0	28	-70	-1335	0	23	-60	-1342	0	20	-53	-1350	0
16	Max	650	2650	2370	511	644	2720	2370	502	638	2777	2370	494	633	2822	2370	486
	N = 0	120	0	0	184	96	0	0	181	83	0	0	179	76	0	0	176
	Min	68	-204	-1330	0	53	-168	-1337	0	43	-144	-1344	0	37	-130	-1351	0
20	Max	703	2399	2370	520	691	2496	2370	513	680	2579	2370	505	670	2644	2370	497
	N = 0	206	0	0	194	166	0	0	193	149	0	0	191	135	0	0	189
	Min	113	-377	-1413	0	88	-312	-1426	0	72	-267	-1440	0	62	-246	-1455	0
25	Max	791	2310	2370	549	769	2401	2370	541	750	2467	2370	534	732	2512	2370	526
	N = 0	332	0	0	225	294	0	0	223	262	0	0	221	235	0	0	219
	Min	177	-642	-1643	0	146	-560	-1659	0	118	-480	-1676	0	104	-448	-1693	0
32	Max	942	2034	2370	587	903	2192	2370	578	869	2310	2370	570	838	2396	2370	562
	N = 0	520	0	0	264	466	0	0	262	422	0	0	260	386	0	0	257
	Min	271	-1045	-1944	0	234	-957	-1963	0	208	-907	-1982	0	182	-846	-2002	0
40	Max	1162	1568	2370	626	1093	1821	2370	617	1035	2010	2370	608	985	2150	2370	600
	N = 0	823	0	0	306	719	0	0	303	638	0	0	300	573	0	0	297
	Min	409	-1659	-2264	0	344	-1485	-2287	0	301	-1387	-2310	0	268	-1317	-2333	0

EC2 DESIGN TOOL

CAPACITY CHARTS AND TABLES

HAC-PRO 1 - 5 - 2 Tables 3

HAC

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SERVICE CAPACITY TABLES

Axial (N kN) with Moment (M kNm) or Shear (V kN)

k1	0.800
	Default

W =	0.2	Ctrs	=	150	mm	As2	=	0.50	As1	Fck	40	H	600	CC	1.5	LF	1.35
Dia	Cov	40				50				60				70			
		M	N	N	V	M	N	N	V	M	N	N	V	M	N	N	V
	Max	616	2903	2370	512	614	2947	2370	504	612	2981	2370	496	609	3006	2370	487
12	N = 0	59	0	0	184	47	0	0	182	39	0	0	179	36	0	0	177
	Min	36	-86	-1328	0	28	-70	-1335	0	23	-60	-1342	0	20	-53	-1350	0
	Max	650	2650	2370	511	644	2720	2370	502	638	2777	2370	494	633	2822	2370	486
16	N = 0	120	0	0	184	96	0	0	181	83	0	0	179	76	0	0	176
	Min	68	-204	-1330	0	53	-168	-1337	0	43	-144	-1344	0	37	-130	-1351	0
	Max	703	2399	2370	520	691	2496	2370	513	680	2579	2370	505	670	2644	2370	497
20	N = 0	206	0	0	194	166	0	0	193	149	0	0	191	135	0	0	189
	Min	113	-377	-1413	0	88	-312	-1426	0	72	-267	-1440	0	62	-246	-1455	0
	Max	791	2310	2370	549	769	2401	2370	541	750	2467	2370	534	732	2512	2370	526
25	N = 0	332	0	0	225	294	0	0	223	262	0	0	221	235	0	0	219
	Min	177	-642	-1643	0	146	-560	-1659	0	118	-480	-1676	0	104	-448	-1693	0
	Max	942	2034	2370	587	903	2192	2370	578	869	2310	2370	570	838	2396	2370	562
32	N = 0	520	0	0	264	466	0	0	262	422	0	0	260	386	0	0	257
	Min	271	-1045	-1944	0	234	-957	-1963	0	208	-907	-1982	0	182	-846	-2002	0
	Max	1162	1568	2370	626	1093	1821	2370	617	1035	2010	2370	608	985	2150	2370	600
40	N = 0	823	0	0	306	719	0	0	303	638	0	0	300	573	0	0	297
	Min	409	-1659	-2264	0	344	-1485	-2287	0	301	-1387	-2310	0	268	-1317	-2333	0

W =	0.15	Ctrs	=	150	mm	As2	=	0.50	As1	Fck	40	H	600	CC	1.5	LF	1.35
Dia	Cov	40				50				60				70			
		M	N	N	V	M	N	N	V	M	N	N	V	M	N	N	V
	Max	628	3186	2370	512	626	3226	2370	504	623	3255	2370	496	621	3273	2370	487
12	N = 0	44	0	0	184	35	0	0	182	29	0	0	179	27	0	0	177
	Min	27	-64	-1328	0	21	-53	-1335	0	17	-45	-1342	0	15	-40	-1350	0
	Max	659	2976	2370	511	654	3041	2370	502	648	3091	2370	494	643	3128	2370	486
16	N = 0	90	0	0	184	72	0	0	181	62	0	0	179	57	0	0	176
	Min	51	-153	-1330	0	40	-126	-1337	0	33	-108	-1344	0	28	-98	-1351	0
	Max	706	2775	2370	520	695	2867	2370	513	685	2940	2370	505	676	2995	2370	497
20	N = 0	155	0	0	194	124	0	0	193	112	0	0	191	101	0	0	189
	Min	85	-283	-1413	0	66	-234	-1426	0	54	-200	-1440	0	47	-184	-1455	0
	Max	783	2660	2370	549	764	2734	2370	541	747	2783	2370	534	731	2828	2370	526
25	N = 0	262	0	0	225	221	0	0	223	197	0	0	221	177	0	0	219
	Min	140	-506	-1643	0	110	-420	-1659	0	89	-360	-1676	0	78	-336	-1693	0
	Max	916	2497	2370	587	882	2629	2370	578	852	2721	2370	570	825	2782	2370	562
32	N = 0	425	0	0	264	383	0	0	262	350	0	0	260	319	0	0	257
	Min	222	-858	-1944	0	190	-781	-1963	0	156	-682	-1982	0	136	-634	-2002	0
	Max	1106	2195	2370	626	1047	2403	2370	617	997	2552	2370	608	954	2656	2370	600
40	N = 0	657	0	0	306	578	0	0	303	516	0	0	300	467	0	0	297
	Min	330	-1337	-2264	0	282	-1217	-2287	0	249	-1147	-2310	0	223	-1096	-2333	0

W =	0.1	Ctrs	=	150	mm	As2	=	0.50	As1	Fck	40	H	600	CC	1.5	LF	1.35
Dia	Cov	40				50				60				70			
		M	N	N	V	M	N	N	V	M	N	N	V	M	N	N	V
	Max	638	3548	2370	512	635	3580	2370	504	632	3600	2370	496	630	3608	2370	487
12	N = 0	29	0	0	184	23	0	0	182	19	0	0	179	18	0	0	177
	Min	18	-43	-1328	0	14	-35	-1335	0	12	-30	-1342	0	10	-27	-1350	0
	Max	667	3393	2370	511	661	3447	2370	502	656	3486	2370	494	651	3509	2370	486
16	N = 0	60	0	0	184	48	0	0	181	41	0	0	179	38	0	0	176
	Min	34	-102	-1330	0	27	-84	-1337	0	22	-72	-1344	0	19	-65	-1351	0
	Max	707	3253	2370	520	697	3332	2370	513	688	3389	2370	505	679	3427	2370	497
20	N = 0	103	0	0	194	83	0	0	193	74	0	0	191	68	0	0	189
	Min	56	-189	-1413	0	44	-156	-1426	0	36	-133	-1440	0	31	-123	-1455	0
	Max	774	3084	2370	549	757	3192	2370	541	741	3275	2370	534	726	3334	2370	526
25	N = 0	175	0	0	225	147	0	0	223	131	0	0	221	118	0	0	219
	Min	93	-338	-1643	0	73	-280	-1659	0	59	-240	-1676	0	52	-224	-1693	0
	Max	887	3046	2370	587	858	3140	2370	578	832	3197	2370	570	809	3226	2370	562
32	N = 0	317	0	0	264	274	0	0	262	240	0	0	260	213	0	0	257
	Min	162	-625	-1944	0	127	-520	-1963	0	104	-455	-1982	0	91	-423	-2002	0
	Max	1046	2917	2370	626	997	3068	2370	617	956	3166	2370	608	919	3223	2370	600
40	N = 0	491	0	0	306	437	0	0	303	394	0	0	300	355	0	0	297
	Min	250	-1016	-2264	0	207	-894	-2287	0	174	-799	-2310	0	150	-737	-2333	0

Crack Width Formulae and Derivation of Charts and Tables

Ref EN 1992-1-1 Clause 7.3.4 & National Annex

W = (Crack Spacing = Srmax) x (Basic Strain Due to Applied Forces - Strain Due to Concrete Stiffening)

= $((k_3 * Cov) + (k_1 * k_2 * k_4 * \varphi / \rho_{p,eff}))$ * ($(Fs1 / Es)$ - $((K_t * f_{ct,eff} / \rho_{p.eff}) / Es)$ - $(K_t * f_{ct,eff} * MR / Es)$)

= ((3.4*Cov) + (k1*0.5*0.425*φ*B*Teff /As1)) * ((Fs1/Es) - ((0.4*$f_{ct,eff}$*B*Teff /As1))/Es) - (0.4*$f_{ct,eff}$*MR/Es))

With the proviso that:- (0.4 * $f_{ct,eff}$ * B * Teff / As1) + (0.4 * $f_{ct,eff}$ * MR) <= 0.4 Fs1

Fs1 = (W * Es / ((3.4 * Cov) + (0.2125 * k1 * φ * B * Teff / As1))) + ((0.4 * $f_{ct,eff}$ * B * Teff / As1) + (0.4 * $f_{ct,eff}$ * MR))

Basic Stress = (W * Es / Spacing) Stress + Stiffening Stress

Es	=	Modulus for Reinf	Teff	=	Concrete in Tension Depth	k_1	=	Bond Factor
Ec	=	Modulus for Conc	K_t	=	Long Term Factor = 0.4	k_2	=	0.5 For 0 < X < H
MR	=	Es / (Ec / (1 + Creep))	$f_{ct,eff}$	=	f_{ctm28} = 28 day Tensile Strength	Fs1	=	F1 Tensile Stress

Teff = Min Of (H - X) / 3 or 2.5 * (Cov + Dia / 2) = 190 or H / 2

Maximum F1 bar centres < = 5 x (Cov + Dia / 2) i.e. for 12 mm Dia & 60 mm Cover = 330 mm

Reinforcement Data
Reads Data From sheet 3
Single Bars Only

F1 Bars	Equiv φ1	Cov1	Ctrs	d1	As1	F2 Bars	Equiv φ2	Cov2	Ctrs	d2	As2
32	32.0	60	150	524	5361.7	32	32.0	60	300	76.0	2680.8

Fs1 is limited by the Cl 7.2 k3 factor — Fs1max = 0.70 x 500 = **350** N/mm²
Max Conc Stress is limited by the Cl 7.2 k value. — Fcmax = 0.45 x 40 = **18.00** N/mm²

Key Values

		Min 50	0.2X	At N = 0	At fc = kFck
X		**0.0**	**50**	**200.9**	**309.1**
WEs	kN/mm	40	40	40	40
Srmax	mm	397	390	339	302
Basic	N/mm²	101	103	118	132
Stiff	N/mm²	67	68	55	45
Fs1	N/mm²	168	170	173	178
Conc	N/mm²	0.00	1.27	7.57	18.00
MR1	Factor	14.2	14.2	14.2	14.2
MR2	Factor	14.2	14.2	13.2	13.2
F1Strn x Ec		11.8	12.0	12.2	12.5

If N = 0, X is found by the following Quadratic Equation.

0.5*B X ^ 2 + ((As1*MR)+(As2*(MR-1))) X
+ ((-As1*D1*MR)+(-As2*D2*(MR-1)) = 0 X = **200.9**

At k Fck - Values From Cubic, Quadratic & Simple Equations

Teff = (H - X) / 3 = 96.95	X	=	309.1
If Stiffening stress is limited to 0.4Fs1	X	=	284.8
Teff = 2.5(Cov +Dia/2) = 190	X	=	N/A
If Stiffening stress is limited to 0.4Fs1	X	=	N/A
X Used		=	**309.1**

Where Capacity is Controlled by Crack Width & Fsmax & Concrete Stress is Variable but <= kFck

Axial Resistance AR F1Strn value is -ve when in tension kN		X = 0	X = 50	At N = 0	At kFck
F1	As1 * F1Strn * Ec * MR1	-901	-914	-926	-952
F2	As2 * F1Strn * Ec * ((D2 - X) / (D1 - X)) * MR2	-65	-25	166	480
Conc	- 0.5 * X * B * F1Strn * Ec * (X / (D1 - X))	0	32	760	2782
	N	**-966**	**-907**	**0**	**2310**
Moment Resistance about Centre MoR to a Clockwise Moment kNm					
F1	- As1 * F1Strn * Ec * MR1 * (D1 - 0.5 H)	201.8	204.7	207.5	213.3
F2	+ As2 * F1Strn * Ec * ((D2 - X) / (D1 - X)) * MR2 * (0.5H - D2)	-14.6	-5.62	37.27	107.6
Conc	- 0.5 * X * B * F1Strn * Ec * (X / (D1 - X)) * (0.5H - (X / 3))	0.0	9.0	177.1	548.0
	M	**187.2**	**208.1**	**421.8**	**868.8**

Where X > = k Fck limit and Capacity is Controlled by Compression - Selected Values

Axial Resistance AR F1Strn value is -ve when in tension kN		X = 309.1	X = 406.1	X = 503	X = 600
F1	- As1 * MR1 * k * Fck * (D1 - X) / X	-952	-398	-57.1	161.3
F2	- As2 * MR2 * k * Fck * (D2 - X) / X	480.2	517.6	540.6	556.1
Conc	0.5 * X * B * Conc	2782	3655	4527	5400
	N	**2310**	**3775**	**5011**	**6117**
Moment Resistance about Centre MoR to a Clockwise Moment kNm					
F1	- As1 * MR1 * k * Fck * (D1 - 0.5 H) * (D1 - X) / X	213.3	89.1	12.78	-36.1
F2	+ As2 * MR2 * k * Fck * (0.5H - D2) * (D2 - X) / X	107.6	115.9	121.1	124.6
Conc	0.5 * X * B * k * Fck * (0.5H - (X / 3))	548	601.7	599.1	540
	M	**868.8**	**806.8**	**732.9**	**628.4**

EC2 DESIGN TOOL

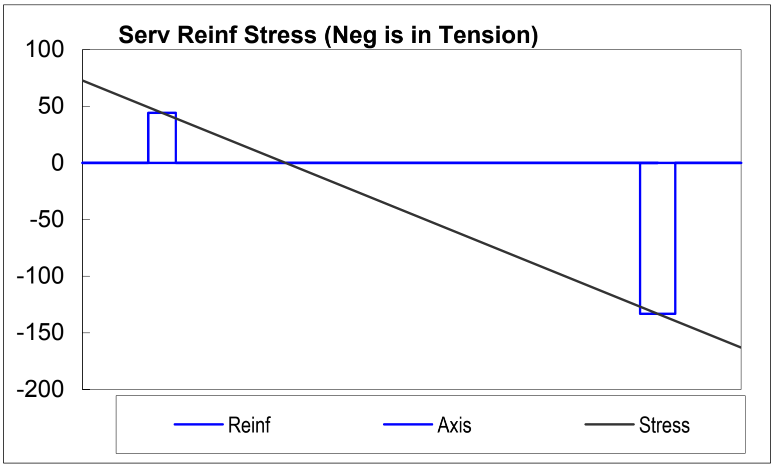
SERVICE ANALYSIS

HAC-PRO 1 - 5 - 2 SERV 1

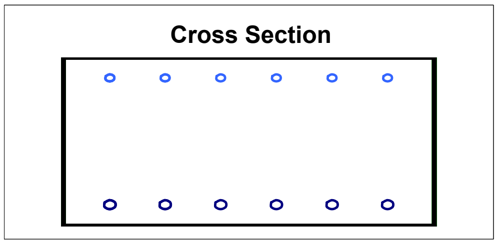
Howes Atkinson Crowder LLP

Service Method Auto CC = **1.553** CC Used **1.500** **Grade** = C **30** / **37**

C



T



Ec = Ecm (at Crack Age) / (1 + Creep Coeff)
MR = Es / Ec or (Es / Ec) - 1 If in Comp

Conc Stress	=	Strain x Ec
Fs1 Reinf	=	F1Strain x Ec x MR1
Fs3 Reinf	=	L3Strain x Ec x MR3
Fs2 Reinf	=	F2Strain x Ec x MR2

H =	**600**	φ1 =	**32**	φ2 =	**25**	φE	0
B =	**1000**	Sp or nr =	**150**	Sp or nr =	**150**	Fact	0
F1	**Bot**	Cov =	**60**	Cov =	**60**	Exposure	**1 & 85**
CC =	**1.50**	Load Age	**28 Days**	CC at Year	**Max**		
CODE	**EC2**	Crack Age	**28 Days**	Ns kN	**-137**	Ms kNm	**296**

Ecm (at Crack Age)	**32.8**	kN / mm²
Modular Ratio (tens)	**15.2**	
N when X = 0 (N_o)	**-1567**	kN
N when X = H (N_h)	**2794**	kN
Max Allowed Conc Stress	**13.5**	N / mm²

As1	**5362** mm²	D1	**524.0** mm
As3	**0** mm²	D3	**524.0** mm
As2	**3272** mm²	D2	**72.5** mm

Where X is between 0 and H **X** = **185.1**
Where X < 0 or X > H **X** = **N/A**

Forces & Strain Equilibrium for 0 > X < H As1 >= As2	**Basic Stress N/mm² 0 < X < H**	**Add Stress N/mm² X<0 or X>H**	**Stress N/mm² Total**	**Force kN**
Axial Resistance AR F1Strn value is Neg in tension				
F1 = As1 * MR1 * (F1Strn * Ec)	-133.2	0.0	-133.2	-714.0
+ L3 = As3 * MR3 * (F1Strn * Ec) * ((D3 - X) / (D1 - X))	0.0	0.0	0.0	0.0
+ F2 = As2 * MR2 * (F1Strn * Ec) * ((D2 - X) / (D1 - X))	44.2	0.0	44.2	135.2
+ Conc = - 0.5 * X * B * (F1Strn * Ec) * (X / (D1 - X)) (Max)	4.8 & 0	0.0	4.8 & 0	441.8
				-137

	Add M CL kNm	**M CL kNm**
Moment Resistance about Centre MoR to a Clockwise Moment M =		
F1 = - As1 * MR1 * (F1Strn * Ec) * (D1 - 0.5 H)	0.0	159.9
+ L3 = - As3 * MR3 * (F1Strn * Ec) * ((D3 - X) / (D1 - X)) * (D3 - 0.5H)	0.0	0.0
+ F2 = + As2 * MR2 * (F1Strn * Ec) * ((D2 - X) / (D1 - X)) * (0.5H - D2)	0.0	30.8
+ Conc = - 0.5 * X * B * (F1Strn * Ec) * (X / (D1 - X)) * (0.5H - (X / 3))	0.0	105.3
	0	**296**

AR / MoR must equal applied N / M so AR = (N /M) * MoR. Therefore - AR + (N/M) * MoR = 0
So, re-arranging and dividing by F1Strn * Ec gives

- As1 * MR1		N / M *	- As1 * MR1 * (D1 - 0.5 H)		
- As3 * ((D3 - X) / (D1 - X)) * MR3	+	N / M *	- As3 * ((D3 - X) / (D1 - X)) * MR3 * (D3 - 0.5H)	=	0
- As2 * ((D2 - X) / (D1 - X)) * MR2		N / M *	+ As2 * ((D2 - X) / (D1 - X)) * MR2 * (0.5H - D2)		
+ 0.5 * B * (X / (D1 - X)) * X		N / M *	- 0.5 * B * (X / (D1 - X)) * X * (0.5H - (X / 3))		

The value of MR1, MR3 & MR2 must be established in each case by testing the applied N / M against the values of N part of the equation. Values at X = 0 and X =H are also established.

For an applied Moment of M, N = M * AR / MoR If X is known N can be found
Therefore the values of N at key positions of X can be found and the Cubic Equation can be solved.

N = **M** *	+ As1 * MR1		- As1 * MR1 * (D1 - 0.5 H)
	+ As3 * ((D3 - X) / (D1 - X)) * MR3	/	- As3 * ((D3 - X) / (D1 - X)) * MR3 * (D3 - 0.5H)
	+ As2 * ((D2 - X) / (D1 - X)) * MR2		+ As2 * ((D2 - X) / (D1 - X)) * MR2 * (0.5H - D2)
	- 0.5 * B * (X / (D1 - X)) * X		- 0.5 * B * (X / (D1 - X)) * X * (0.5H - (X / 3))

For

N =	-137	kN
M =	296	kNm
N / M =	-0.463	/m

F after X = H kN	**M / N at X = 0 m**
0.0	188.8

N at X = 0 kN	N at X = d2 kN	N at X = d3 kN	N at X = d1 kN	N at X = H kN
-1567	-1128	2131	2131	2794

Modular Ratios (Reduced by 1 If In Compression)		
MR1	MR3	MR2
15.2	15.2	14.2

Derivation of Key Values

The following shows the method used to calculate the key values used in the program.
The program values can be checked using the equations below (where Excel notation is used * = x & ^ = Power).
As3, Centroid3, φ3c, L3 & d3 refer to bars in 3rd Layer (L3) and includes column side bars.
φ1 = bars near Face 1, φ2 = bars near Face 2, φE = Extra bars bundled with φ1 or φ1 & φ2 or placed in Layer 3.

BF = Extra Bars Bundle Factor	0 = No Bundle	1 = Bundled Once	2 = Bundled Twice
Layer 3 Extra Bars Factors	Lgap = Layer 3 with Gap in mm from φ1 Max		S1 = Col Side Bars

			φ1	φ2	φE
a & b Refer to Alt Bar Dias	**First Alt Bar**	**a**	32	25	0
If same Dia, φa = φb	**Second Alt Bar**	**b**	32	25	0
	Extra Bars Factor				0
Use φ1 BF or φ2 BF as appropriate	**Extra Bars Bundle Factor BF**		0	0	

Centroid of Bar Group Measured from Start of Bars & Away from Relevant Face

φ1 Centroid (BF = 0) = 0.5 * (φ1a³ + φ1b³) / (φ1a² + φ1b²)
φ1 Centroid (BF > 0) = 0.5 * (φ1a³ + φ1b³ + BF*φEa³ + BF*φEb³) / (φ1a² + φ1b² + BF*φEa² + BF*φEb²)

φ3 Centroid (Extra Bar Factor = Lgap or S1) = 0.5 * (φEa³ + φEb³) / (φEa² + φEb²)

φ2 Centroid (As2 > 0 & BF = 0) = 0.5 * (φ2a³ + φ2b³) / (φ2a² + φ2b²)
φ2 Centroid (As2 > 0 & BF > 0) = 0.5 * (φ2a³ + φ2b³ + BF*φEa³ + BF*φEb³) / (φ2a² + φ2b² + BF*φEa² + BF*φEb²)
φ2 Centroid (As2 = 0 & BF > 0) = 0.5 * (BF*φEa³ + BF*φEb³) / (BF*φEa² + BF*φEb²)

Reinforcement Areas

As1 = π x (0.125 * (φ1a² + φ1b²) + 0.125 * (BF*φEa² + BF*φEb²)) * (Nr1 or B / Spacing1)

As3 = (Extra Bar Factor = Lgap) = π * 0.125 * (φEa² + φEb²) * (Nr1 or B / Spacing1)
(Extra Bar Factor = S1) = π * 0.125 * (φEa² + φEb²) * 2

As2 = π * (0.125 * (φ2a² + φ2b²) + 0.125 * (BF*φEa² + BF*φEb²)) * (Nr2 or B / Spacing2)

φ Composite (Equivalent Similar Bar Size = φc)

φ1c (BF = 0) = ((φ1a² + φ1b²) / 2) ^ 0.5
φ1c (BF > 0) = ((φ1a² + φ1b² + BFφEa² + BFφEb²) / (2 + 2BF)) ^ 0.5

φ3c (Extra Bar Factor = Lgap or S1) = ((φEa² + φEb²) / 2) ^ 0.5

φ2c (As2 > 0 & BF = 0) = ((φ2a² + φ2b²) / 2) ^ 0.5
φ2c (As2 > 0 & BF > 0) = ((φ2a² + φ2b² + BF*φEa² + BF*φEb²) / (2 + 2BF)) ^ 0.5
φ2c (As2 = 0 & BF > 0) = ((BF*φEa² + BF*φEb²) / (2BF)) ^ 0.5

Centroid of Bar Groups mm If As3 = 0, Centroid3 = Centroid1		**Centroid1**	**Centroid3**	**Centroid2**
Centroid 1 & Centroid 3 are away from Face1	Program	16.0	16.0	12.5
Centroid 2 is away from Face 2	Check	16.0	16.0	12.5

Effective Depths mm If As3 = 0, d3 = d1		**d1**	**d3**	**d2**
d1 = H - Cov1 - As1Centroid d2 = Cov2 + As2Centroid	Program	524.0	524.0	72.5
d3 = H - Cov1 - φ1Max - LGap - As3 Centroid or H/2 or d1	Check	524.0	524.0	72.5

Reinforcement Areas mm²		**As1**	**As3**	**As2**
As1 & As2 includes bundled bars as per appropriate BF	Program	5362	0	3272
As3 refers to the Extra bars in Layer 3 or Column Side Bars	Check	5362	0	3272

φ Composite mm (φc)		**φ1c**	**φ3c**	**φ2c**
Equivalent single size bar φ which gives same total Area	Program	32.0	0.0	25.0
Elevation diagrams display bars using φc	Check	32.0	0.0	25.0

Mult all By (D1 - X)

-(As1 * MR1) * (D1 - X)	+	N / M	*	- As1 * MR1 * (D1 - (0.5*H)) * (D1 - X)		
-(As3 * (D3 - X)) * MR3	+	N / M	*	- (As3 * (D3 - X)) * MR3 * (D3 - (0.5*H))		
-(As2 * (D2 - X)) * MR2	+	N / M	*	+ (As2 * (D2 - X)) * MR2 * ((H/2) - D2)		
+(0.5 * B) * X * X	+	N / M	*	- (0.5 * B) * X * X * ((0.5*H) - (X/3))	=	0

Multiply Out

- As1 * MR1 * D1 + As1 * MR1 * X
- As3 * D3 * MR3 + As3 * X * MR3
+ As2 * X * MR2 - As2 * D2 * MR2
+ 0.5 * B * X^2

Key Data

H	B	As1	As3	As2	D1	D3	D2	N/M
600	1000	5362	0	3272	524	524	72.5	-0.000463

+

- (N/M * As1 * MR1* D1 * D1) + (N/M * As1 * MR1 * D1 * X) + (N/M * As1 * MR1* 0.5 * H * D1) - (N/M * As1 * MR1 * 0.5 * H * X)
- (N/M * As3 * MR3 * D3 * D3) + (N/M * As3 * MR3 * D3 * 0.5 * H) + (N/M * As3 * MR3 * X * D3) - (N/M * As3 * MR3 * X * 0.5 * H)
+ (N /M * As2 * MR2 * D2 * 0.5 * H) - (N/M * As2 * MR2 * D2 * D2) - (N/M * As2 * MR2 * X * 0.5 * H) + (N/M * As2 * MR2 * X * D2)
- (N/M * 0.5 * B * 0.5 * H * X^2) + (N/M * 1/3 * 0.5 * B * X^3)

=

0

Which is re-arranged to give the Cubic Equation

		Using Constants		**Using Xo**
+ (N/M * 1/3 * 0.5 * B)		-0.08	X^3	-488847.068
+				
- (N/M * 0.5 * B * 0.5 * H)	69.42567568			
+ (0.5 * B)	500.00	569.4256757	X^2	19499971.9
+				
+ (As1 * MR1)	81641.47			
+ (As3 * MR3)	0.00			
+ (As2 * MR2)	46557.51			
+ (N/M * As1 * MR1 * D1) - (N/M * As1 * MR1 * 0.5 * H)	-8464.23			
+ (N/M * As3 * MR3 * D3) - (N/M * As3 * MR3 * 0.5 * H)	0.00			
+ (N/M * As2 * MR2 * D2) - (N/M * As2 * MR2 * 0.5 * H)	4902.30	124637.05	X	23064583.3
+				
- (As1 * D1 * MR1)	-42780131.03			
- (As3 * D3 * MR3)	0.00			
- (As2 * D2 * MR2)	-3375419.28			
- (N/M * As1 * MR1* D1 * D1) + (N/M * As1 * MR1* 0.5 * H * D1)	4435258.99			
- (N/M * As3 * MR3 * D3 * D3) + (N/M * As3 * MR3 * 0.5 * H * D3)	0.00			
- (N/M * As2 * MR2 * D2 * D2) + (N /M * As2 * MR2 * 0.5 * H * D2)	-355416.83	-42075708.15		-42075708.1
			=	

From Cubic / Quadratic Equation Solution **Xo** **=** **185.1** **mm** **0.000**

For N = 0, the equation becomes a Quadratic So X =

(-((As1*MR)+(As3*MR)+(As2*(MR-1)))+(((As1*MR)+(As3*MR)+(As2*(MR-1)))^2 - 4*0.5*B*((-As1*D1*MR)+(-As3*D3*MR)+(-As2*D2*(MR-1))))^0.5)

Divided By

(2*0.5*B)

-128198.98 + (16434978152 - -92311100627) ^ 0.5

Divided By

1000

=

201.6 mm

Solution of a X^3 + b X^2 + c X + d = 0 Using Iteration or Goal Seek (As1 & As2 only)

a = (1 / 6) * B * N/M **Valid where 0 < X < H**
b = 0.5 * B * (1 - (0.5 * H * N/M))
c = (MR1 * As1 + MR2 * As2) + ((N/M) * (MR1 * As1 * (D1 - 0.5H) + MR2 * As2 * (D2 - 0.5H)))
d = - ((MR1 * As1 * D1) + (MR2 * As2 * D2)) + (N/M) * ((MR1 * As1 * D1) * (D1 - 0.5H) + (MR2 * As2 * D2) * (D2 - 0.5H))

Data

φ1	Cov1	Ctrs Nr <50	φ2	Cov2	Ctrs Nr <50	MR	H	B	N kN	M kNm	N / M (N / Nmm)	D1	D2	As1	As2
32.0	**60**	**150**	**25.0**	**60**	**150**	**15.2**	**600**	**1000**	**-137**	**296**	**-0.000463**	**524**	**72.5**	**5362**	**3272**

1 N / M When X = 0 **If N < No, Set X = 0 & Add Additional Stresses as Step 8**

= - (As1 + (As2 * (D2 / D1))) / (As1 * (D1 - 0.5 H) + As2 * (D2 / D1) * (D2 - 0.5H))

= -5814 / 1098003 = **-0.005295** No = **-1567** kN

2 N / M When X = H **If N > Nh, Set X = H & Add Additional Stresses as Step 9**

(As1*(MR-1) + As2*((D2-H)/(D1-H))*(MR-1) - 0.5*B*(H/(D1-X))*H)
/ (-As1* (MR-1)*(D1-0.5H) + As2*((D2-H)/(D1-H))*(MR-1)*(0.5H-D2) - 0.5*B*(H^2/(D1-H))*(0.5H-(H/3)))

= 2767847 / 293271108 = **0.009438** Nh = **2794** kN

3 N / M When X = D2 If N / M > Nd2 / M, MR2 = MR -1

As1 * MR - 0.5 * B * (D2² / (D1 - D2)) / - As1 * MR * (D1 - 0.5H) - 0.5 * B * (D2 / (D1 - D2)) * D2 * (0.5H - (D2 / 3))

= 75821 / -19893281 = **-0.003811** MR2 **14.2** Nd2 = **-1128** kN

4 N / M When X = D1 If N / M > Nd1 / M, MR1 = MR-1

((As2 * (D2 - D1)) * (MR-1) - (0.5 * B) * D1^2) / ((As2 * (D2 - D1)) * (MR-1) * ((H/2) - D2) - (0.5 * B) * D1^2 * ((0.5*H) - (D1/3)))

= -158308715 / -21988975227 = **0.007199** MR1 **15.2** Nd1 = **2131** kN

5 Equation Constants Using MR1 & MR2 Values

a = -0.07713964 b = 569 c = 124637 d = -42075708

6 If No < N < Nh, Change X by Iteration until Equation Value = 0 (Start with X = 0.5H)

X = **185.05** mm If N < No Set X =0 If N = 0, X quadratic = 201.6 mm

-488847 + 19499972 + 23064583 + -42075708 = **0**

7 Stresses in As1 & As2 for 0 < X < H.

Fs1 = - MR1*M/(As1*MR1*(D1-0.5H) + As2*((D2-X)/(D1-X))*MR2*(0.5H-D2) - 0.5*X*B*(X/(D1-X))*(0.5H-(X/3))) **-133** N/mm²
Fs2 = Fs1* ((D2 - X) / (D1 - X)) * (0.5H - D2)*MR2 / MR1 = **41** N/mm²

8 Additional Stresses If N < No

Ecc = As1 * (0.5H - Cov1 - 0.5Dia) - As2 * (0.5H - Cov2 - 0.5Dia2) / (As1 + As2) = **N/A** mm

N - No = **N/A** kN Mecc = (N - No) * er = **N/A** kNm

Extra Fs1 = (N - No) / (As1 + As2) - (Mecc / (d1 -d2) / As1 = N/A - N/A = **N/A** N/mm²
Extra Fs2 = (N - No) / (As1 + As2) + (Mecc / (d1 -d2) / As1 = N/A + N/A = **N/A** N/mm²

9 Additional Stresses If N > N_h

The reinforcement will be within the concrete compression zone so, in order to avoid taking the area twice, the equivalent concrete area for reinforcement factor is reduced by 1.
The calculated reinforcement in compression stress is less than the real stress by the concrete stress.

Eccentricity of Centroid of Composite Section about Centre Line

er = As1*MR1*(0.5H - Cov1 - 0.5φ1) - As2*MR2*(0.5H - Cov2 - 0.5φ2) / (As1*MR1+ As2*MR2 + B*H)) **N/A** mm

Area of Composite Section

A = As1*MR1 + As2*MR2 + B * H **N/A** mm²

Moment of Inertia about Composite Centroid

Ixx = (B*H^3/12)+(B*H*Ecc^2)
+ As1*MR1*(0.5H-Cov1-0.5φ1-Ecc)^2 + As2*MR2*(0.5H-Cov2-0.5φ2+Ecc)^2
+ As2*MR2*(0.5H-Cov2-0.5φ2+Ecc)^2 **N/A** mm4

N - N_h = **N/A** kN Mecc = (N - Nh) * er = **N/A** kNm

Concrete Stress at Faces 1 & 2

F1 = (N-Nh) / A - Mecc*(0.5H - Ecc) / Ixx	**N/A**	-	**N/A**	=	**N/A**	N/mm²
F2 = (N-Nh) / A + Mecc*(0.5H + Ecc) / Ixx	**N/A**	+	**N/A**	=	**N/A**	N/mm²

Reinforcement Stresses at As1 and As2

Fs1 = (N-Nh) / A - MR*Mecc * (0.5H-Cov1-0.5φ1-Ecc) / Ixx	**N/A**	-	**N/A**	=	**N/A**	N/mm²
Fs2 = (N-Nh) / A + MR*Mecc * (0.5H-Cov2-0.5φ2+Ecc) / Ixx	**N/A**	+	**N/A**	=	**N/A**	N/mm²

Concrete Forces

	Stress		H		B			F		Ecc about Centre		
Rect Part	**N/A**	x	**600**	x	**1000**		=	**N/A**	kN	Rect	**0**	mm
Tri Part	**N/A**	x	**600**	x	**1000**	x 0.5	=	**N/A**	kN	Tri	**100**	mm
						Total		**N/A**	kN			

Reinforcement Forces

	Stress		As1			F		Ecc about Centre		
As1	**N/A**	x	**5362**		=	**N/A**	kN	As1	**224**	mm
As2	**N/A**	x	**3272**		=	**N/A**	kN	As2	**227.5**	mm
				Total		**N/A**	kN			

Check Concrete Force + Reinf Force = N - Nh **N/A** + **N/A** = **N/A** kN

Check Moments about Centre Equate to Zero

Concrete	**N/A**	x	**0**	/	1000	**=**	**0**				
	N/A	x	**100**	/	1000	**=**	**N/A**	kNm	Total	**N/A**	kNm
Reinf	**N/A**	x	**224**	/	1000	**=**	**N/A**				
	N/A	x	**228**	/	1000	**=**	**N/A**	kNm	Total	**N/A**	kNm
									Total	**N/A**	kNm

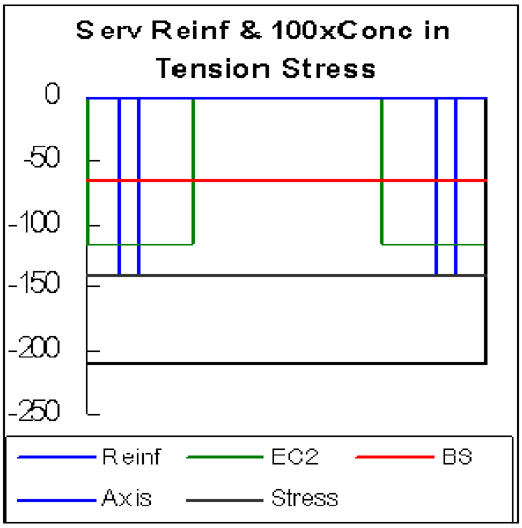
The concrete and reinforcement stresses are calculated about the Composite Centroid
The equations are simpler in respect of the reinforcement.

The section must also be in overall equilibrium about the Centre of the Section

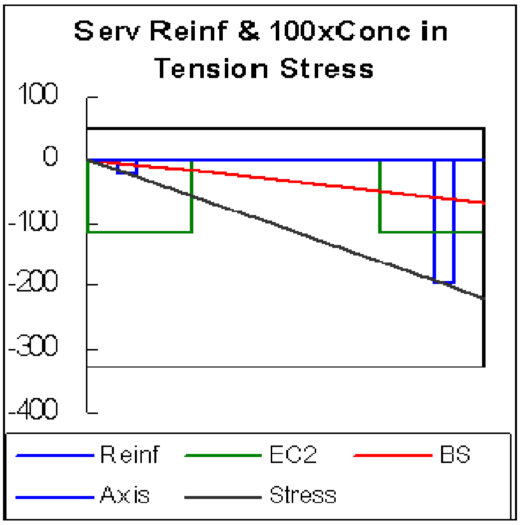
As there is no additional moment applied after N = N_h, The resultant Moment must equal Zero.

SERVICE ANALYSIS Cont.

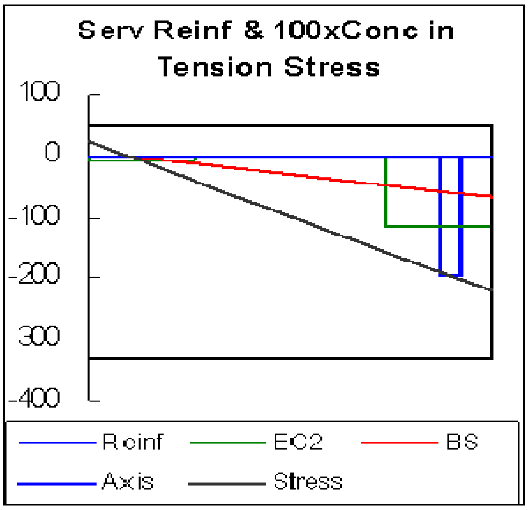
Stress Diagrams Relating to Key Points



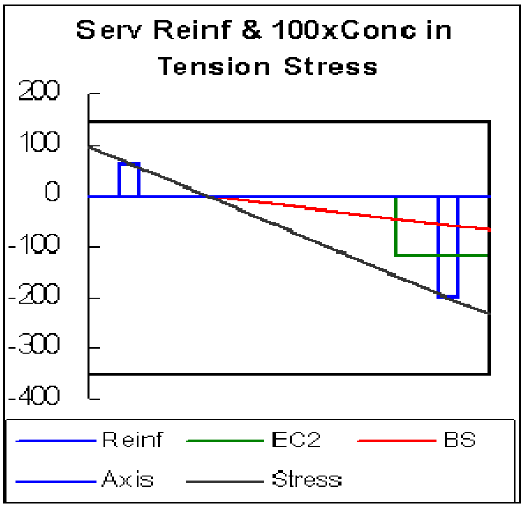
At X = -∞



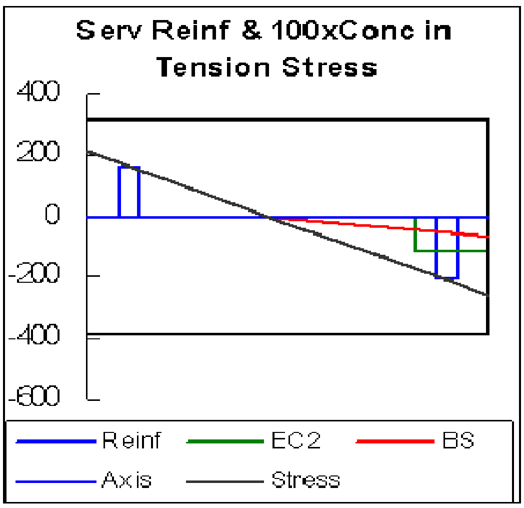
At X = 0



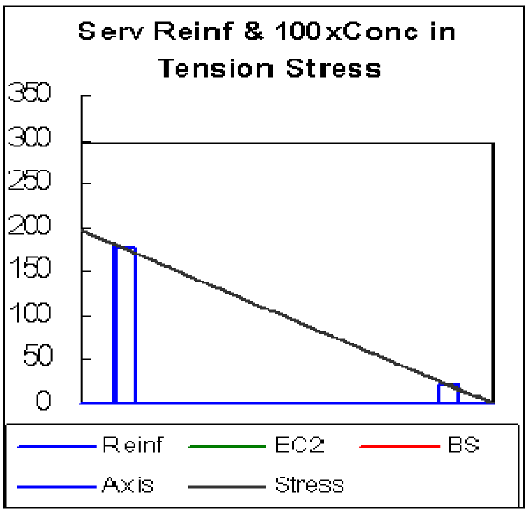
At X = Min 50mm or 0.2H



At N = 0



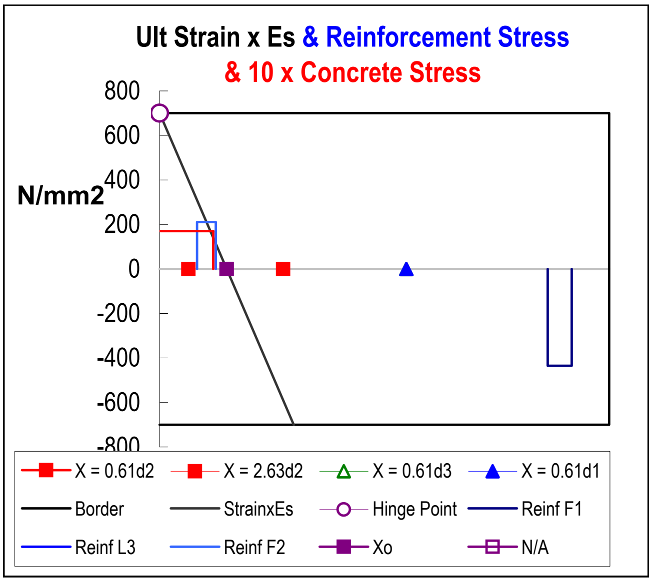
At fc = 0.45fck

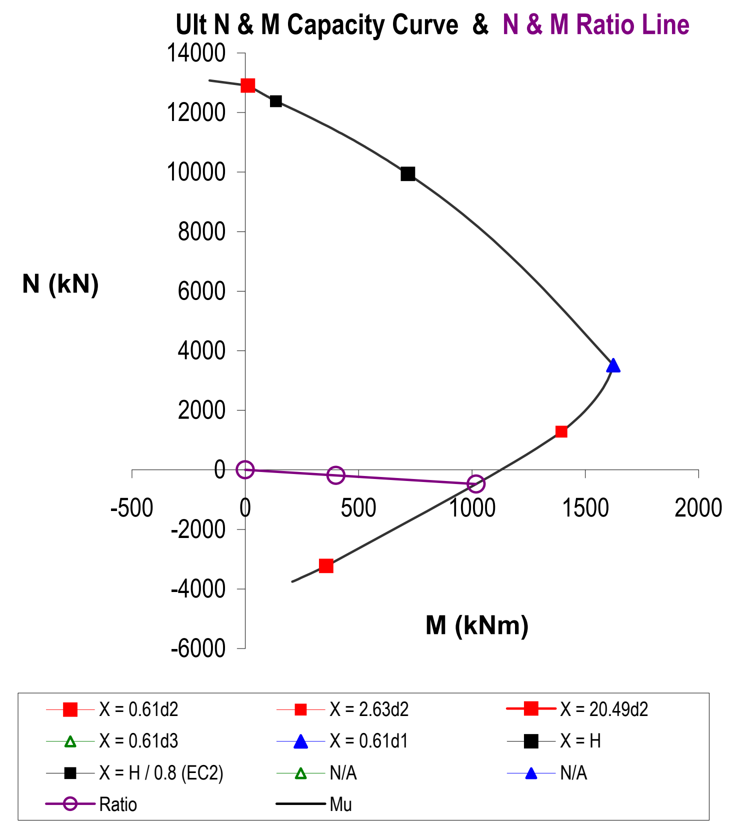


At X = H

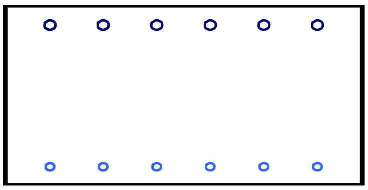
	EC2 DESIGN TOOL ULTIMATE EQUATION HAC-PRO 1 - 5 - 2 ULT 1	HAC Howes Atkinson Crowder LLP Copyright © 2009 HAC

Ultimate Method **Based on Ultimate Theory** **Grade = C 30 / 37**





Cross Section



Notation For X Dependant Constants **Cap 0.39**

S or U	U
LF	1.35

F1 φ	32
@ , nr	150
Cov	50
F2 φ	25
@ , nr	150
Cov	50
Ex φ	0
Fact	0

Type	Wall
Face 1	Int
H	600
B	1000
V or T	297
N	-187
M	400
B,M,δ	
Code	EC2

L, K & DC have suffixes according to As1 or As3 or As2

HY	If X / λ < = H = 1, else = 0 so stress block <= H.
L	If the value is -1, Fs = -Fsmax, if 1, Fs = Fsmax, if 0, Fs is variable.
BC	If 1, "Hinge Point" is at X = 0, if 0, it is at X = 0.5H for EC2 and X > H
K	(1 - L^2)εcuEs*0.5*(BC+1) = Fs at "Hinge Point" if variable Fs, if fixed = 0.
DC	Displaced Concrete stress reduction of reinforcement in compression.
Q	If EC2 and X > H value is 0.5H, otherwise 0. Sets "hinge" point.

		H	TD2	CD2	TD3	CD3	TD1	CD1	H / λ	D2 / λ		D3 / λ		D1 / λ	
										- φ / 2	+ φ / 2	- φ / 2	+ φ / 2	- φ / 2	+ φ / 2
X	mm	600	39	165	N/A	N/A	329	1409	750	64	92	N/A	N/A	650	685
N	kN	9940	-3230	1279	N/A	N/A	3516	12925	12377	-1394	-402	N/A	N/A	10825	11332
M	kNm	718	357	1395	N/A	N/A	1624	-8	135	800	1036	N/A	N/A	534	415
α	deg	234.2	138	185	N/A	N/A	192	270	264	170	178	N/A	N/A	244	250

Design Constants

N / M	B	H	Conc	λ	As1	As3	As2	Fsmax	d1	d3	d2	α deg
-0.0004675	1000	600	17.00	0.80	5362	0	3272	434.8	534	534	63	177.3

X Dependant Constants which relate to N / M

HY	L1	L3	L2	BC	K1	K3	K2	DC1	DC3	DC2	Q	X
1.0	-1.0	-1.0	0.0	1.0	0	0	700	0.00	0.00	-15.99	0	89.5

As1 * (- K1 * (d1 - X) / (X - Q)) + L1 * Fsmax + DC1) + As3 * (- K3* (d3 - X) / (X - Q)) + L3 * Fsmax + DC3)
+ As2 * (- K2 * (d2 - X) / (X - Q)) + L2 * Fsmax - DC2) + HY * (B * λ * Conc * X) + (B * λ * Conc * H / λ) * (1 - HY)

EQUALS (N / M) * - As1 * (- K1 * (d1 - X) / (X - Q)) + L1 * Fsmax + DC1) * (d1 - H / 2)
+ (N / M) * - As3 * (- K3* (d3 - X) / (X - Q)) + L3 * Fsmax + DC3) * (d3 - H / 2)
+ (N / M) * - As2 * (- K2 * (d2 - X) / (X - Q)) + L2 * Fsmax + DC2) * (d2 - H / 2)
+ (N / M) * + HY * (B* λ * Conc * X) * ((0.5 * H) - (0.5* λ * X))

Re-arrange to Give $aX^3 + bX^2 + cX + d = 0$

DERIVATION OF THE UNIVERSAL ULTIMATE N - M EQUATION

Establish Following Values:- **Values in Bold Blue derive from Global & Local Input**

Steel Modulus of Elasticity Es - **This value is fixed by the program** Es **200** kN / mm²

Maximum concrete compressive strain εcu2 Value reduces if Fcu > 50 N/mm² Abbrev Used	εcu	**0.0035**	
Maximum Strain x Es value (i.e. equiv Reinf Stress) at compression face unless EC2 and X > H	εcuEs	**700**	N / mm²
Strain x Es value (i.e. equivalent Reinforcement Stress) at centre for EC2 when X >= H	0.5εcuEs	**350**	N / mm²
Max Reinf Stress fpd = fyk / γ This is defined in Global values.	fpd = Fsmax =	**435**	N / mm²
Max concrete stress either EC2 or BS value but EC2 symbol used (NA αct = 0.85)	fcd = Conc =	**17.00**	N / mm²

TD where reinf Tens value is locked	= 1 / ((1 + (Fsmax / Es) / εcu)) * D	=	**0.616**	x	D
CD where reinf Comp value is locked	= εcu / (εcu - (Fsmax / Es)) * D	=	**2.639**	x	D
CeD2 stress variable again if EC2 & X>H & ((Fsmax*0.5*H) - (0.5*εcuEs*D2))/(Fsmax - (0.5*εcuEs))*D2		=	**20.4**	x	D2

N & M values and polar angle value when X = H in order to reset the hinge point for EC2 design.
N & M values and polar angle value when X = H / λ in order to set moment due to stress block to zero and lock any increase in length of it
N & M polar angle values for X / λ at start and finish of F1, L3 & F2 reinf bars using equivalent squares to establish if within stress block
N & M values and polar angle values for X at control pointsTD and CD for F1, L3 & F2 reinforcement to check for locks.
N / M polar angle of applied N - M Forces. Angle is 90 when M=0 and N is negative and increases in an anticlockwise rotation

How To deal with All the Variables and Create a Universal Equation for BS and EC2
It is essential to set up a system of abbreviations and "variable constants" which are established according to where X is along the N - M curve
The polar angle of the applied N - M ratio is then checked against the angles for the key control points and the constants are then established
Once all of the constants are known, the equation can be completed, re-arranged into a Cubic Equation and then solved

How To Find N / M and Polar Angle when X is at the key Locking Points and Reinforcement Locations.
Compare X against TD and CD to establish if the reinf stress is fixed at -Fsmax (ten) or + Fsmax (comp) or variable and set L1, L3 and L2
Check at X = H / λ and EC2 only for the case where X is > H and > CeD to see if reinf is variable again for L2 and note L2e.
Check X at bar locations i.e. D2 - φ/2 to D2 + φ/2, D1 - φ/2 to D1 + φ/2, D3 - φ/2 to D3 + φ/2 to calculate displaced concrete deductions
Enter values into equations below to find N & M and N / M at each point. Then calculate the Polar Angles for all key points

Variable Constants	**BC**	IF code is EC2 and X > H	virtual hinge at X = 0.5 H	=	0	Fs =0.5εcuEs N/mm² at X = 0.5H
		Otherwise	virtual hinge at X = 0	=	1	Fs = εcuEs N/mm2 at X =0
	L1 or L3	IF X < 0.616 D1 or D3		=	-1	Stress = - Fs max
		IF X > 2.639 D1 or D3	except if EC2 & X > H	=	1	Stress = + Fsmax
		Otherwise and including if EC2 & X > H		=	0	Stress is Variable
	L2	IF X < 0.616 D2	(CeD2 value relates to H and D2)	=	-1	Tens Stress = - Fs max
		IF X > 2.639 D2 and if EC2 & X > H & X < CeD2		=	1	Comp Stress = + Fsmax
		Otherwise, incl if = EC2 & X > H & X > CeD2		=	0	Stress is Variable
	DC1	Displaced concrete stress x prop of bar in stress block		=	0	to -17.00 N / mm²
	DC3	Displaced concrete stress x prop of bar in stress block		=	0	to -17.00 N / mm²
	DC2	Displaced concrete stress x prop of bar in stress block		=	0	to -17.00 N / mm²
	HY	If X / λ > = H HY = 0 but to avoid a divide / zero use		=	1E-07	Ensures the conc stress
		Otherwise, where stress block is within section		=	1	block does not exceed H

N = (N / M) * Moment about Centre **N / M values is always known** Excel notation has been used for mult (*) and power (^)

N = As1 * (- (1 - L1^2) * 0.5εcuEs * (BC+1) * (d1 - X) / (X - (0.5H*(1-BC)))) + L1 * Fsmax + DC1)
+ As3 * (- (1 - L3^2) * 0.5εcuEs * (BC+1) * (d3 - X) / (X - (0.5H*(1-BC)))) + L3 * Fsmax + DC3)
+ As2 * (- (1 - L2^2) * 0.5εcuEs * (BC+1) * (d2 - X) / (X - (0.5H*(1-BC)))) + L2 * Fsmax + DC2)
+ HY * (B * λ * Conc * X) + (B * λ * Conc * H / λ) * (1 - HY)
=
(N / M) * (- As1 * (- (1 - L1^2) * 0.5εcuEs * (BC+1) * (d1 - X) / (X - (0.5H*(1-BC)))) + L1 * Fsmax + DC1) * (d1 - H / 2))
+ (N / M) * (- As3 * (- (1 - L3^2) * 0.5εcuEs * (BC+1) * (d3 - X) / (X - (0.5H*(1-BC)))) + L3 * Fsmax + DC3) * (d3 - H / 2))
+ (N / M) * (- As2 * (- (1 - L2^2) * 0.5εcuEs * (BC+1) * (d2 - X) / (X - (0.5H*(1-BC)))) + L2 * Fsmax + DC2) * (H / 2 - d2))
+ (N / M) * (HY * (B * λ * Conc * X) * ((0.5 * H) - (0.5* λ * X)))

These terms are multiplied out and re-arranged and ordered to give a Cubic Equation in the format:-

$$aX^3 + bX^2 + cX + d = 0$$

Extract From Moody Charts For a Wall Panel

Values are for Hydrostatic, Full to Brim, Fixed at Base and Sides and Free at Top for a/b = 3/4 & a/b = 1

NOTES a = Length / 2 b = Height x = hor distance y = vert distance

If a / b = 3 / 4, L / H = 1.5 If a / b = 1, L / H = 2

x / a = 1 is at Mid Length y / b = 1 is at Top of Wall

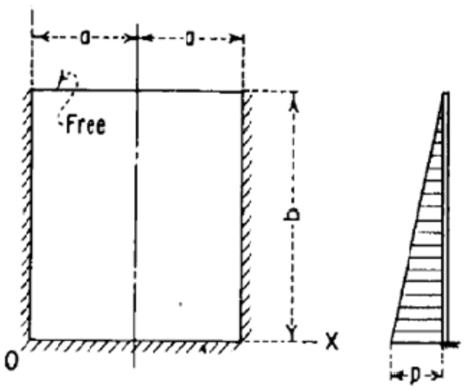
Mx = Horizontal Moment Coeff My = Vertical Moment Coeff
Rx = Horizontal Reaction Coeff Ry = Vertical Reaction Coeff

Values are for Hydrostatic, Full to Brim, Fixed at Base and Sides and Free at Top

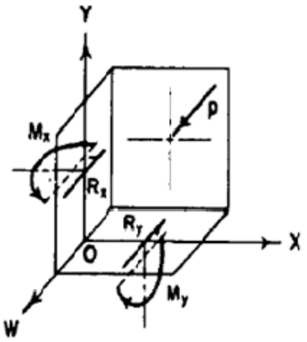
Highlighted Zones indicate key Mx & Rx (hor) & My & Ry (vert) Coefficients

MOMENTS AND REACTIONS FOR RECTANGULAR PLATES

			M_x						M_y					
	y/b	R_x \ x/a	0	0.2	0.4	0.6	0.8	1.0	0	0.2	0.4	0.6	0.8	1.0
a/b = 3/4	1.0	+.1061	+.0406	+.0196	+.0013	-.0115	-.0190	-.0214	0	0	0	0	0	0
	0.8	+.2077	+.0433	+.0177	-.0003	-.0119	-.0184	-.0205	+.0087	+.0031	-.0012	-.0042	-.0061	-.0067
	0.6	+.2408	+.0426	+.0145	-.0026	-.0124	-.0174	-.0189	+.0085	+.0010	-.0055	-.0102	-.0130	-.0139
	0.4	+.2542	.0349	+.0091	-.0039	-.0102	-.0130	-.0138	+.0070	-.0011	-.0075	-.0115	-.0137	-.0143
	0.2	+.1337	+.0163	+.0031	-.0017	-.0031	-.0033	-.0033	+.0033	+.0001	-.0000	+.0014	+.0029	+.0035
	0	-.0196	0	+.0028	+.0064	+.0093	+.0111	+.0117	0	+.0139	+.0320	+.0465	+.0554	+.0584
		R_x \ R_y	-.0196	+.1256	+.2666	+.3496	+.3923	+.4055						
a/b = 1	1.0	+.1985	+.0644	+.0253	-.0013	-.0172	-.0252	-.0276	0	0	0	0	0	0
	0.8	+.2564	.0601	+.0210	-.0028	-.0161	-.0226	-.0245	+.0120	+.0034	-.0026	-.0065	-.0088	-.0095
	0.6	+.2485	+.0515	+.0149	-.0047	-.0145	-.0189	-.0201	+.0103	+.0003	-.0075	-.0125	-.0151	-.0159
	0.4	+.2411	+.0372	+.0078	-.0049	-.0100	-.0118	-.0122	+.0074	-.0021	-.0076	-.0099	-.0106	-.0107
	0.2	+.1108	+.0154	+.0025	-.0006	-.0006	-.0000	+.0003	+.0031	+.0018	+.0060	+.0116	+.0160	+.0175
	0	-.0241	0	+.0044	+.0096	+.0137	+.0161	+.0169	0	+.0220	+.0482	+.0683	+.0804	+.0845
		R_x \ R_y	-.0241	+.1691	+.3199	+.4038	+.4457	+.4584						



Moment = (Coefficient)(pb^2)
Reaction = (Coefficient)(pb)



POSITIVE SIGN CONVENTION

FIGURE 4.—*Plate fixed along three edges, moment and reaction coefficients, Load IV, uniformly varying load.*

These tables can be difficult to use and normally the highlighted values are all that are needed or used.

The following sheet displays the key values graphically for various Loadings, Depths and Top Fixity.
Common a / b or Length / Height ratios are available together with 2 additional values for Mvert.

EC2 DESIGN TOOL

MOMENT AND SHEAR COEFFICIENTS

HAC-PRO 1 - 5 - 2 COEFF 2

Howes Atkinson Crowder LLP

Rectangular Tanks

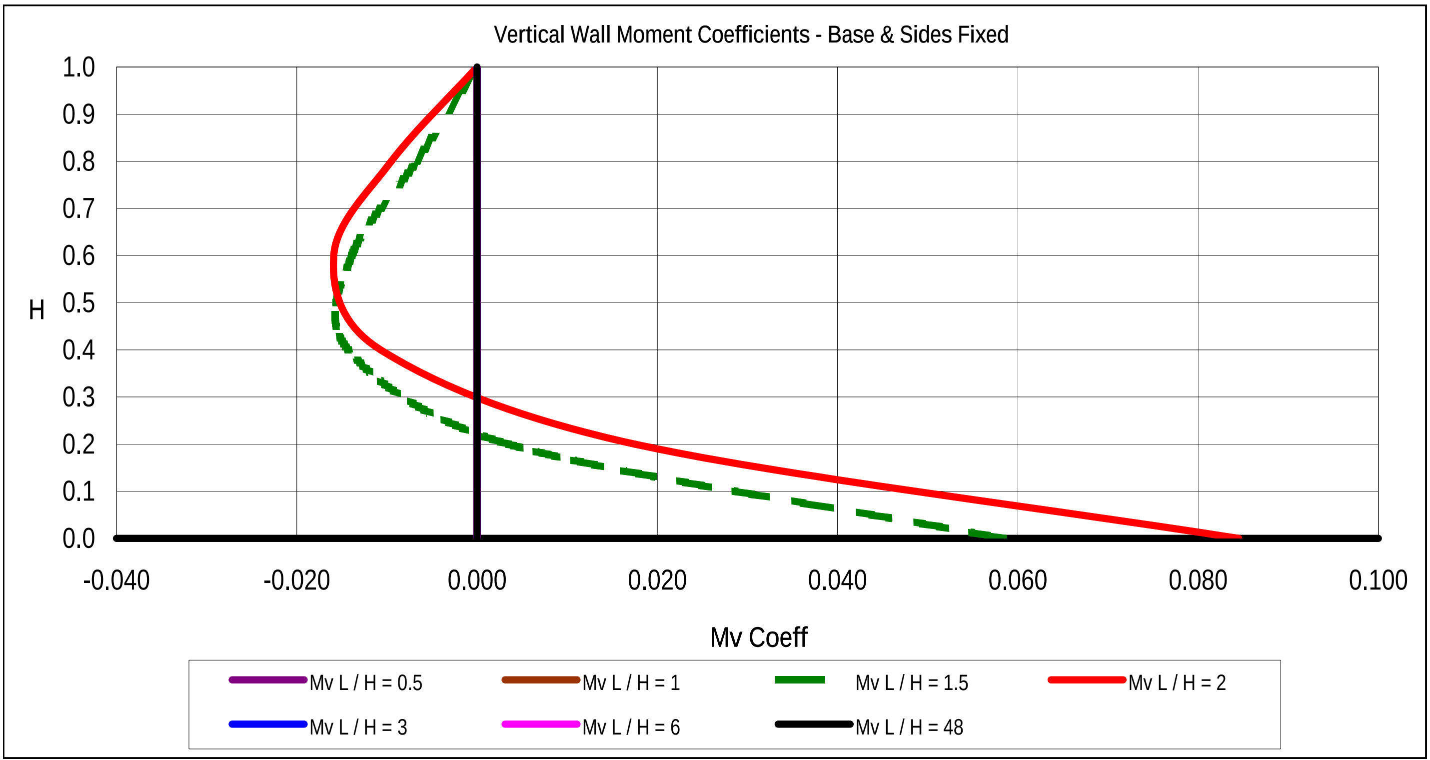
Moment and Shear Coefficient Charts
Base and Sides Fixed

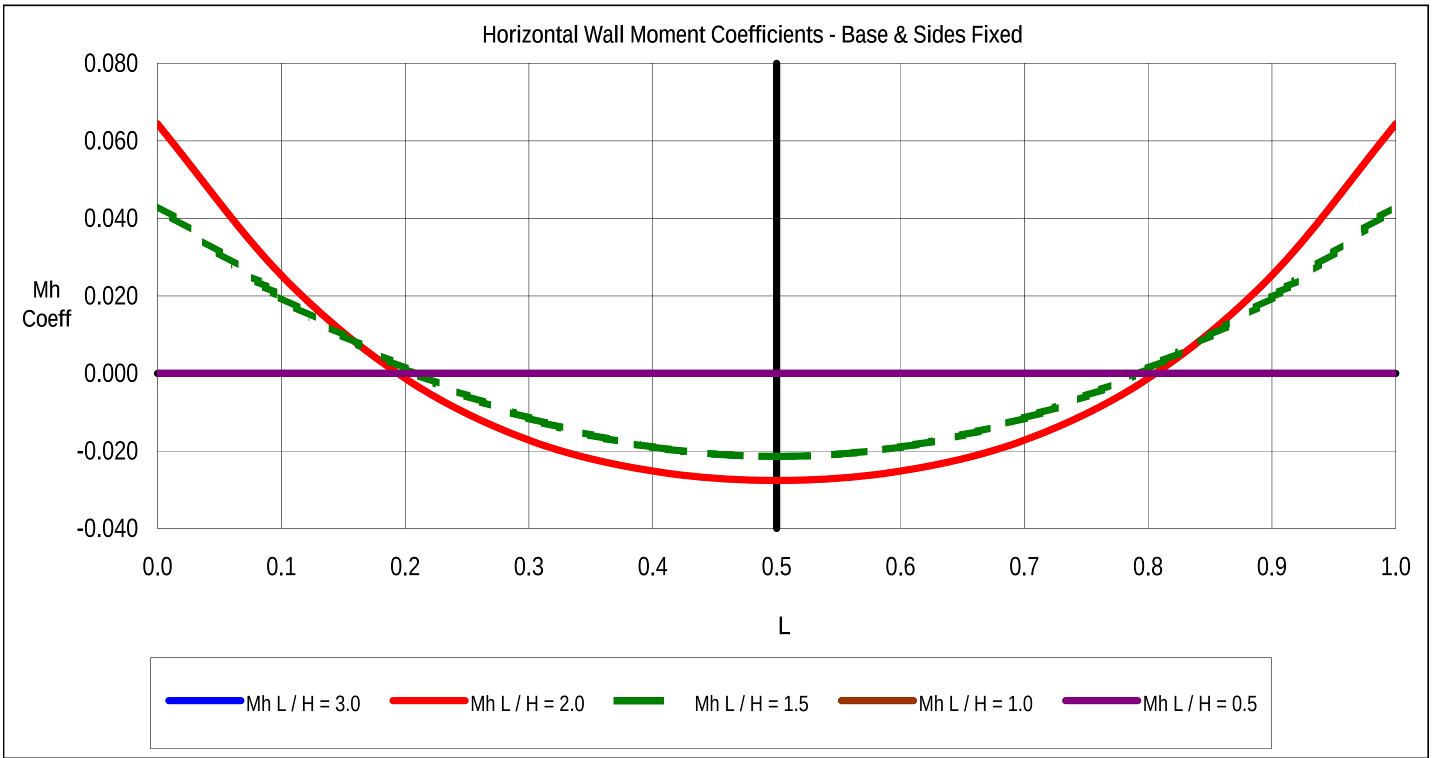
Mv = Mv Coeff x Base Pressure x H²
Mh = Mh Coeff x Base Pressure x H²
Rv = Rv Coeff x Base Pressure x H
Rh = Rh Coeff x Base Pressure x H

Load Type	Hydro
Depth / H	1.000
Top	Free

Values taken From:
Moments and Reactions For Rectangular Plates
Engineering Monograph No. 27 by W. T. Moody
United States Department of the Interior
Bureau of Reclamation, Denver, Colorado
http://www.usbr.gov/pmts/hydraulics_lab/pubs/EM/EM27.pdf

a / b	0.25	0.5	0.75	1	1.5	3	24
L / H =	0.5	1	1.5	2	3	6	48
Rv Coeff T	0	0	0	0	0		
Rv Coeff B	0.195	0.3235	0.4055	0.4564	0.505	0.4234	0.500
Rh Coeff	0.1514	0.2421	0.2542	0.2564	0.313		
Display	N	N	Y	Y	N	N	N





	EC2 DESIGN TOOL MOMENT AND SHEAR COEFFICIENTS HAC-PRO 1 - 5 - 2 COEFF 3	Howes Atkinson Crowder LLP Copyright © 2009 HAC

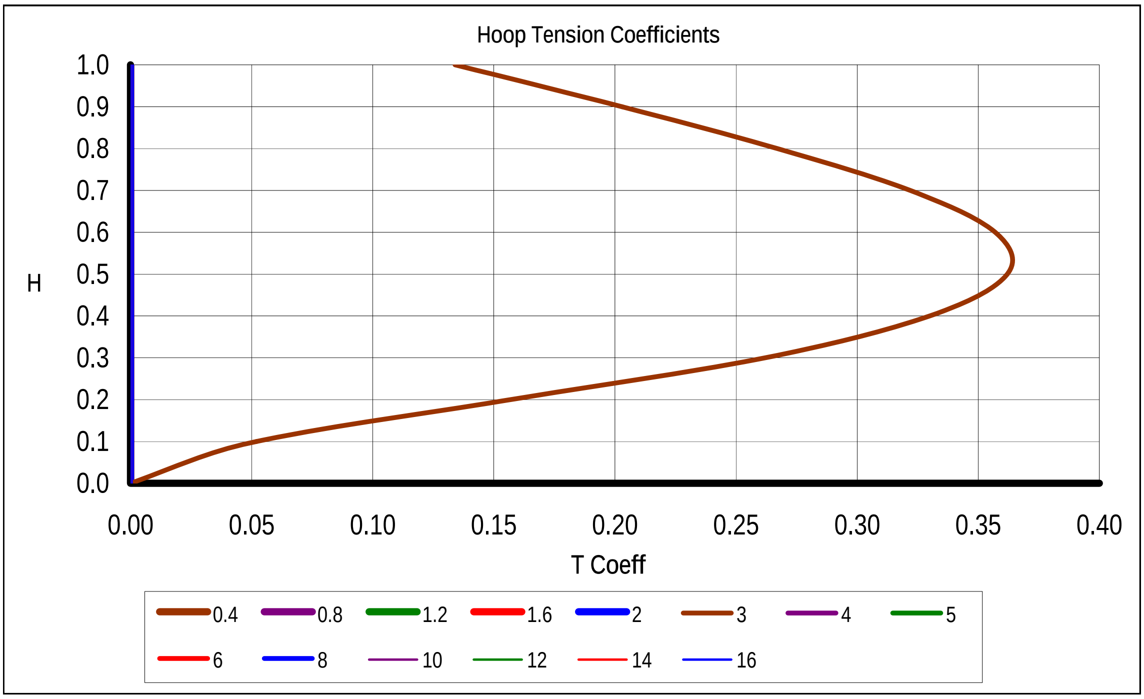
Circular Tanks

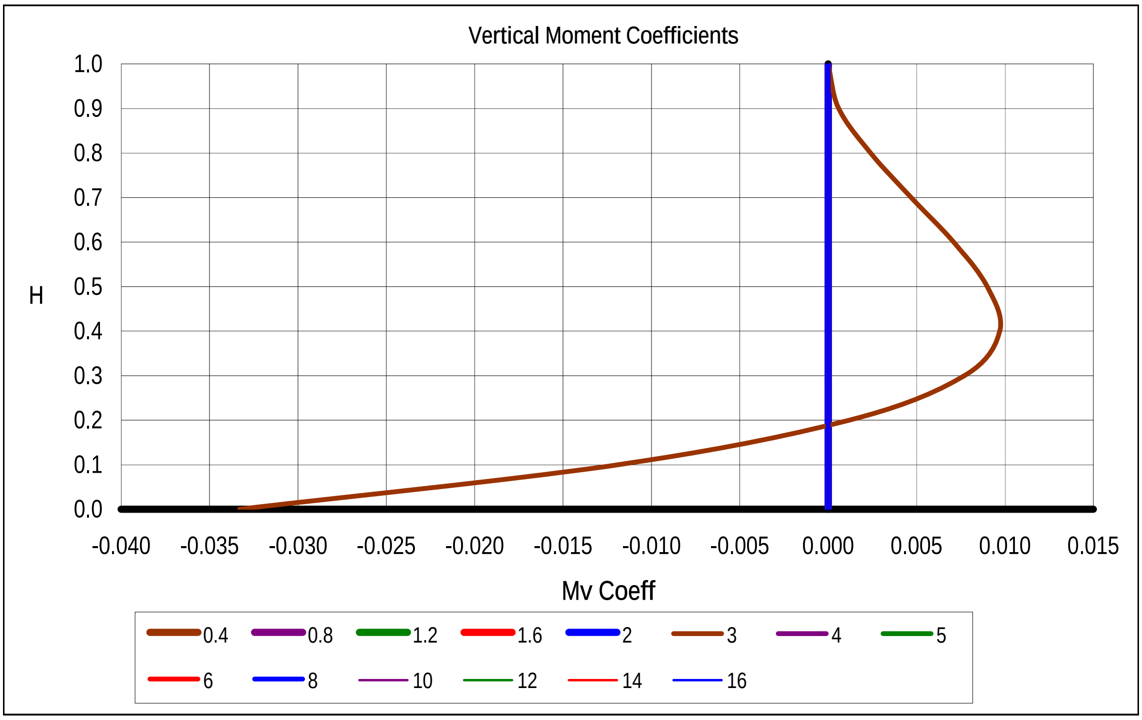
Tension, Moment and Shear Coefficient Charts Full Depth

Values taken From:
Circular Tanks Without Prestressing
by
Portland Cement Association
Skokie, Illinois, USA
http://www.cement.org/bookstore/profile.asp?pagenum=1&pos=9&catID=&id=218

(H²)/Dt	0.4	0.8	1.2	1.6	2	3	4	5	6	8	10	12	14	16
Display (A = Auto)	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Rv Coeff	0.436	0.374	0.339	0.317	0.299	0.262	0.236	0.213	0.197	0.174	0.158	0.145	0.135	0.127

H m	6.0	(H²)/Dt Exact	3.00	Max V =	0.262	x	360	=	94	kN / m
Dia m	40.0	(H²)/Dt Used	3.00							
t m	0.30	Base P kN/m²	60.0	Max T =	0.362	x	1200	=	434	kN / m
γ kN/m³	10	Base P x H	360							
K Factor	1.00	Base P x Dia /2	1200	Min M =	-0.033	x	2160	=	-72	kNm / m
Base	Fixed	Base P x H²	2160	Max M =	0.010	x	2160	=	21	kNm / m





Worked Examples

1 Rectangular Tank

Design a concrete tank 16m x 12m x 8m high on piles at 4m ctrs with a settlement of 300kN / mm

The normal water level is at 7m. Interpolate chart values between 0.667 H and 1.0 H

It is possible that the tank can be full to the brim in occasional but short duration cases.

Design as Free at top and then consider possibilities of connecting the tops of the long sides

Backfill is granular and ground level is at 2 / 3 of tank ht for charts analysis and at 5m for computer analysis.

Ground Water is taken to be at ground level

Surcharge is a Variable Action of 10 kN / m²

Design for Tightness Class 1 under Normal Conditions

For Full To Brim Conditions - Assess acceptable crack widths. (Class 0 or 1)

Aggregate is Default. Relative Humidity on non water retaining faces is 85%

Drying will be from 1 Face

Concrete grade is C 30 / 37, Class N with 340 kg / m3 O/A cement with 50% GGBS

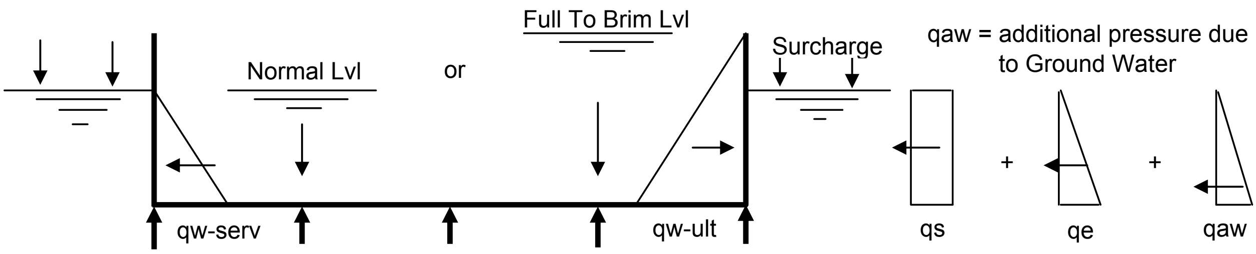
Construction will be in Summer. Seasonal Temp drop is 20 Deg for Walls and 15 Deg for Slabs

Exposure class is XC2. Design life to a major maintenance / repair = 60 yrs. Permitted Cover Dev = 10mm

Walls are designed as Edge Restrained. Base is End Restrained to some degree by piles.

Assess what Restraint Factors should be used

Consider the restraint provided by piles
a 350 x 350 Driven Piles
b 700 Dia CFA Piles



Use Coefficient Charts and Moody Tables to calculate the maximum horizontal & vertical forces

Calculate the base slab flat slab moments by hand and distribute into column and middle strips

Calculate the ultimate pile loads, multiply by appropriate β factors and consider punching shear

Assess Uplift on Piles for case where tank is empty

Compare results for Full to Brim from those generated from a computer model.

Assess Reinforcement for Shrinkage and Applied Loads based on results from computer model.

Questions

Geotechnical and External Effects

1 What is a reasonable K factor (Ke) to apply to the external earth to give horizontal forces

For a granular soil, Ke is usually taken as 0.5

2 How does ground water affect and combine with the soil forces

Add water as a separate load and give it a density of 10 x (1 - Ke) and a K value of 1.0.

3 What factors need to be considered when assessing surcharge value

Compaction forces, vehicle loads, plant slabs, raft loads.

4 What Pile settlement values should be chosen in relation to the SWL in clay and in granular ground

A settlement of 3 to 4mm per Safe Working Load is normally proved in pile tests.

5 How much relief can the external earth and water loads give to the design of a full tank

None

6 What FOS should be applied to uplift when resting on the ground

It should now be based on 1.1 x Uplift Forces - 0.9 x Down Forces.

7 What can be a problem with achieving a tension resistance from piles

It may be difficult to mobilise enough friction before the pile reaches a refusal in dense gravels.

8 What are the implications of aggressive chemicals on the concrete

Increased cover and cement content, combination mixes and lower water cement ratio

9 What publications are used if the soil is classified as AC

BS EN 206 - 1, BS8500 and BRE Special Digest 1 : 2005 Concrete in aggressive ground

10 What cover is required if the soil is classified as AC

50mm if cast against formwork and 75mm if cast against the ground

11 What other protection is often required for high AC values

Low permeability formwork may be required for AC-4 and AC-5 categories

Show Answers

	EC2 DESIGN TOOL **WORKED EXAMPLE** HAC-PRO 1 - 5 - 2 EXAM 3 / 13	**Howes Atkinson Crowder LLP**

Rectangular Tank

Analysis **Using "Moments and Reactions For Rectangular Plates" by W. T. Moody**

For Automatic Design:- L / H or W / H must be :- **0.5** or **1** or **1.5** or **2** or **3**

Length = **16** m Width = **12** m Height = **8** m =

Panel 1	L	/	H	=	16	/	8	=	**2.00**	Top	**Free**
Panel 2	L	/	H	=	12	/	8	=	**1.50**	Top	**Free**

All Actions are considered to be Permanent (Gk) except Surcharge which is a Lead Variable (Qk)
All Actions are considered Fixed and Direct. All loads are the full characteristic values.
The design must ensure that the full to brim case is a reversible service limit state
Full To Brim case applies a reduced Partial Safety Factor γ and a more relaxed Leakage Class
Permanent Loads are accurately definable so Gksup = Gkinf
Characteristic Loads are used for serviceability design

Actions - Fixed and Direct		Ult γ U1	Ult γ U2	Ult γ U3	Hydrostatic Ratios ho	H	ho/H	Max Service Wmm Class 1a Acc	1b Gen	1c Full Depth
Gk	Self Weight	1.35	1.35	1.00						
	Internal Water at Normal level		1.35		7000	600	11.7		0.2	
	Internal Water at Top Of Tank	1.20			8000	600	13.3	0.3		0.158
	External Earth & Water			1.35	5333	600	8.9		0.2	
Qk	External Surcharge			1.50	5333	600	8.9		0.2	

Internal Actions Coefficients are interpolated between 0.667 H values and 1.0 H values

Design Level Gk Depth = **0.875** H Loading **Hydro**

Pressure at base = 10 x 1.00 x 0.875 x 8 = **70.0** kN/m²

											S	U	
										Factor	**1.0**	**1.35**	
Panel 1	Mv at Base	=	0.0701	x	70.0	x	8	x	8	=	313.98	423.88	kNm / m
	Mv at mid ht	=	-0.0138	x	70.0	x	8	x	8	=	-61.98	-83.68	kNm / m
	Rv Max at Top	=	0.0000	x	70.0	x	8			=	0	0	kN / m
	Rv Max at Base	=	0.4053	x	70.0	x	8			=	226.95	306.39	kN / m
	Mh at Sides	=	0.0480	x	70.0	x	8	x	8	=	215.19	290.51	kNm / m
	Mh at Mid - Span	=	-0.0207	x	70.0	x	8	x	8	=	-92.87	-125.4	kNm / m
	Rh Max at Sides	=	0.2191	x	70.0	x	8			=	122.69	165.63	kN / m
Panel 2	Mv at Base	=	0.0500	x	70.0	x	8	x	8	=	223.79	302.12	kNm / m
	Mv at mid ht	=	-0.0130	x	70.0	x	8	x	8	=	-58.35	-78.77	kNm / m
	Rv Max at Top	=	0.0000	x	70.0	x	8			=	0	0	kN / m
	Rv Max at Base	=	0.3661	x	70.0	x	8			=	205.01	276.76	kN / m
	Mh at Sides	=	0.0342	x	70.0	x	8	x	8	=	153.12	206.71	kNm / m
	Mh at Mid - Span	=	-0.0163	x	70.0	x	8	x	8	=	-73	-98.55	kNm / m
	Rh Max at Sides	=	0.2199	x	70.0	x	8			=	123.16	166.27	kN / m

Full To Brim Loads Gk Depth = **1.000** H Loading **Hydro**

Pressure at base = 10 x 1.00 x 1.000 x 8 = **80.0** kN/m²

											S	U	
										Factor	**1.0**	**1.20**	
Panel 1	Mv at Base	=	0.0845	x	80.0	x	8	x	8	=	432.64	519.17	kNm / m
	Mv at mid ht	=	-0.0159	x	80.0	x	8	x	8	=	-81.41	-97.69	kNm / m
	Rv Max at Top	=	0.0000	x	80.0	x	8			=	0	0	kN / m
	Rv Max at Base	=	0.4564	x	80.0	x	8			=	292.1	350.52	kN / m
	Mh at Sides	=	0.0644	x	80.0	x	8	x	8	=	329.73	395.67	kNm / m
	Mh at Mid - Span	=	-0.0276	x	80.0	x	8	x	8	=	-141.3	-169.6	kNm / m
	Rh Max at Sides	=	0.2564	x	80.0	x	8			=	164.1	196.92	kN / m
Panel 2	Mv at Base	=	0.0584	x	80.0	x	8	x	8	=	299.01	358.81	kNm / m
	Mv at mid ht	=	-0.0143	x	80.0	x	8	x	8	=	-73.22	-87.86	kNm / m
	Rv Max at Top	=	0.0000	x	80.0	x	8			=	0	0	kN / m
	Rv Max at Base	=	0.4055	x	80.0	x	8			=	259.52	311.42	kN / m
	Mh at Sides	=	0.0433	x	80.0	x	8	x	8	=	221.7	266.04	kNm / m
	Mh at Mid - Span	=	-0.0214	x	80.0	x	8	x	8	=	-109.6	-131.5	kNm / m
	Rh Max at Sides	=	0.2542	x	80.0	x	8			=	162.69	195.23	kN / m

EC2 DESIGN TOOL

WORKED EXAMPLE

HAC-PRO 1 - 5 - 2 EXAM 4 / 13

Howes Atkinson Crowder LLP

External Actions

Dry Earth Gk Depth = 0.667 H Loading = Hydro K = 0.5

Pressure at base Hydro Dry Soil 18 x 0.50 x 0.667 x 8 = 48.0 kN/m²

											S	U	
									Factor		1.0	1.35	
Panel 1	Mv at Base	=	0.0461	x	48.0	x	8	x	8	=	141.69	191.28	kNm / m
	Mv at mid ht	=	-0.0104	x	48.0	x	8	x	8	=	-31.96	-43.15	kNm / m
	Rv Max at Top	=	0.0000	x	48.0	x	8			=	0	0	kN / m
	Rv Max at Base	=	0.3202	x	48.0	x	8			=	123.02	166.07	kN / m
	Mh at Sides	=	0.0208	x	48.0	x	8	x	8	=	63.93	86.305	kNm / m
	Mh at Mid - Span	=	-0.0093	x	48.0	x	8	x	8	=	-28.58	-38.59	kNm / m
	Rh Max at Sides	=	0.1570	x	48.0	x	8			=	60.318	81.429	kN / m
Panel 2	Mv at Base	=	0.0359	x	48.0	x	8	x	8	=	110.34	148.96	kNm / m
	Mv at mid ht	=	-0.0109	x	48.0	x	8	x	8	=	-33.5	-45.23	kNm / m
	Rv Max at Top	=	0.0000	x	48.0	x	8			=	0	0	kN / m
	Rv Max at Base	=	0.3005	x	48.0	x	8			=	115.45	155.86	kN / m
	Mh at Sides	=	0.0190	x	48.0	x	8	x	8	=	58.397	78.836	kNm / m
	Mh at Mid - Span	=	-0.0078	x	48.0	x	8	x	8	=	-23.97	-32.36	kNm / m
	Rh Max at Sides	=	0.1629	x	48.0	x	8			=	62.585	84.49	kN / m

Extra Due To Water Gk Depth = 0.667 H Loading = Hydro Ke = 0.5

Note Equivalent Density For Additional Water = 10 - (10 x Ke) = 10 - 5 = 5 kN/m³

Pressure at base Hydro Extra Due to Water 5 x 1.00 x 0.667 x 8 = 26.7 kN/m²

											S	U	
									Factor		1.0	1.35	
Panel 1	Mv at Base	=	0.0461	x	26.7	x	8	x	8	=	78.717	106.27	kNm / m
	Mv at mid ht	=	-0.0104	x	26.7	x	8	x	8	=	-17.76	-23.97	kNm / m
	Rv Max at Top	=	0.0000	x	26.7	x	8			=	0	0	kN / m
	Rv Max at Base	=	0.3202	x	26.7	x	8			=	68.343	92.264	kN / m
	Mh at Sides	=	0.0208	x	26.7	x	8	x	8	=	35.516	47.947	kNm / m
	Mh at Mid - Span	=	-0.0093	x	26.7	x	8	x	8	=	-15.88	-21.44	kNm / m
	Rh Max at Sides	=	0.1570	x	26.7	x	8			=	33.51	45.239	kN / m
Panel 2	Mv at Base	=	0.0359	x	26.7	x	8	x	8	=	61.3	82.755	kNm / m
	Mv at mid ht	=	-0.0109	x	26.7	x	8	x	8	=	-18.61	-25.13	kNm / m
	Rv Max at Top	=	0.0000	x	26.7	x	8			=	0	0	kN / m
	Rv Max at Base	=	0.3005	x	26.7	x	8			=	64.139	86.587	kN / m
	Mh at Sides	=	0.0190	x	26.7	x	8	x	8	=	32.443	43.798	kNm / m
	Mh at Mid - Span	=	-0.0078	x	26.7	x	8	x	8	=	-13.32	-17.98	kNm / m
	Rh Max at Sides	=	0.1629	x	26.7	x	8			=	34.769	46.939	kN / m

Surcharge Qk Depth = 0.667 H Loading = UDL Ke = 0.5

Pressure at base UDL Surcharge 10 x 0.50 = 5.0 kN/m²

											S	U	
									Factor		1.0	1.50	
Panel 1	Mv at Base	=	0.1184	x	5.0	x	8	x	8	=	37.888	56.832	kNm / m
	Mv at mid ht	=	-0.0296	x	5.0	x	8	x	8	=	-9.472	-14.21	kNm / m
	Rv Max at Top	=	0.0000	x	5.0	x	8			=	0	0	kN / m
	Rv Max at Base	=	0.6149	x	5.0	x	8			=	24.596	36.894	kN / m
	Mh at Sides	=	0.0753	x	5.0	x	8	x	8	=	24.096	36.144	kNm / m
	Mh at Mid - Span	=	-0.0271	x	5.0	x	8	x	8	=	-8.672	-13.01	kNm / m
	Rh Max at Sides	=	0.4093	x	5.0	x	8			=	16.372	24.558	kN / m
Panel 2	Mv at Base	=	0.0835	x	5.0	x	8	x	8	=	26.72	40.08	kNm / m
	Mv at mid ht	=	-0.0255	x	5.0	x	8	x	8	=	-8.16	-12.24	kNm / m
	Rv Max at Top	=	0.0000	x	5.0	x	8			=	0	0	kN / m
	Rv Max at Base	=	0.5438	x	5.0	x	8			=	21.752	32.628	kN / m
	Mh at Sides	=	0.0617	x	5.0	x	8	x	8	=	19.744	29.616	kNm / m
	Mh at Mid - Span	=	-0.0271	x	5.0	x	8	x	8	=	-8.672	-13.01	kNm / m
	Rh Max at Sides	=	0.4133	x	5.0	x	8			=	16.532	24.798	kN / m

External Actions Cont

Combination Of All Three External Actions

			Service						Ultimate	Fundamental				
		ψ	1.0	1.0	1.0			γ	1.35	1.35	1.50			
			Earth	Water	Surch				Earth	Water	Surch			
Panel 1	Mv at Base	=	141.7	78.7	37.9	=	258.3		191.3	106.3	56.8	=	354.4	kNm / m
	Mv at mid ht	=	-32.0	-17.8	-9.5	=	-59.2		-43.2	-24.0	-14.2	=	-81.3	kNm / m
	Rv Max at Top	=	0.0	0.0	0.0	=	0.0		0.0	0.0	0.0	=	0.0	kN / m
	Rv Max at Base	=	123.0	68.3	24.6	=	216.0		166.1	92.3	36.9	=	295.2	kN / m
	Mh at Sides	=	63.9	35.5	24.1	=	123.5		86.3	47.9	36.1	=	170.4	kNm / m
	Mh at Mid - Span	=	-28.6	-15.9	-8.7	=	-53.1		-38.6	-21.4	-13.0	=	-73.0	kNm / m
	Rh Max at Sides	=	60.3	33.5	16.4	=	110.2		81.4	45.2	24.6	=	151.2	kN / m
Panel 2	Mv at Base	=	110.3	61.3	26.7	=	198.4		149.0	82.8	40.1	=	271.8	kNm / m
	Mv at mid ht	=	-33.5	-18.6	-8.2	=	-60.3		-45.2	-25.1	-12.2	=	-82.6	kNm / m
	Rv Max at Top	=	0.0	0.0	0.0	=	0.0		0.0	0.0	0.0	=	0.0	kN / m
	Rv Max at Base	=	115.4	64.1	21.8	=	201.3		155.9	86.6	32.6	=	275.1	kN / m
	Mh at Sides	=	58.4	32.4	19.7	=	110.6		78.8	43.8	29.6	=	152.3	kNm / m
	Mh at Mid - Span	=	-24.0	-13.3	-8.7	=	-46.0		-32.4	-18.0	-13.0	=	-63.4	kNm / m
	Rh Max at Sides	=	62.6	34.8	16.5	=	113.9		84.5	46.9	24.8	=	156.2	kN / m

Slab Design Gk **Unfactored Values**

Self Wt	24	x	0.6	=	14.4	kN / m²		
NWL Loading	10	x	7	=	70	kN / m²		
FTB Loading	10	x	8	=	80	kN / m²		
Pile Spacing	4.00	m					SW	Water
NWL Loading	14.4	+	70	=	84.4	kN / m²	0.171	0.829
FTB Loading	14.4	+	80	=	94.4	kN / m²	0.153	0.847

Design Water Level Analysis

Load per Width of Panel	84.4	x	4			=	337.6	kN / m							L / F
Load per Span	337.6	x	4			=	1350	kN		Ult =	1823	kN			1.35
Support Moment	1350	x	4	/	12	=	450.1			kNm / Panel			112.5	/ m	
Column Strip	450.1	x (	0.6 to 0.8	) Use	0.7	=	315	kNm							
Middle Strip	450.1	x (	0.2 to 0.4	) Use	0.3	=	135	kNm							
Span Moment	1350	x	4	/	24	=	225			kNm / Panel					
Column Strip	225	x (	0.6 to 0.8	) Use	0.55	=	124	kNm							
Middle Strip	225	x (	0.2 to 0.4	) Use	0.45	=	101	kNm							

Full To Brim Analysis

Load per Width of Panel	94.4	x	4			=	377.6	kN / m		kNm / Panel					L / F
Load per Span	377.6	x	4			=	1510	kN		Ult =	1847	kN			1.223
Support Moment	1510	x	4	/	12	=	503.5			kNm / Panel			125.9	/ m	
Column Strip	503.5	x (	0.6 to 0.8	) Use	0.7	=	352	kNm	x	1.35	=	476	kNm		
Middle Strip	503.5	x (	0.2 to 0.4	) Use	0.3	=	151	kNm	x	1.35	=	204	kNm		
Span Moment	1510	x	4	/	24	=	252			kNm / Panel					
Column Strip	252	x (	0.5 to 0.7	) Use	0.55	=	138	kNm	x	1.35	=	187	kNm		
Middle Strip	252	x (	0.3 to 0.5	) Use	0.45	=	113	kNm	x	1.35	=	153	kNm		

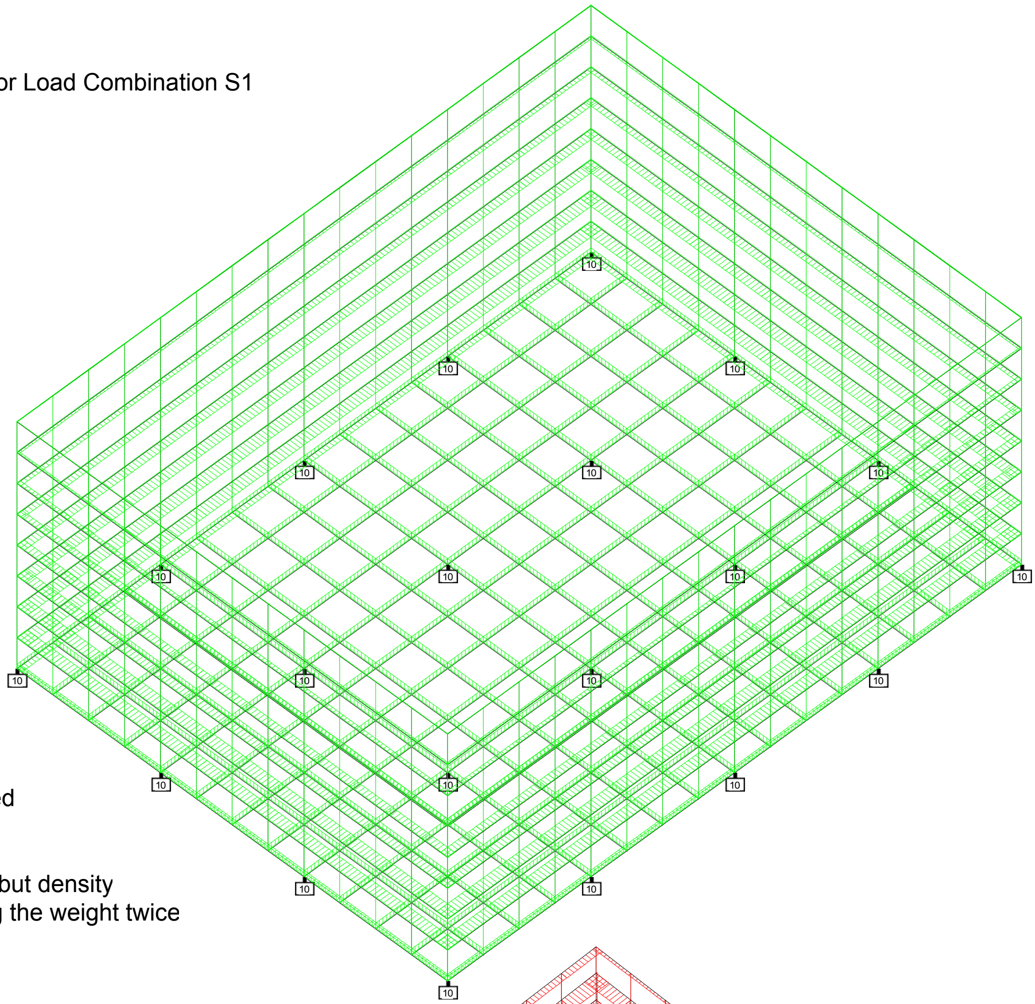
Note that the moments from the independent base slab analysis will rarely match the panel base fixed moments
In order to give realistic values, the reinforcement will be calculated from the results of a Grillage / Finite Element Analysis

Grillage Analysis

Input and Output Diagrams For Load Combination S1

SW + Full To Brim

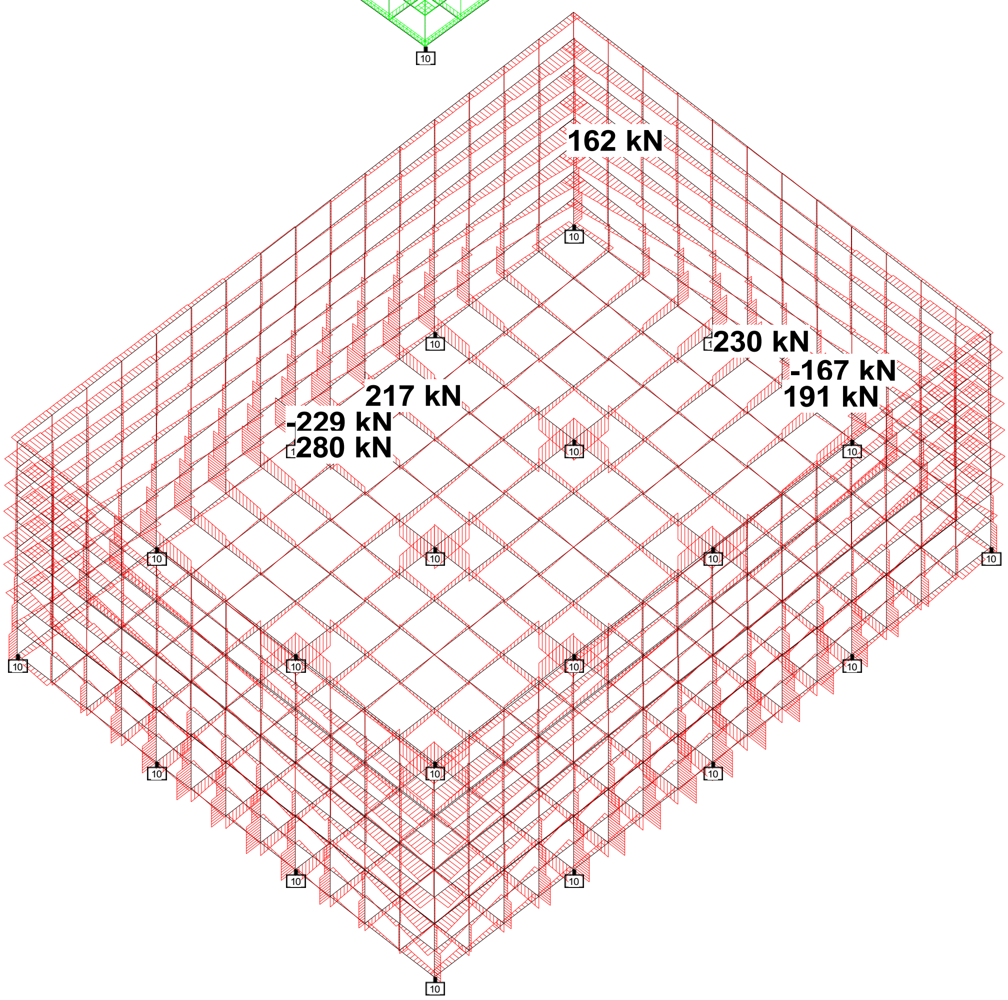
Elements are at 1m ctrs



Loading / Element

50% of Vertical Load is applied
onto slab in each direction

SW is calculated by program but density
is 50% Normal to avoid taking the weight twice



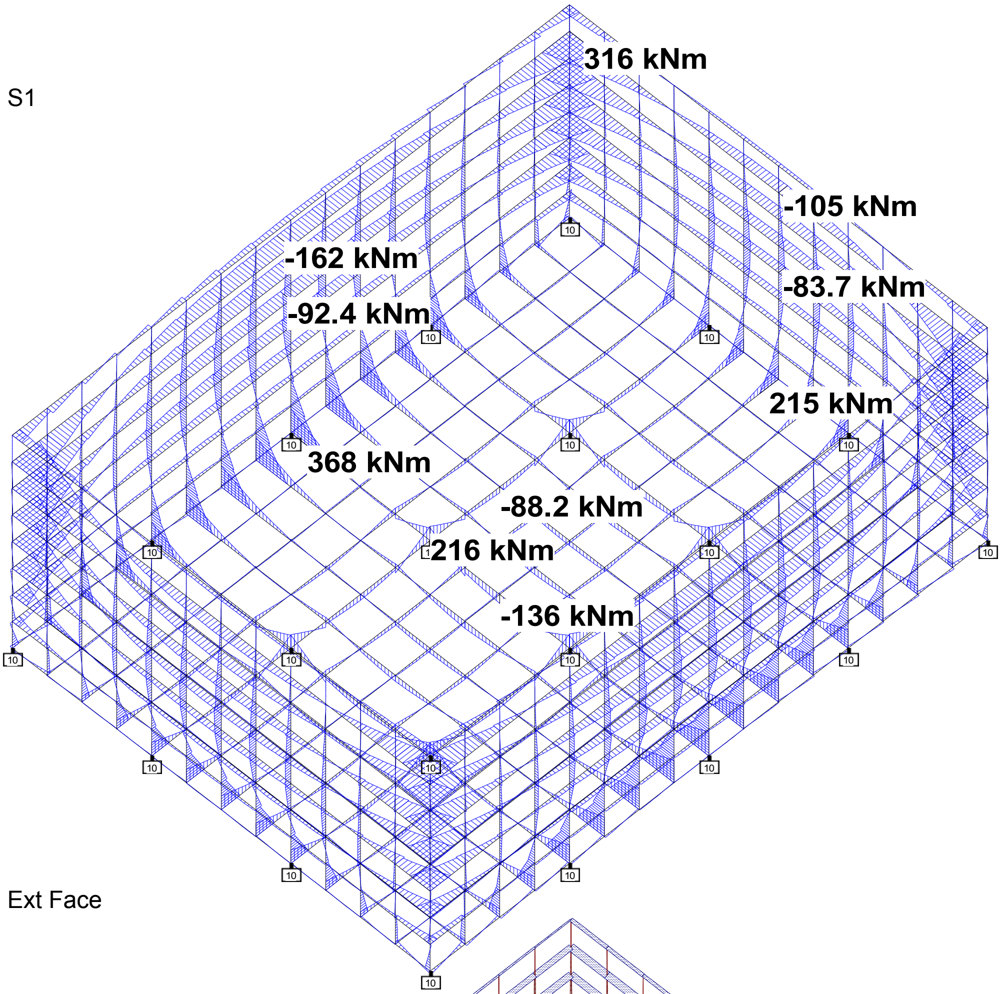
Shear / Element
kN

Grillage Analysis

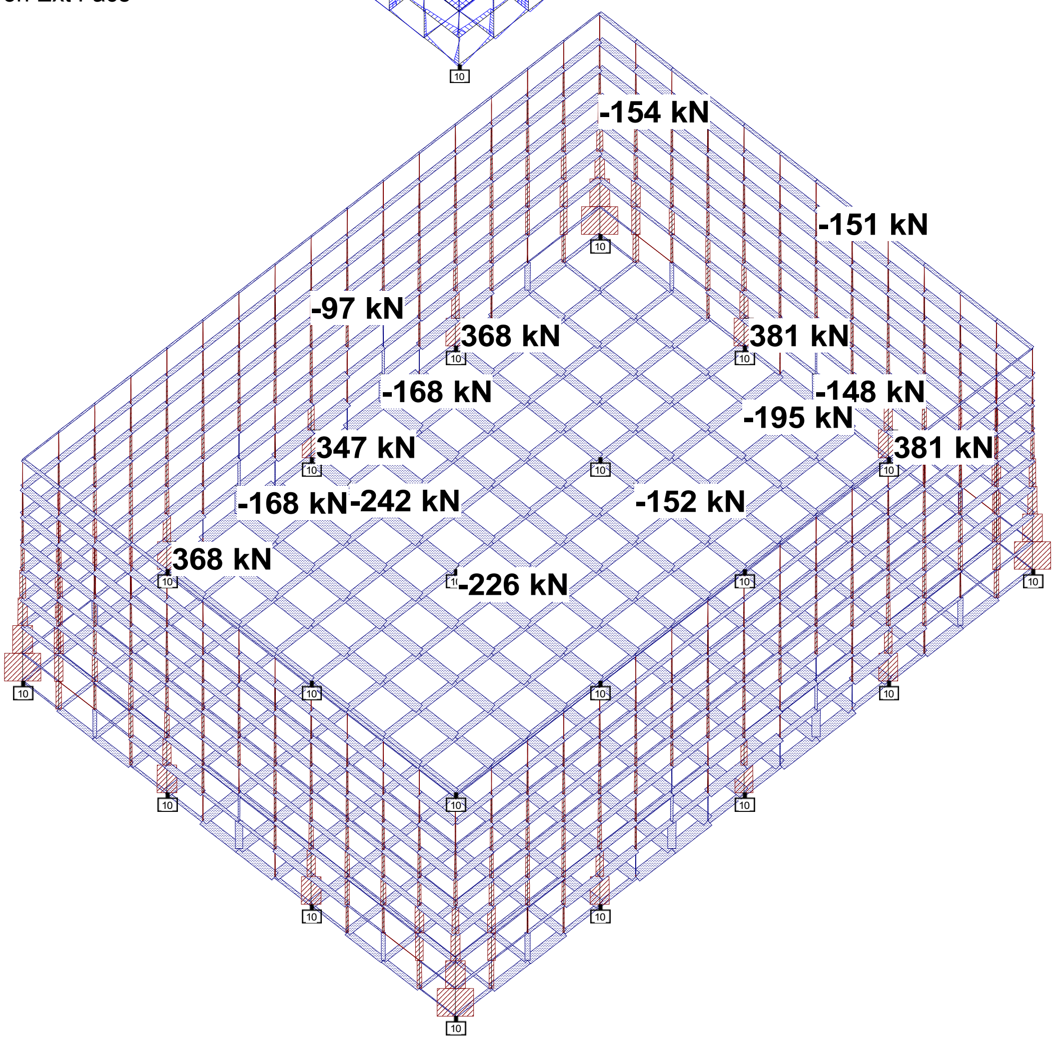
Output For Load Combination S1

SW + Full To Brim

Elements are at 1m ctrs



Moments / Element
kNm
Negative Denotes Tension on Ext Face



Axial / Element
kN
Negative Denotes Tension

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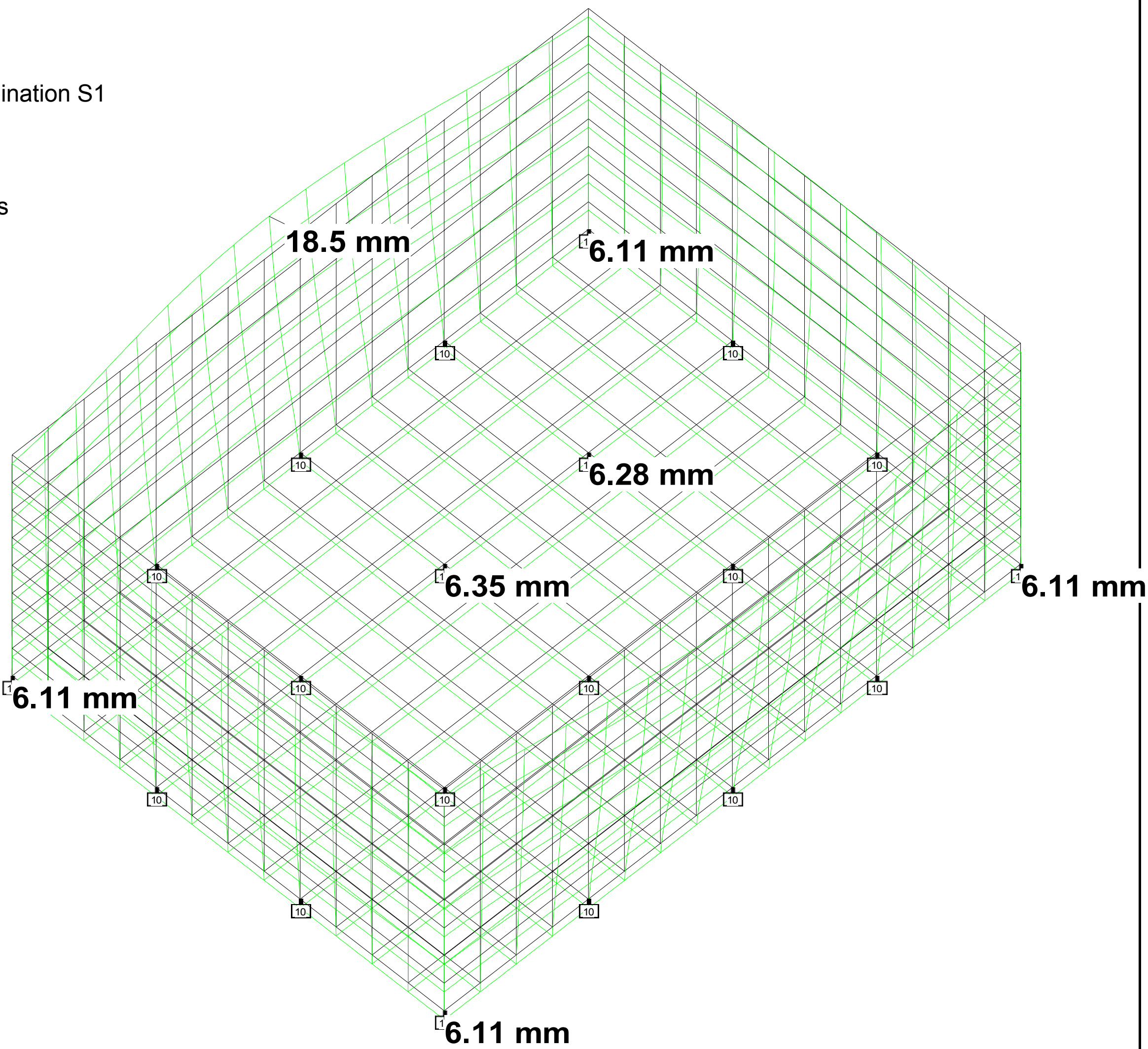
Grillage Analysis

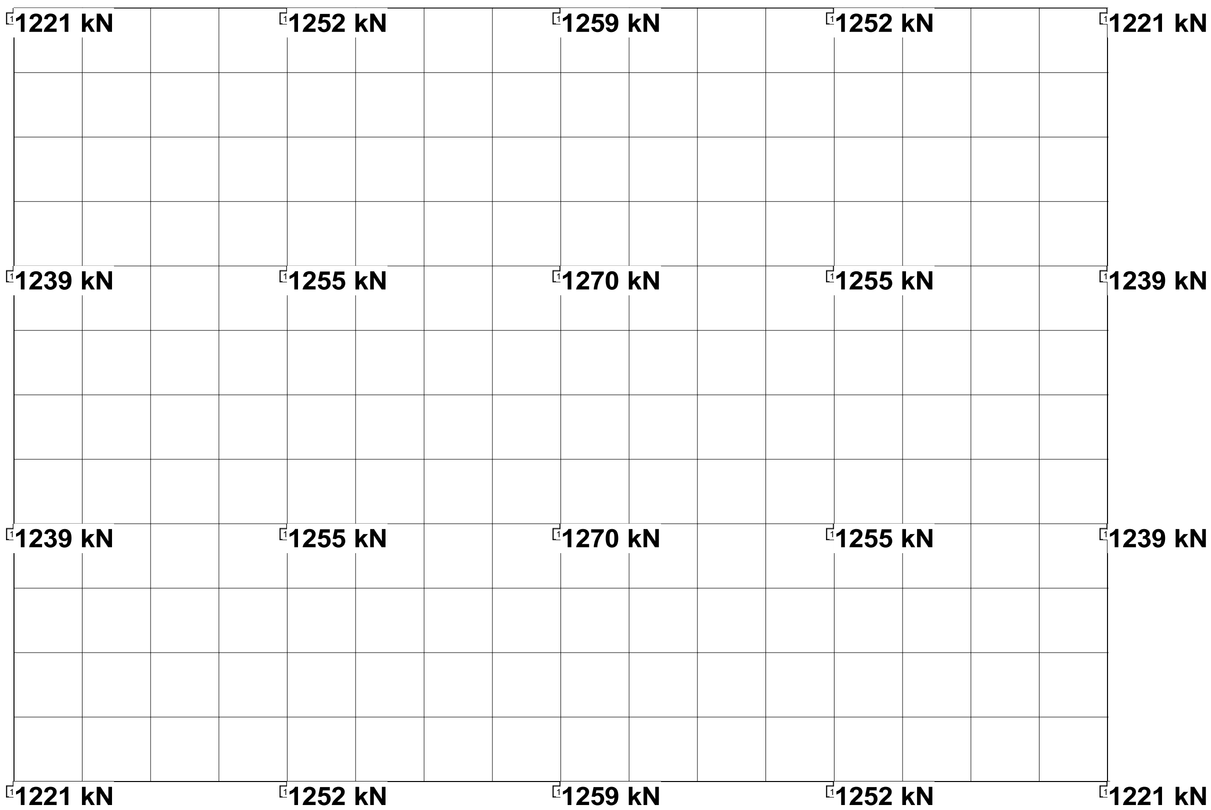
Output For Load Combination S1

SW + Full To Brim

Elements are at 1m ctrs

Displacements
Note: Value for
Panel 1 under
NWL = 12mm





Pile Loads

Combinations

	ψ =	1.0		1.0	1.0	1.0
Service	**S1**	SW				Water at FTB
	S2	SW		Water at NWL		
	S3	SW		Earth & Water at GL	Surcharge	
	γ =	1.35	1.35	1.0 / 1.35	1.5	1.2
Ultimate	**U1**	SW				Water at FTB
	U2		SW	Water at NWL		
	U3			SW / Earth & Water at GL	Surcharge	

Forces

v = Shr Stress N/mm² n = Axial Stress N/mm² V = Shr kN N = Axial kN M = Mom kNm
Some FEA programs generate output as stress Values per element width or per m for FEA
Values are arranged so they can be Copied and Pasted Special as Values into the MAIN sheet

Walls

Panel 1 H = 600 Panel 2 H = 600

			P1 S1	S2	S3	U1	U2	U3	P2 S1	S2	S3	U1	U2	U3
Vert	Base	v												
		n												
		V	229	220	183	275	297	247	230	170	167	276	230	225
		N	-168	-137	150	-202	-185	203	-148	-124	140	-178	-167	189
		M	368	296	-225	442	400	-304	215	209	-173	258	282	-234
Vert	Span	v												
		n												
		V	30	20	20	36	27	27	20	10	20	24	14	27
		N	30	30	70	36	41	95	20	20	60	24	27	81
		M	-92	-67	62	-110	-90	84	-84	-62	58	-101	-84	78
Hor	Corn	v												
		n												
		V	162	125	115	194	169	155	162	125	115	194	169	155
		N	-154	-123	110	-185	-166	149	-154	-110	110	-185	-149	149
		M	316	205	-131	379	277	-177	316	205	-131	379	277	-177
Hor	Span	v												
		n												
		V	20	10	5	24	14	7	20	20	5	24	27	7
		N	-97	-90	40	-116	-122	54	-158	-92	56	-190	-124	76
		M	-162	-86	57	-194	-116	77	-151	-69	35	-181	-93	47

Base Slab

X Dir H = 600 Y Dir

		X S1	S2	S3	U1	U2	U3	Y S1	S2	S3	U1	U2	U3
At Wall	v												
	n												
	V	280	212	130	336	286	176	230	205	120	276	277	162
	N	-242	-215	184	-290	-290	248	-195	-172	163	-234	-232	220
	M	368	300	-225	442	405	-304	215	209	-173	258	282	-234
Column Strip at Pile T	v												
	n												
	Pi	1461	1342	-404	1753	1812	-545	1461	1300	-404	1753	1754	-545
	N	-226	-200	172	-271	-270	232	-145	-121	127	-174	-163	171
	M	216	180	-50	259	243	-68	216	180	-40	259	243	-54
Middle Strip at Supp T	v												
	n												
	V	80	70	30	96	95	41	90	80	50	108	108	68
	N	-226	-200	172	-271	-270	232	-145	-121	127	-174	-163	171
	M	50	45	-50	60	61	-68	88	66	-50	106	89	-68
Span Strips B	v												
	n												
	V	50	45	30	60	61	41	50	50	50	60	68	68
	N	-226	-200	172	-271	-270	232	-145	-121	127	-174	-163	171
	M	-136	-120	92	-163	-162	124	-88	-80	40	-106	-108	54
Punching	VED	1270	1167	-351	1565	1575	-474	1270	1130	-351	1565	1526	-474

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Reinforcement

All Reinforcement and Section Compliance is calculated and displayed via the MAIN sheet

Typical Calculations Input

Shear, Axial and Moments — Above values are copied and pasted into the MAIN sheet

Shrinkage — This sheet allows the designer to add additional explanation and derive actual restraint values.. The values are copied and pasted (values only) into the MAIN sheet

Walls

Shrinkage Data — Formwork / Faces & Rel Humidity / T1 value or Auto / Seasonal Temp drop

Edge Restraint Values

Fmwk	Ply
Rh	1 & 95
T1	Auto
T2	20

1 Horizontal Edge Restraint, Ref Restraint Diagram adjusted to suit C660 — Wall H Edge Restr Base

Restraint type	Restr	Edge
3 Day curing restraint	R1	0.60
28 Day / T2 curing restraint	R2	0.60
Long Term drying restraint	R3	0.30

2 Horizontal Edge Restraint, Ref Restraint Diagram adjusted to suit C660 — Wall H Edge Restr Mid Ht

Restraint type	Restr	Edge
3 Day curing restraint	R1	0.35
28 Day / T2 curing restraint	R2	0.35
Long Term drying restraint	R3	0.15

3 Vertical Edge Restraint, Ref Restraint Diagram adjusted to suit C660 — Wall V Edge Restr Base

Restraint type	Restr	Edge
3 Day curing restraint	R1	0.35
28 Day / T2 curing restraint	R2	0.35
Long Term drying restraint	R3	0.00

Slab

Shrinkage Data — Formwork / Faces & Rel Humidity / T1 value or Auto / Seasonal Temp drop

End Restraint Values

Fmwk	Grnd
Rh	1 & 95
T1	Auto
T2	15

4 End restraint, Assuming near full restraint As an Example — Slab End Restr High

Restraint type	Restr	End
3 Day curing restraint	R1	0.77
28 Day / T2 curing restraint	R2	0.77
Long Term drying restraint	R3	0.77

5 End Restraint, According To Pile Siffness, More Realistic, See Below — Slab End Restr Piles

Restraint type	Restr	End
3 Day curing restraint	R1	0.20
28 Day / T2 curing restraint	R2	0.20
Long Term drying restraint	R3	0.20

Actual End Restraint Offered By Piles

Free Strain due to T2 = 15 deg & alpha = 12 = **180** με

Maximum Restrained Strain = 0.65 x 180 = **117** με

Free Shrinkage over 8 m due to T2 = 15 deg & alpha = 12 = **1.44** mm
Free Shrinkage over 4 m due to T2 = 15 deg & alpha = 12 = **0.72** mm

Pile Resistance = 150 kN per mm Slab = 12 m x 600 mm

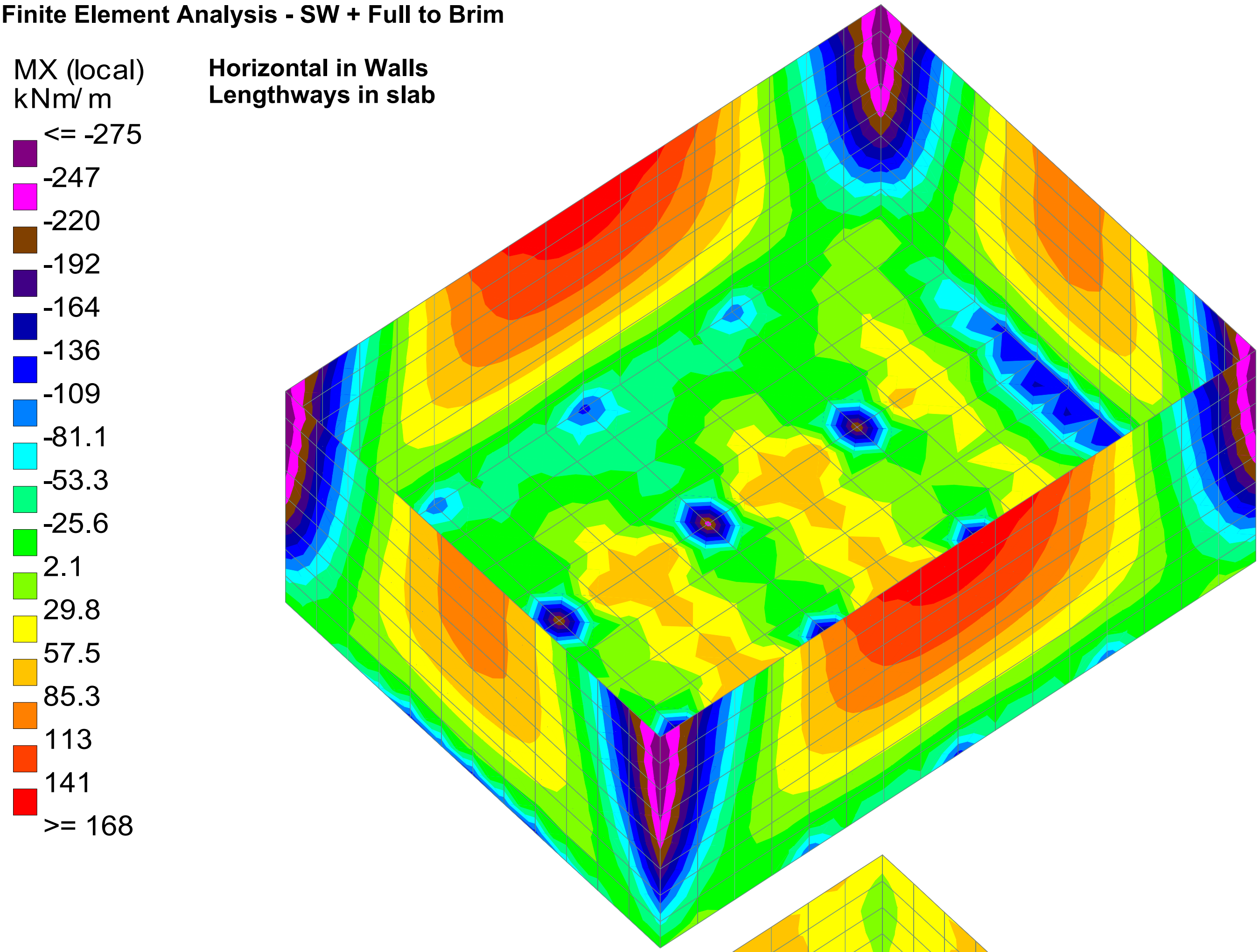
Force at Centre = 4 x 150 x 1.44 = **864** kN
4 x 150 x 0.72 = **432** kN = **1296** kN

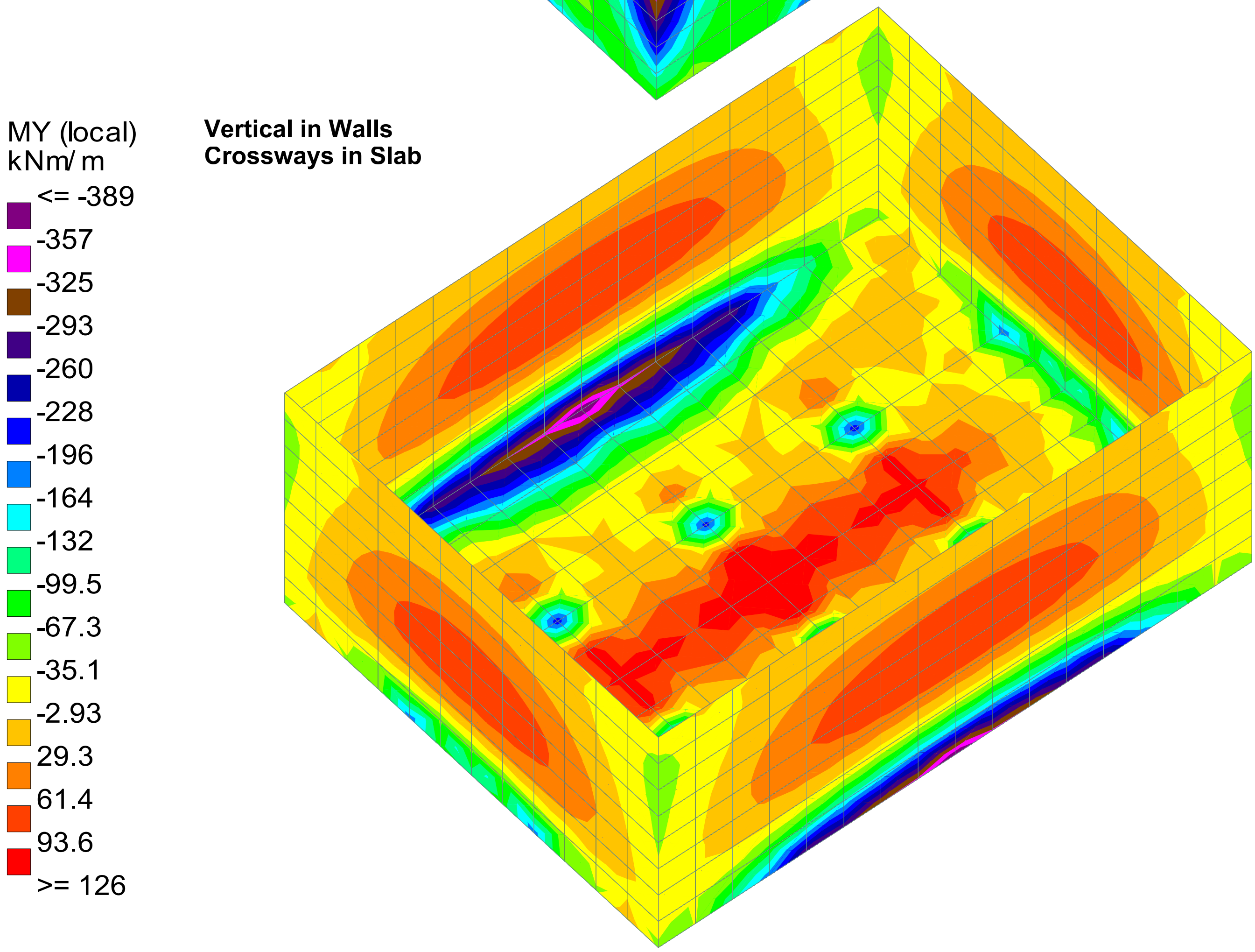
Average Restrained Stress 0.65 x 1296 / (12 x 600) = 0.18 N / mm²

Average Restrained Strain = Stress / (Es / MR28) = 0.18 / (200 / 6.09) = **5** με

Therefore Maximum End Restraint Factor R = **5** / 117 = **0.047** Adopt **0.2**

Finite Element Analysis - SW + Full to Brim





Worked Examples Cont.

2 Circular Tank

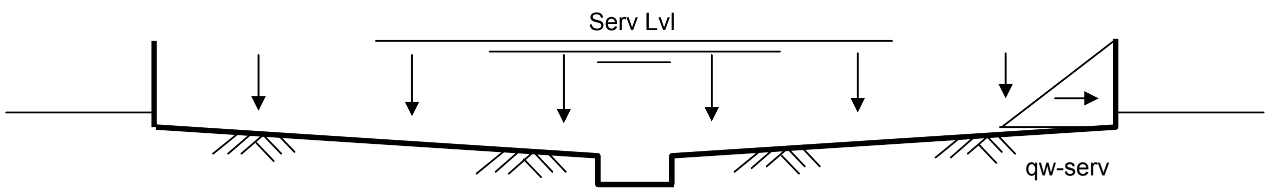
Design a concrete tank 40m dia x 6m high cast on ground with Subgrade Reaction 10kN/m2 / mm

Base Slab slopes 2m towards a 2m deep central sump

Service design water level is full to brim

Wall is either fixed or hinged to the base slab

Other criteria are as for rectangular tank



Use Coefficients from provided charts

Consider how much base fixity can be generated

Consider the effects of high tension on reinforcement stresses and crack widths

Consider thermal implications

Consider how to reinforce the main base and the hopper bottom

For a 300 thick wall

For a Fixed Base

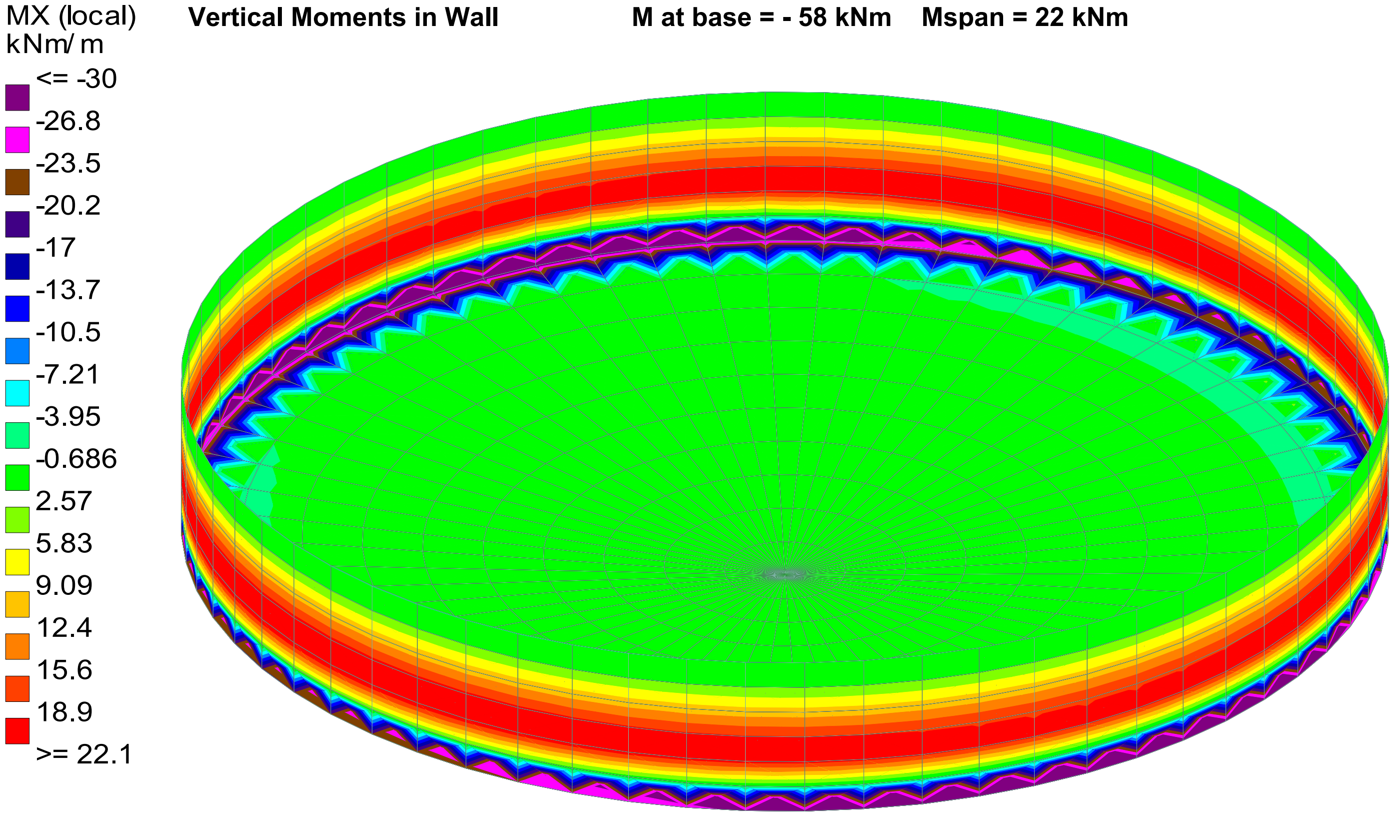
Hoop Tension per M width	=	**434**	kN
Vertical Moment at Base	=	**-72**	kNm
Max Reverse Vertical Moment	=	**21**	kNm

For a Hinged Base

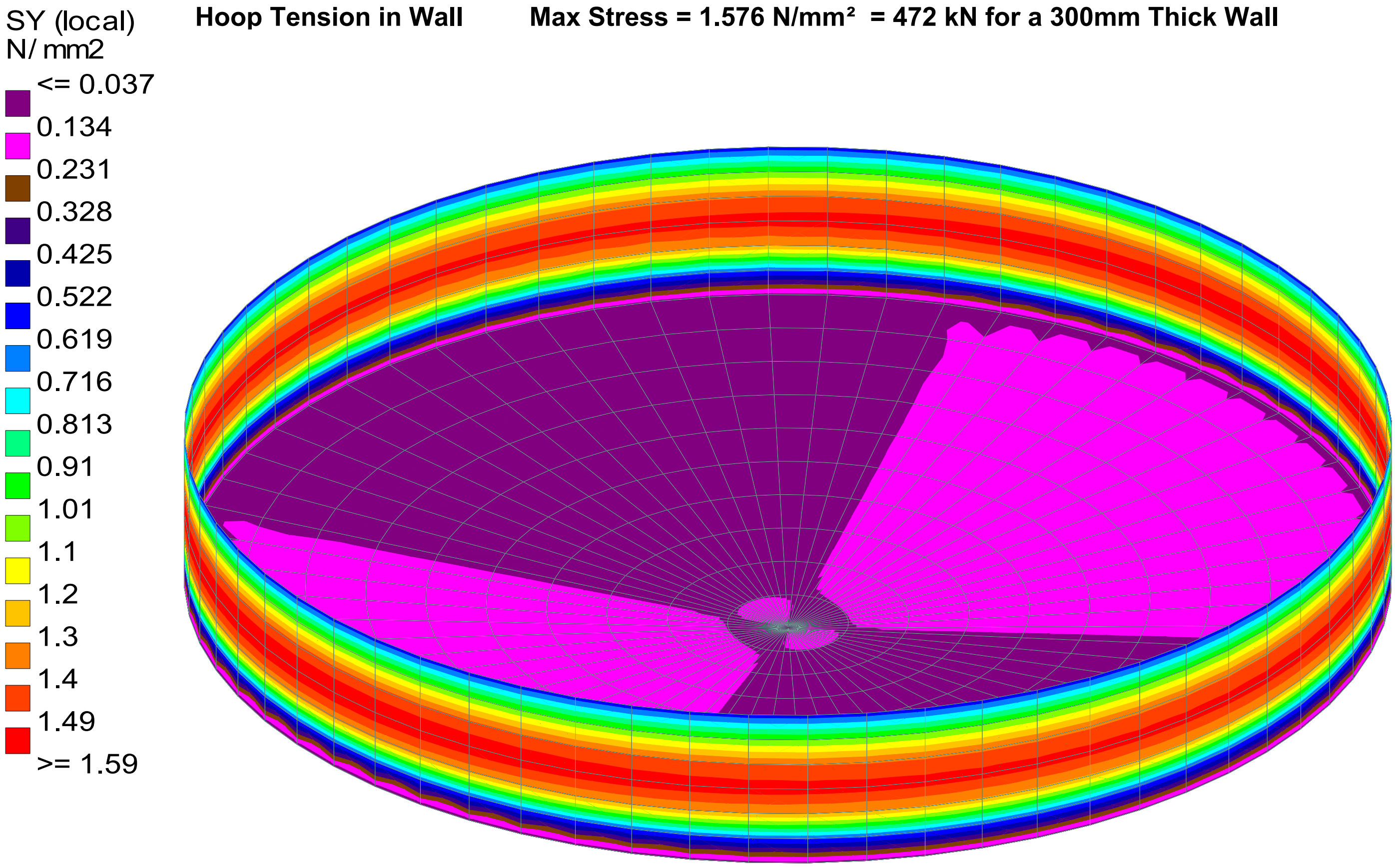
Hoop Tension per M width	=	**623**	kN
Vertical Moment in Wall	=	**33**	kNm

Circular Tank - Finite Element Analysis

Vertical Moments in Wall **M at base = - 58 kNm** **Mspan = 22 kNm**



Hoop Tension in Wall **Max Stress = 1.576 N/mm² = 472 kN for a 300mm Thick Wall**



Control Of Cracking Due To Restrained Shrinkage

Ref:- EC2 Pt 3 & CIRIA C660

Free Shrinkage Strain ε Types

Thermal T x α	Temperature Drop x Coefficient of Expansion α which depends on Aggregate Type
Autogenous Ag	Due to the chemical reaction causing a reduction in volume.
Drying Cd	Due to the drying out of the concrete over the long term

Restraint Types

Edge	Induces cracking strain due to restraint at side of new pour.
End	Induces cracking strain due to restraint at ends or from piles or ground friction.
Internal	Induces cracking strain due to restraint caused by internal temperature differentials.

Restraint Values

R1, R2, R3 — R varies between 1 for Full and 0 for None. Suffix denotes Shrinkage Stage - see below.

Creep Factor K1

K1 Value — Due to relaxation of the concrete under load. Fixed at 0.65 at all stages.

Restrained Strain

Up To 3 Days		3 Days to 28 days		28 Days to LT
k1 R1 (T1 α + Ag1)	+	k1 R2 (T2 α + Ag2)	+	k1 R3 Drying

Key Data Affecting Shrinkage and Strain Capacity

Example Values

Strength	**30**	**/**	**37**
LT Drying Period	**60**	**Yrs**	
LT Strength at	**60**	**Yrs**	
LT Strain at	**60**	**Yrs**	
Creep K1	=		**0.65**
R1	=		**0.32**
R2	=		**0.40**
R3	=		**0.19**
Aggregate	=		**Default**
3 Day με	=		**76**
28 Day με	=		**109**
LT με	=		**119.1**
Agg Factor	=		**1**
Exp μα	=		**12**

Ult Microstrain Capacity				**Agg**	**Exp**
Aggregate	**3 Day**	**28 Day**	**LT**	**Factor**	**μα**
Basalt	63	90	98	0.826	10
Default	**76**	**109**	**119**	**1**	**12**
Dolomite	85	122	133	1.119	9
Flint	65	93	102	0.853	12
Gabbro	75	108	118	0.991	10
Granite	75	108	118	0.991	10
Limestone	85	122	133	1.119	9
Quartzite	76	109	119	**1**	14
Sandstone	108	155	169	1.422	12.5
Autogenous	**15**	**33**	**50**	Gain beyond 28 is within Drying If Drying > Gain	

Variation Of Values According To Strength and Age

	At 28 Days	Strength Factors					Age Factors		
Concrete Strength Fck	**30**	**30 / 37**	**32 / 40**	**35 / 45**	**40 / 50**		**3D**	**28D**	**LT**
μStrain Capacity	**109**	1.000	1.030	1.080	1.130		0.698	1	1.092
Autogenous μStrain	**33**	1.000	1.100	1.250	1.500	x	0.448	1	1.531
Drying Shrinkage μStrain	**1**	1.000	0.976	0.942	0.887	Age	0	0	1.000
Fctm N/mm2	**2.90**	1.000	1.067	1.167	1.333	Factor	0.598	1	1.174
Modular Ratio	**6.09**	1.000	1.015	1.040	1.073		1.167	1	0.930

Note: If drying shrinkage is based on Fck = 30 N/mm² the reduction where Fck = 32 N/mm² is < 3%.

CIRIA C660 LT Values

C660 advises using the 28 Day Strain Capacity, Tensile Strength and Modular Ratio for the Long Term (LT) stage check.
This program allows the full LT values to be displayed and used for information and to demonstrate the effects.

Shrinkage Cont.

Thermal Strain Due To T1 Curing Temperature Drop

Fresh concrete heats up as a result of the chemical reaction.
It is called heat of hydration.

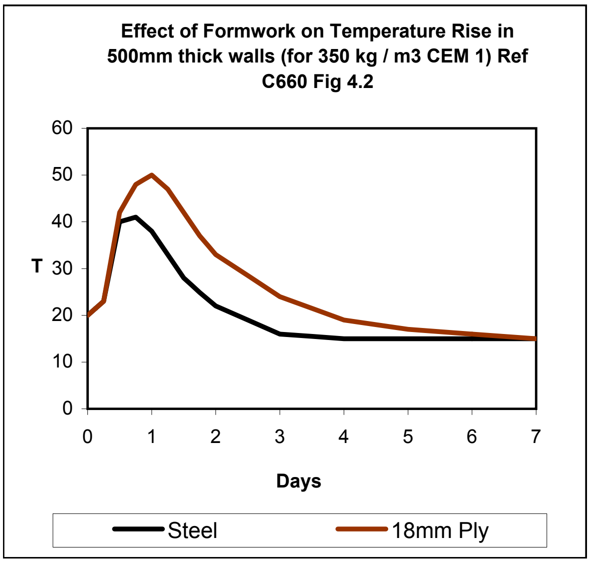
This process takes about 24 hours to reach a peak temperature.

The rise is dependant on the placing temperature, cement content, formwork and section thickness.

It then cools down to the ambient temperature over the next 2 to 6 days and shrinks.

The rate at which it cools down depends on the type of formwork and strike time and external temperature.

Shrinkage Calculations assume the cooling is complete at 3 days.



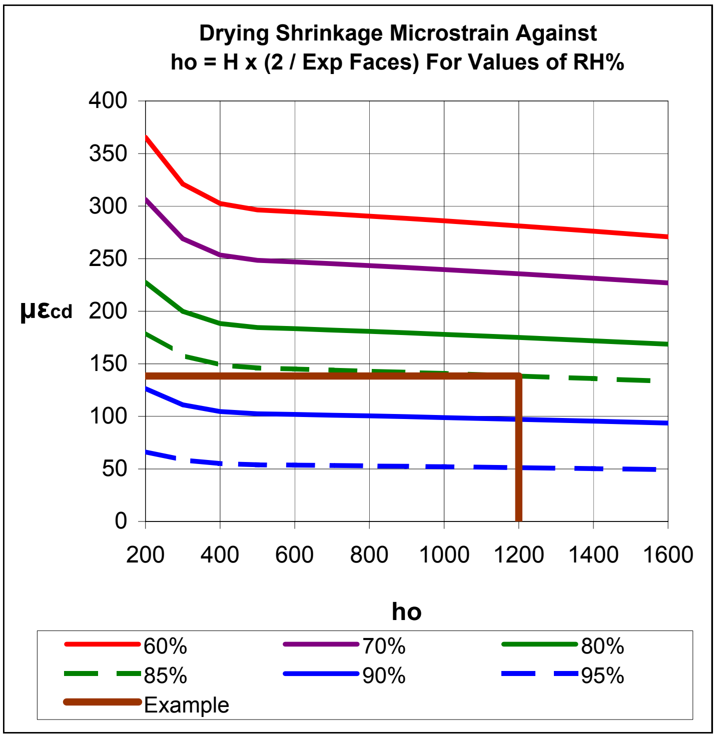
Thermal strain Due To T2 Seasonal Temperature Drop

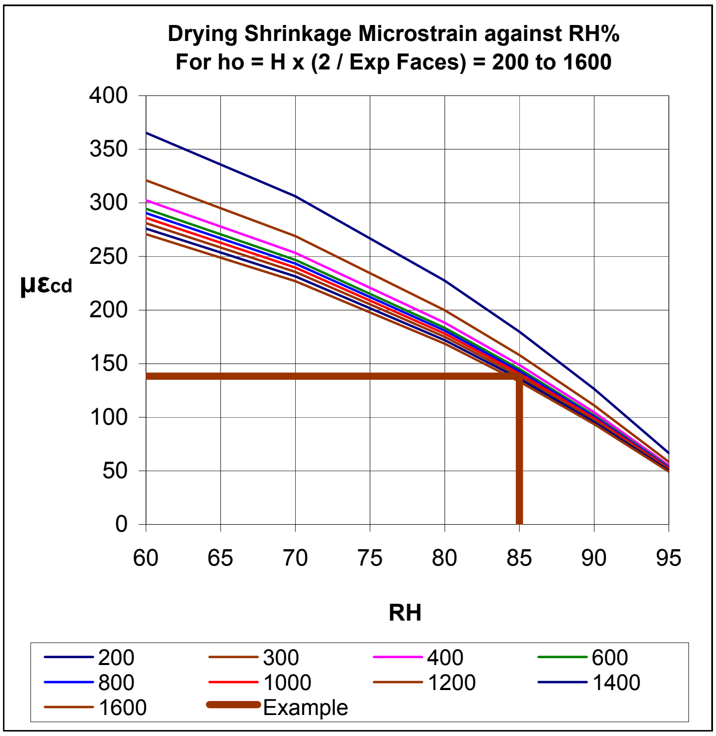
T2 is normally taken as 20 deg for exposed structures and 15 deg for buried structures.
The design method in this program conservatively assumes that T2 drop will occur evenly between 3 days and 28 days

Drying Shrinkage με For RH% Between 60 & 95 Value for RH% = 100 = 0 ho = H x (2 / Exp Faces)

Based On Data Control Sheet		Basic Value	ho	200	300	400	500	600	700	800	900	1000	1200	1400	1600	Value Used
RH%	85	με	kh	0.85	0.75	0.71	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	με
Period - Yrs	60	432.1	60	365	321	302	296	295	293	290	288	286	281	276	271	
Fck - N/mm²	30	362.1	70	306	269	253	248	247	245	243	242	240	236	231	227	
Depth H	600	269	80	227	200	188	185	183	182	181	179	178	175	172	169	
Exp Faces	1	212.7	85	180	158	149	146	145	144	143	142	141	138	136	133	138.4
u = 2 / Exp	2	149.4	90	126	111	105	102	102	101	100	100	99	97	95	94	
ho =	1200	79	95	66	58	55	54	54	53	53	52	52	51	50	49	

Example From Table = 138 με From charts or formula = 138.4 με
LT Strain = Maximum of:- (LT Autogenous - 28 Day Autogenous) & Drying Shrinkage = 138.4 με





Drying Shrinkage Cont.

Drying Shrinkage Equations **Ref EN 1992-1-1**

Equ B.11 Basic strain $\varepsilon cd,0 = 0.85 \times (220 + 110 \times \alpha ds1) \times \exp(-\alpha ds2 \times fcm / 10) \times 10E\text{-}6 \times \beta RH$

Equ B.12 $\beta RH = 1.55 \times (1 - (RH\% / 100)^3$ exp(VALUE) = 2.718^{VALUE}

For Class	S	αds1	=	3	αds2	=	0.13
	N	αds1	=	4	αds2	=	0.12
	R	αds1	=	6	αds2	=	0.11

Note: fcm = fck + 8 N/mm²

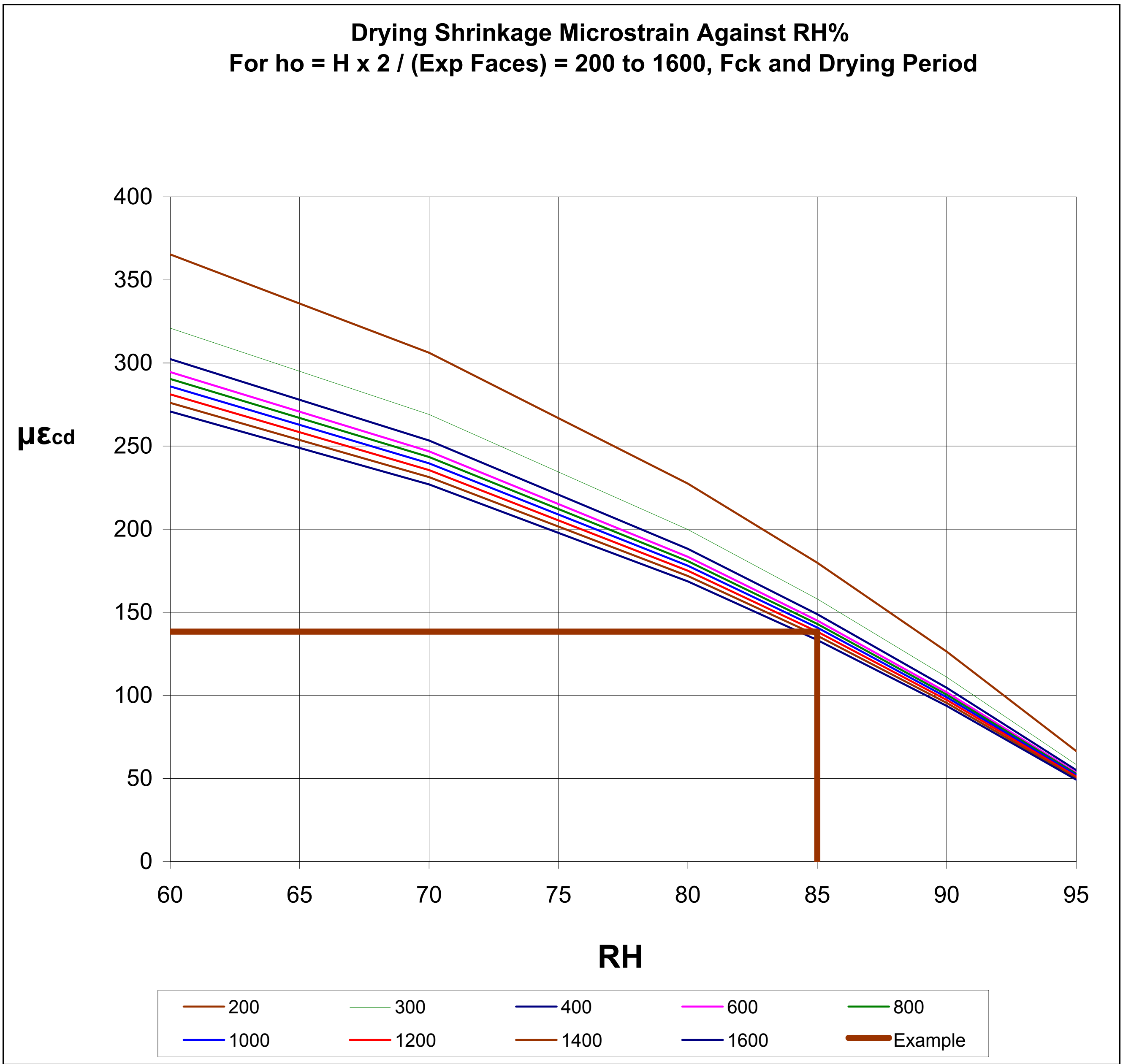
Equ 3.9 Strain at Time t days $\varepsilon cd(t) = \beta ds(t,ts) \times kh \times \varepsilon cd,0$ ts = start time in days

If Exp Faces = 2, ho = h If Exp Faces = 1, ho = 2h

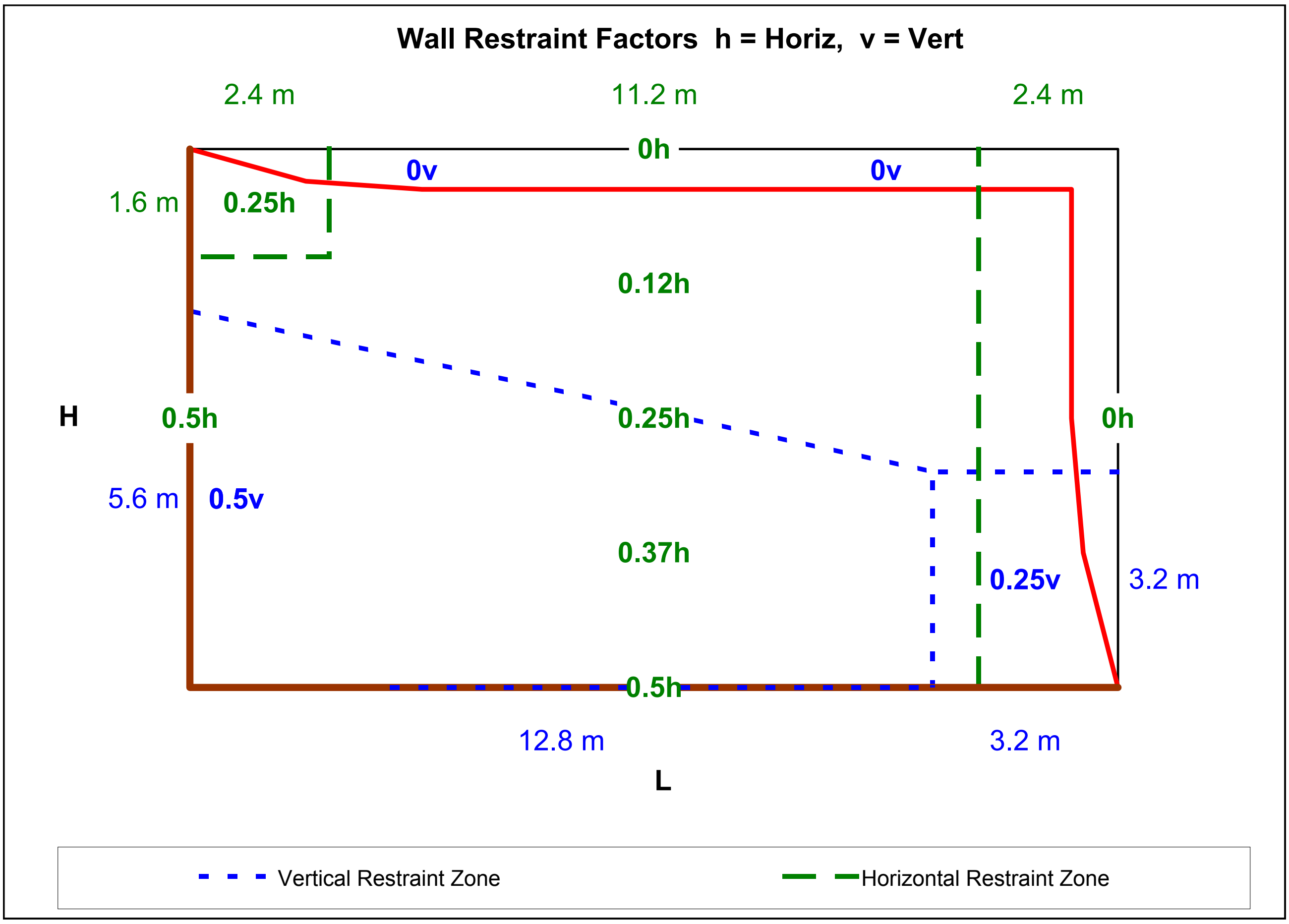
If ho >=500, kh = 0.7
If ho <=100, kh = 1.0 Otherwise, kh = 0.7 + (0.3 x (500 - ho) / 400)

Equ 3.10 $\beta ds(t,ts) = (t - ts) / ((t - ts) + (0.04 \times \sqrt{ho^3})) = t / (t + (0.04 \times \sqrt{ho^3}))$ If ts is taken as 0

Fck = 30 N / mm² Drying Period = 60 Yrs = 21915 Days



Edge Restraint **Ref EN 1992 - 3 - 2006 Annex L Fig L1**



Type of Construction	Sequential	H =	8.000	L =	16.000
With Construction Joints	No	0.2 x H =	1.600	0.2 x L =	3.200
Maximum Factor	0.50	0.5 x H =	4.000	L / H =	2.000
Diagram Displays	All	L / 4.8 =	3.333	Hor Factor	1.000

Single values within zones are constant throughout. Multiple values denote a varying restraint.
Values on the edge of a zone or outline show that the restraint varies linearly towards another zone or value.

Horizontal Central Zone Centreline Values For Isolated and Sequential Cases

L / H	At Base	At Top
1	0.5	0
2	0.5	0
3	0.5	0.05
4	0.5	0.3
>=8	0.5	0.5
2.000	**0.50**	**0.00**

These values are EC2 Pt 3 Fig L1 values x Factor / 0.5
and are multiplied by L / 4.8 if L < 4.8m

The values are a minimum of 0.25 x Creep Factor / 0.5
if construction joints are included. (BS8007 only)

Design Values for chosen case are shown in bold

Vertical Central Zone Values - Infill Case	Where L <= 2H	R = CF (1 - L / 2H)	**Design =**	**N/A**
Vertical Central Zone Values - End Case	Where L <= H	R = CF (1 - L / H)	**Design =**	**N/A**

VERY IMPORTANT NOTE

These values and diagrams were previously included in BS8007 and are now included in EN1992 - 3
EC2 Pt3 Fig L1 includes a Creep Factor of 0.5 (Ref A.5). C660 uses a creep factor of 0.65 with unfactored R values.
If the published chart values are used with a C660 calculation:-

Multiply all values by (1 / .65 = 1.54) and use K1 = 0.65 in C660 calculations Note:- 0.5 x 1.54 = 0.77

It is vital that the designer makes it absolutely clear what has been done.

The following C660 method shows the restraint is generally < 0.77 unless the wall / base section areas ratio is very small.

Edge Restraint Cont.

Ref C660 Equ 4.6

Restraint at Joint Rj = 1 / (1 + ((An / Ao) x (En / Eo))

Where	An	=	Cross Section Area of new concrete pour
	Ao	=	Cross Section Area of old restraining concrete
	En	=	Modulus of Elasticity of new pour concrete (assumed 0.7 x Eo)
	Eo	=	Modulus of Elasticity of old concrete

Example

Wall	ht	=	8	m	Base	Width	=	8	m
	H	=	0.3	m		H	=	0.4	m

Ao = 8 x 0.4 = 3.2 m² An / Ao = 0.75

An = 8 x 0.3 = 2.4 m² En / Eo = 0.7

Rj = 1 / (+ (0.75 x 0.7)) = **0.656**

Simplified Method

For a wall cast at the edge of a slab	An / Ao	=	hn	/	ho
For a wall cast remote from the edge of a slab	An / Ao	=	hn	/	2ho
For a slab cast against an existing slab	An / Ao	=	hn	/	ho

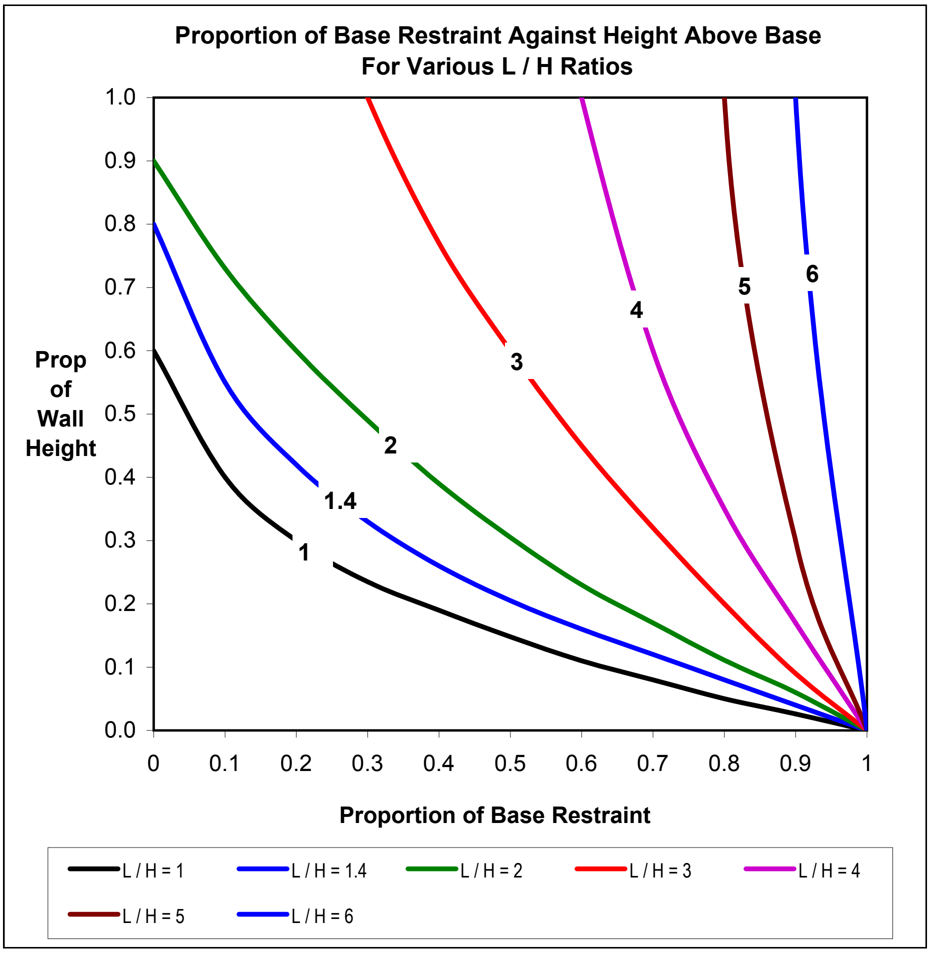
An / Ao = 0.3 / 0.4 = **0.75**

Rj = 1 / (+ (0.75 x 0.7)) = **0.66**

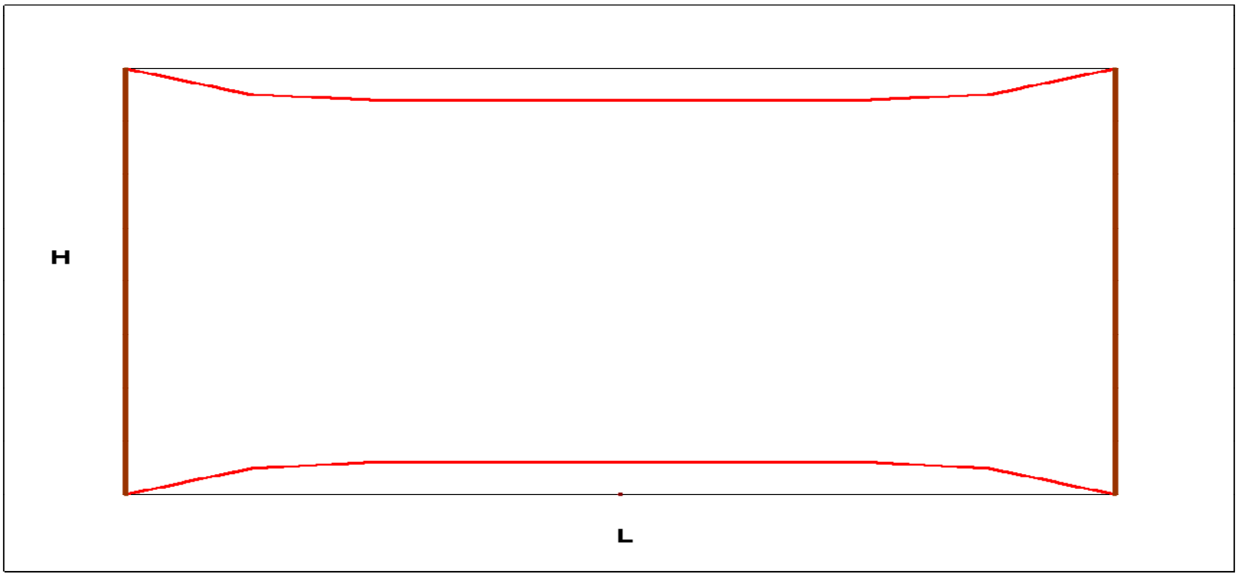
THESE VALUES DO NOT INCLUDE CREEP

Variation of Horizontal Restraint According To Height Above Base

Ref CIRIA Figure 4.17 and Enborg 2003 **This can be compared with the data on previous page**



End Restraint



Walls can be restrained when a new section is placed between previously cured sections or existing structures.
Slabs can be restrained in a similar way but also by friction, pile stiffness and or passive resistance.

Where the restraint is a robust immovable existing structure R should be = 1.0.
Consequently, it is advisable to try and arrange structures and pours to minimize End Restraints wherever possible.

Note. When a tank is in service or is buried, the liquid retaining faces should not experience any drying shrinkage.
Therefore in those circumstances the design need only consider T1 & Autogenous 1 and T2 and Autogenous 2.

To Calculate Restraint From Piles or Passive Resistance.

1 Establish the sources of Restraint and check at 3 Days or 28 Days or Long Term

2 Using the analysis computer model or manually:-

A Set Ec = the full 28 day value and do not allow for creep coefficient.
The 3 day adjustment factor is 0.86 and the LT factor is 1.07.
Set the correct coeff of expansion
Consider a load case with a 15 degree temperature drop say.

B Restrain the structure horizontally at ends and calculate the restrained stress.
Record the stresses in each direction, which should be uniform.

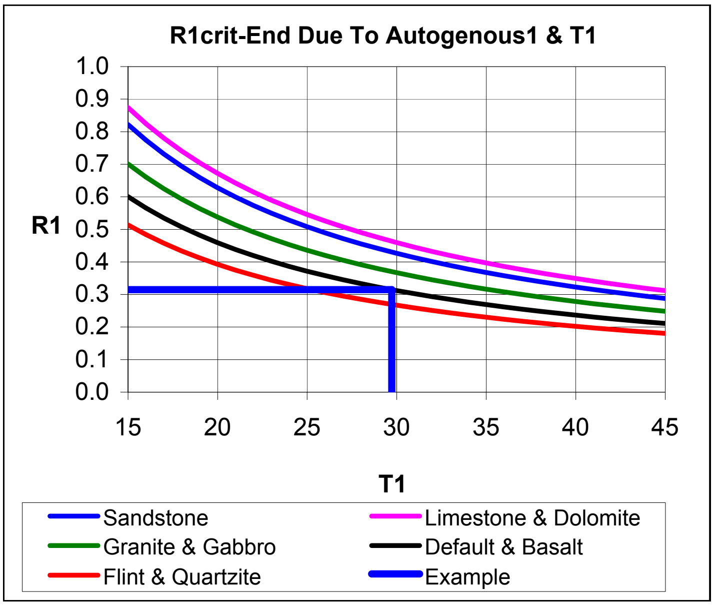
C Remove all previous restraints
Set the restraint sources to have an elastic force / displacement criteria
For Piles and or Passive Resistance test at 50% of the vertical settlement stiffness.
Record the stresses at the centre and outwardly between restraints.
Multiply these values by 3 Day and LT Ec factors if required.
You will note that the piles offer a cumulative but reducing restraint towards the centre.

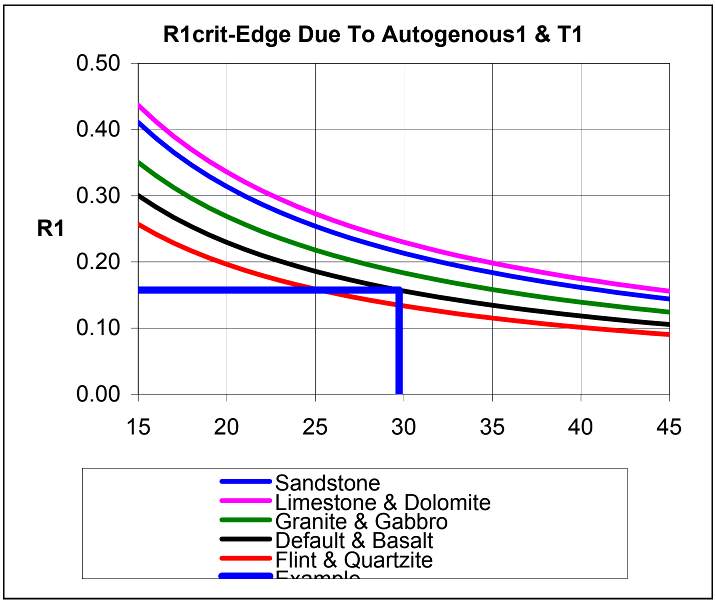
D The Restraint Factor R will be:- Stress Due to C / Stress due to B

To Calculate Restraint from Friction

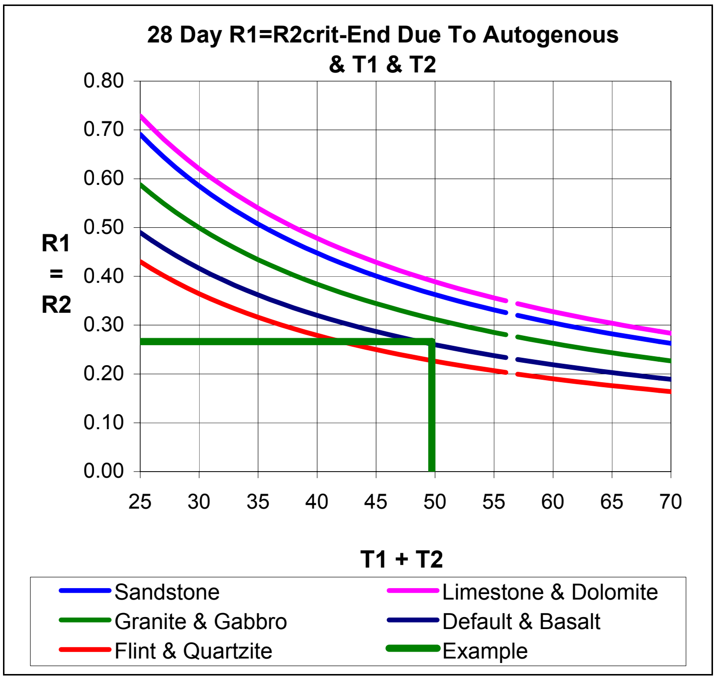
1 Where friction exceeds the tensile strength, no movement can occur so full restraint occurs and R = 1.
2 Establish the coefficient of friction μ or assume 0.7 say.
3 Establish the fctm in N/mm² at 3D, 28D & LT For Fck = 30 N/mm² 1.73 2.90 3.40
4 Apply horizontal loads to the slab = Vertical Load x μ away from each centre line and analyse.
5 Record the stress at each centre line and compare it with the appropriate tensile stress capacity fctm.
6 If k1 (= 0.65) x Stress is more than the appropriate fctm value, the slab cannot slide and Rmax = 1.
7 If k1 (= 0.65) x Stress is less than the appropriate fctm value, Rmax = 0.65 x Stress / fctm
8 Care must be used in calculating the empty condition as the weight of walls must be added.
9 This analysis must be performed using the loads which apply at the stages considered.
10 Therefore, for T2 and Long Term it would be prudent to assume the tank is full.

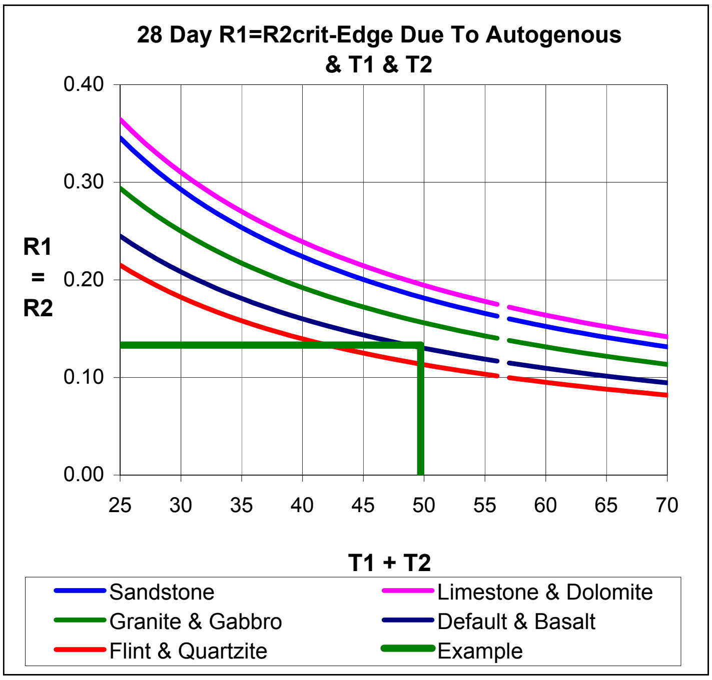
Using Capacity Charts For R1 & R2 **End Restraint R Values based on FOS = 1.0**





R1 at 3 Days		3 Day Strain Capacity / (K1 * (3D Autogenous + (T1 x α)))						
T1	**Curing Temp Drop**	=	**29.7**	Deg	**R1 Applied**	=	0.315	
	R1 Crit	**End**	=	**0.315**	**Reserve R**	=	0.000	Cracked
		Edge	=	**0.157**		=	-0.158	Cracked





If R2 = R1 - at 28 Days 28 Day Cap - 3 Day Strain / (K1 * (28D - 3D Autogenous + (T2 x α)))

Applied 3 Day Restraint		R1	=	0.315	**Seasonal Temp Drop**			**20**	Deg
Applied 28 Day Restraint		R2	=	0.315	**T1 + T2 =**	29.7	+ 20	=	**50**
R2 Crit	**End**	=	**0.266**		**Reserve R**	=	**-0.049**	Cracked	
	Edge	=	**0.133**			=	**-0.182**	Cracked	

(R2-end / R2crit-end)	=	**0.315**	/	**0.266**	=	**1.18**	=	**28Day Proportion Used-End**
(R2-edge / R2crit-edge)	=	**0.315**	/	**0.133**	=	**2.36**	=	**28Day Proportion Used-Edge**

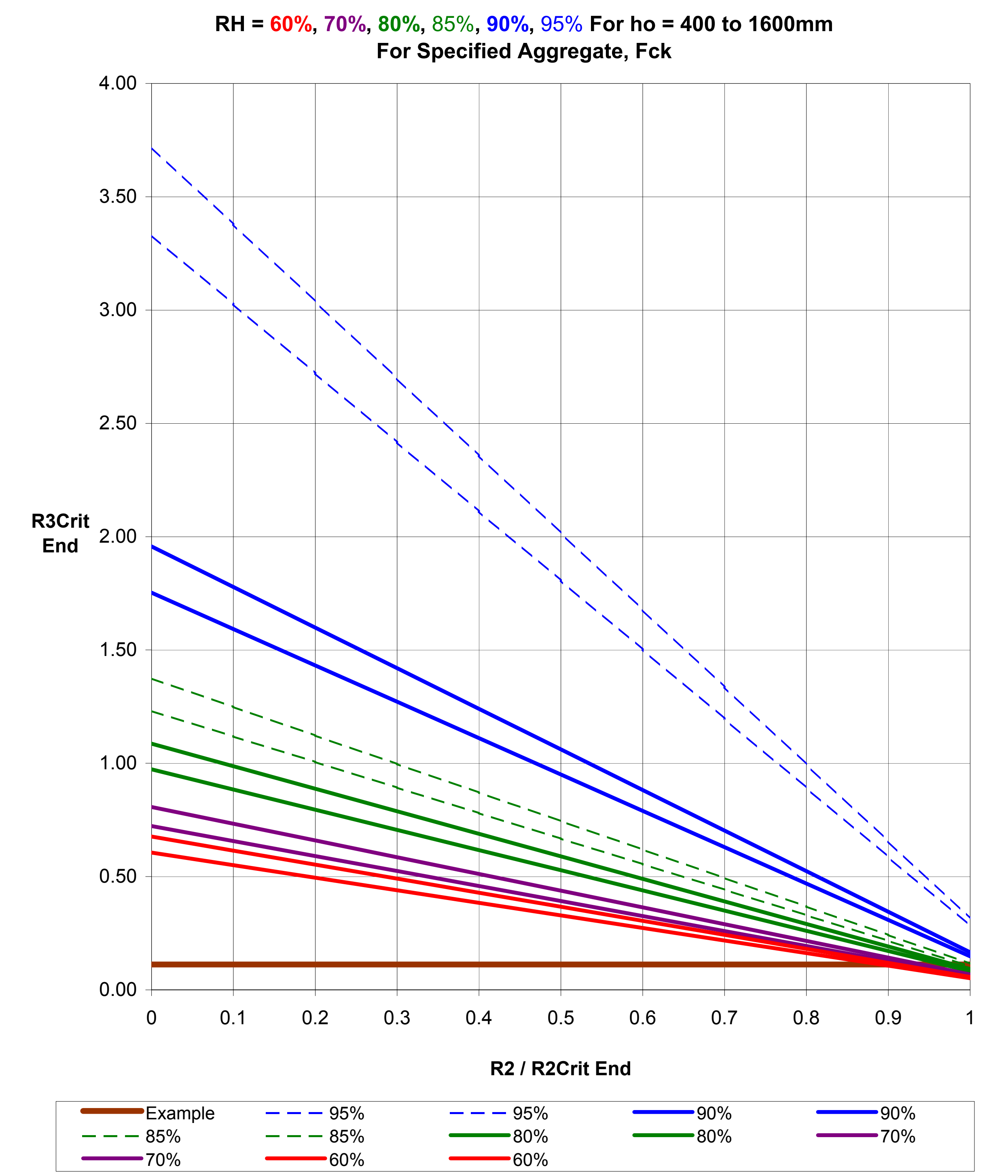
A max value of 1.0 is used from hereon when cracked

R3Crit Chart

The bands cover the commonly used %RH values and their spread covers the ho depth range from 400mm to 1600mm. For Edge restraint, R3crit-Edge will be half of these values and if cracked at 28 days use R2 / R2Crit = 1. For other Fck values, divide R3crit by Shrinkage Factor (i.e. 0.942 for Fck = 35), however the capacity increase will be very slight.

It is acceptably accurate to interpolate within these bands. It can be seen that an accurate assessment of Relative Humidity has a far greater effect on the value of strain that any loss of accuracy due to interpolating for ho within the bands.

The chart allows a direct reading from the R2 / R2crit proportion without the need for adjusting the values for the strength gain between 28 Days and Long Term. For an End Restraint, If the section has cracked at 28 Days, further analysis is irrelevant.



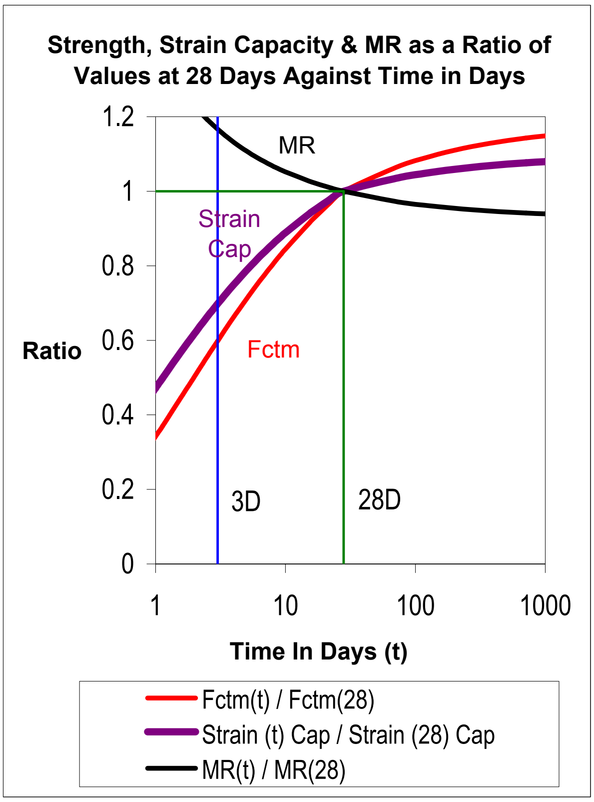
At Long Term **R3 Crit** = **0.112**

End Restraint Crack Development

General

- fctm3 is 0.6fctm28 and fctmLT = 1.17fctm28
- εCap3 is 0.7εCap28 and εCapLT = 1.09εCap28
- See adjacent chart for values up to 1000 days.
- Cracks occur if Restrained Strain is > Capacity.
- A crack will cause a reduction in concrete strain.
- End Restraint cracks form at the weakest point.
- Crack width = Srmax x Strain based on fctm(t).
- Srmax is 2 x bond length x factors + 3.4 x Cover.
- Srmax is NOT the End Restraint crack spacing.
- Cracks will widen until another crack forms.

Long Term Values Used In Example
MR & Strain Cap & Fctm Values at **60 Yrs**



At 3 Days - Includes Curing Temperature Drop T1

- The stage also includes small autogenous strain.
- No cracks occur if the R and T1 are low enough.
- The first crack may occur before 3 Days.
- Further strain widens the crack before another crack forms.
- This process continues until no more cracks form.

At 28 Days - Includes Seasonal Temperature Drop T2

- This stage is used to check T2 strain effects.
- T2 = 20° for exposed and 15° for buried elements.
- Further small autogenous strain occurs.
- The strain is checked against the 28 day capacity.
- 28 Day cracks will be 70% wider than 3 Day cracks.

At Long term - Includes Drying Shrinkage

- This shrinkage is due to Autogenous and Drying .
- The small amount of autogenous strain is included within the Drying Shrinkage.
- The rate of increase in drying shrinkage is slower than the small increase in strain capacity.
- 70 % of the Drying Strain has occurred after 7 years it takes up to 60 yrs for the process to complete.
- If the section is uncracked at 28 Day and Long term it will not have cracked in between.
- Drying shrinkage is primarily dependant on the Relative Humidity.
- Drying Shrinkage may be ignored where the face is permanently exposed to a liquid.
- A Long Term stage crack width will be 17% wider than a 28 Day crack.

Crack Width Scenarios Assuming Strain Increases After First Crack

- C660 makes the checks at 3D, 28D and LT. When a crack forms at 3 or 28 Days, it will increase in width (W +) if there is an increase in strain and capacity. W + will be proportional to the ratio of (restrained strain increase / strain capacity increase between stages) and the increase in formed crack widths between stages (see below). If the increase in restrained strain begins to exceed the stage capacity, another crack will form.

3D to 28D W + = (Additional Restrained Strain / (28D εCap - 3D εCap)) x (Cracked W2 - Cracked W1)
3D to LT W + = (Additional Restrained Strain / (LT εCap - 3D εCap)) x (Cracked W3 - Cracked W1)
28D to LT W + = (Additional Restrained Strain / (LT εCap - 28D εCap)) x (Cracked W3 - Cracked W2)

	Stages At Which Cracks Form		1 Due to T1 & A1 3D W1 mm	1 - 2 Due to T2 & A2 W + mm		2 At 28D W2 mm	2 - 3 Due to Drying W + mm		3 At LT W3mm
1	No Crack		0	0		0	0		0
2	28 D		0	0	C	0.192	0.026		0.218
3	LT		0	0		0	0	C	0.224
4	28D & LT		0	0	C	0.192	0.032	C	0.224
5	3D	C	0.117	0.037		0.154	0.026		0.180
6	3D & 28D	C	0.117	0.075	C	0.192	0.026		0.218
7	3D & LT	C	0.117	0.037		0.154	0.070	C	0.224
8	3D & 28D & LT	C	0.117	0.075	C	0.192	0.032	C	0.224

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Shrinkage and Restraint Ref C660 Cl 1.4 & 3.2.1 T1 from C660 - Charts or Prog Prog

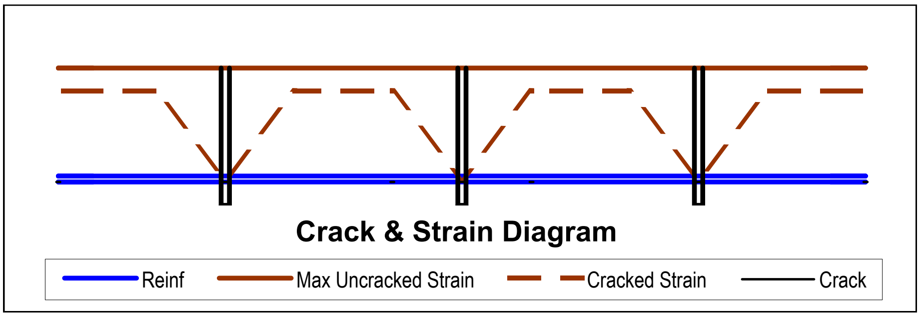
3 Day Ult με (3D με)	76.0
28 Day Ult με (28D με)	109.0
LT Ult με (LT με)	119.1
LT-28D Ult με (LT-28D με)	10.1
Aggregate Strain Factor	1.00
28 Day Cyl Fck N/mm²	30
Coeff of Exp x 10^{-6}	12.0
Bond Factor k1	1.14
Section Type - Position	Slab
Formwork	Grnd
Aggregate Type	Default
Section Depth H mm	600
LT Drying Period	60 Yrs
LT fctm & MR taken at	60 Yrs
LT Strain Cap taken at	60 Yrs
End Restraint Lr or N/A	30000
T2 Temp Drop °C	20
Crack & Strain Diagram	End-LT
Chart Shows Restraint	All
Wk Limit mm	0.2

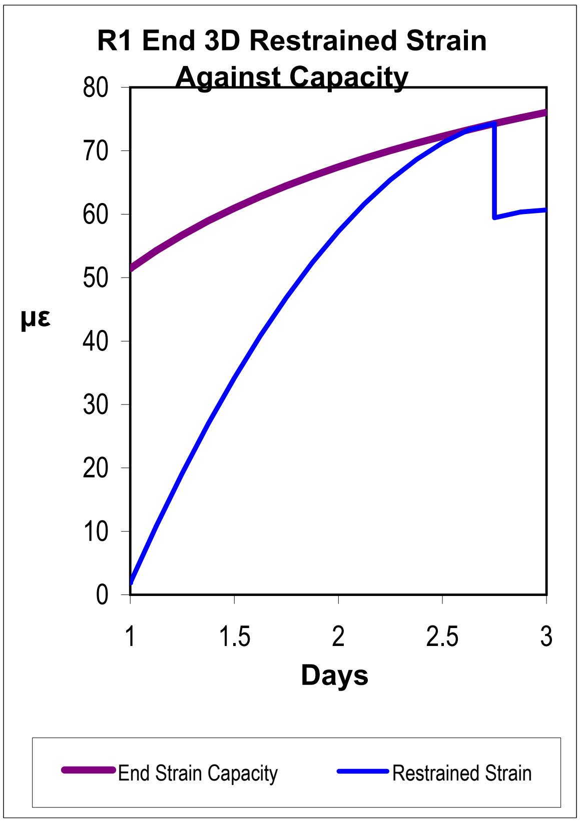
End 3D με x GR / FOS	76.0
28D με / FOS	109.0
LT με / FOS	119.1
LT-28D με / FOS	10.0
3D Autogenous με	14.6
28D Autogenous με	32.6
3D fctm N/mm²	1.73
3D Modular Ratio	7.11
Binder Kg/m³	350
GGBS %	50
PFA %	0
PC or SR	PC
Reinf fyk N/mm²	500
Creep Coefficient K1	0.65
Conc Tension Coeff αct	0.80
Free T1 x α Coeff με	357
Free Autogenous1 με	15
Free T2 x α Coeff με	240
Free Autogenous2 με	18
Free Drying με	138

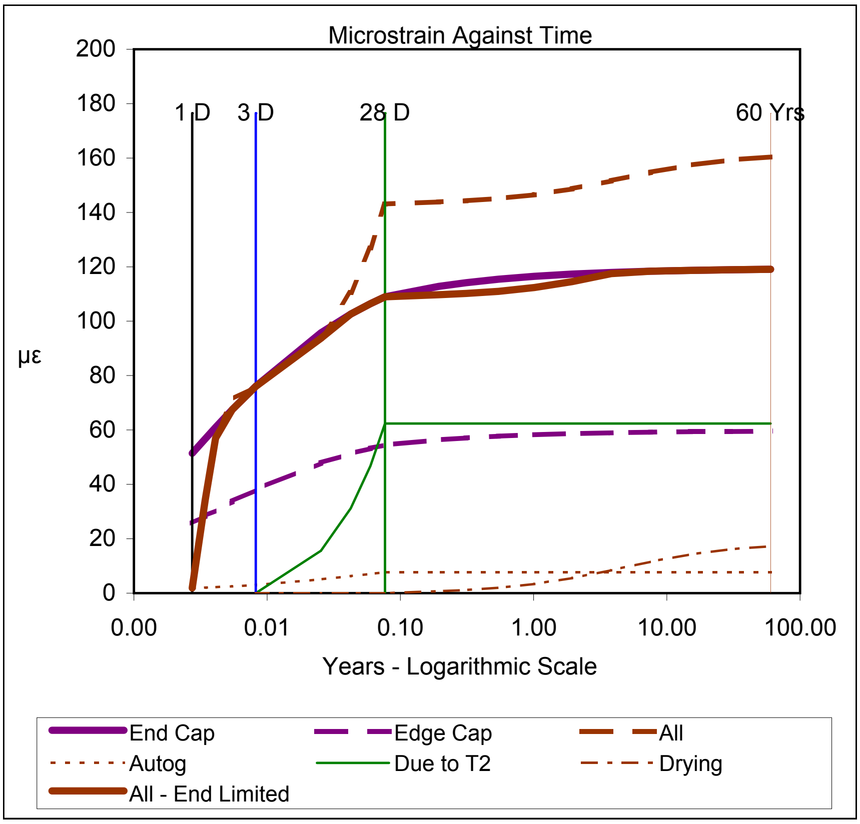
Edge 3D με x GR x 50%	38.0
28 με x 50%	54.5
LT με x 50%	59.5
LT-28D με x 50%	5.0
28D fctm N/mm²	2.90
28D Modular Ratio	6.09
LT fctm N/mm²	3.40
LT Modular Ratio	5.67
28 Day Cube Fcu N/mm²	37
Class	N
Show Cracked Strain	Y
End Restraint FOS	1.0
Exposed Faces	1
% RH Value	85
Mean Daily Temp Tm °C	15
Placing Temp Tp °C	20
Edge R1crit	0.157
Edge R2crit	0.000
Edge R3crit	0.000
3 Day Temp Drop T1	29.7

Reinforcement	Bars	Cov	Ctrs	φEq	As	Asmin	Srmax	με 1	W1	με 2	W2	με 3	W3	Wk
End Restraint	32	60	150	32	5362	884	753.4	186	0.117	306	0.192	356	0.224	0.224
Edge Restraint	20	60	150	20	2094	884	1014	38	0.039	89	0.090	101	0.102	0.102
BS8007	20	60	150	20	2094	1040	954.9	73	0.070	122	0.117	0	0.000	0.117

RS = Free Strain x Restr x Creep Fact - Full Strain Cap For End Restr - 50% Strain Cap For Edge Restr			
End R1crit	0.315	W3D	0.117
End R2crit	0.197	W28	0.192
End R3crit	0.112	WLT	0.224
3D (T1 & AG1) Restr R1	0.315		
28D (T2 & AG2) Restr R2	0.400		
LT (Drying) Restr R3	0.190		
Crack & Strain Diag Ratio	0.8		
R1 End Restr Strain Ratio	0.8		







	EC2 DESIGN TOOL **THERMAL, SHRINKAGE, RESTRAINT & CREEP** HAC-PRO 1 - 5 - 2 RESTR 11	**Howes Atkinson Crowder LLP** Copyright © 2009 HAC

Example **Concrete** **C 30 / 37** **Aggregate Default**

Crack Width = Crack Spacing Srmax x Crack Inducing Strain CIS x Lr Factor

End Crack Inducing Strain CIS = (1 / Es) x (0.5 x kc x k x αct) x ((fctm x MR) + (fctm x 0.5 x H x 1000 / As1))

Concrete in Tension Coefficient αct = 0.8 **Mod Ratio MR = Varies - See Below**

For kc & k - Ref C660 Table 3.1

If H <= 300, k = 1. If H >= 800, k =0.75
Or k = 0.75 + (0.25 x (800 - H) / 500)

H = 600
k = 0.85

For external restraint kc = 1.0

At 3 Days **fctm = 1.73** **MR = 7.11**

T1 Curing Temp Drop = 29.7 Deg

End Restraint If Cracked CIS							=	**186**	**με**
End Strain Capacity / (FOS = 1)							=	**76**	**με**
Edge Strain Capacity (50% End Cap)							=	**38**	**με**
Free Strain = 3 Day Autogenous + (T1 x α)	=	15	+ (	29.7	x	12)	=	371	με
K1 x Free Strain	=	0.65	x	371			=	241	με
R1 x K1 x Basic Strain	=	0.32	x	241			=	**76**	**με**

Strain - Capacity	**End**	**76**	**-**	**76**	**=**	**0**	**με**	**CIS**	**= 186**	**με**
	Edge	**76**	**-**	**38**	**=**	**38**	**με**	**CIS**	**= 38**	**με**

At 28 Days **fctm = 2.9** **MR = 6.1**

T2 Seasonal Temp Drop = 20.0 Deg

End Restraint If Cracked CIS							=	**306**	**με**
End Strain Capacity / (FOS = 1)							=	**109**	**με**
Edge Strain Capacity (50% End Cap)							=	**55**	**με**
Free Strain = 3 to 28 Day Autogenous + (T2 x α)	=	18	+ (	20.0	x	12)	=	258	με
K1 x Free Strain	=	0.65	x	258			=	168	με
R2 x K1 x Basic Strain	=	0.40	x	168			=	**67**	**με**
R1 x K1 x Strain1 + R2 x K1 x Strain2	=	76	+	67			=	**143**	**με**
Uncracked 3D End Strain + 28D End Strain	=	0	+	67			=	**67**	**με**

If End Restraint is cracked at 3 Days, the extra strain after 3 days is compared against 28D - 3D capacity
Otherwise, compare the cumulative 28D strain against the 28D capacity. Uncracked 3D strain is added.
End Restraint cracks from 3 Days increase in width according to increased strain & strength.

								28D CIS		**Uncracked**		**Strain**	
Strain - Capacity	**End**	**67**	-	**33**	=	**34**	με	**306**	or	**0**	=	**306**	με
	Edge	**143**	-	**55**	=	**89**	με			**CIS**	=	**89**	με

Long Term **fctm = 3.4** **MR = 5.7**

End Restraint If Cracked CIS							=	**356**	**με**
End Strain Capacity / (FOS = 1)							=	**119**	**με**
Edge Strain Capacity (50% End Cap)							=	**60**	**με**
Free Strain = Drying Strain	=	From Table or Charts				)	=	**138**	**με**
K1 x Free Strain	=	0.65	x	138			=	**90**	**με**
R3 x K1 x Basic Strain	=	0.19	x	90			=	**17**	**με**
R1K1xStrain1 + R2K1xStrain2 + R3K1xStrain3	=	76	+	67	+	17	=	**160**	**με**
Uncracked 28D End Strain + LT End Strain	=	0	+	17			=	**17**	**με**

If End Restraint is only cracked at 3 Days, the extra strain after 3 days is compared against LT - 3D capacity
If End Restraint is cracked at 28 Days, the extra strain from 28 days is compared against LT- 28D capacity
Otherwise, compare the cumulative LT strain against the LT capacity. Uncracked strain is added.
End Restraint cracks from 3 Days and 28 Days increase in width according to increased strain & strength.

								LT CIS		**Uncracked**		**Strain**	
Strain - Capacity	**End**	**17**	-	**10**	=	**7**	με	**356**	or	**0**	=	**356**	με
	Edge	**160**	-	**60**	=	**101**	με			**CIS**	=	**101**	με

Crack Spacing Srmax = 3.4 x Cov + 1.14 x (K2=1) x 0.425 x φ / (As1 / (1000 x 2.5 x (H - d)))

For End Restraint Reinf	=	204	+	549	=	**753**	mm
For Edge Restraint Reinf	=	204	+	810	=	**1014**	mm

Asmin per m width = kc k Act fctm(t) / fky Act = 0.5 x H x 1000 Zone Depth = 0.5 k H **255**

For First Cracking At **3 Days 884 mm²** **28 Days 1477 mm²** **Long Term 1735 mm²**

Lr Factor Using 28 Day MR = 1 / (1 + (Srmax / Lr) (k x kc / (MR x As1 / (0.5 x H x 1000))))

1 / (1 + (0.025 x 0.85 / (6.1 x 0.018)))

1 / (1 + (0.021 / 0.109)) = 0.836

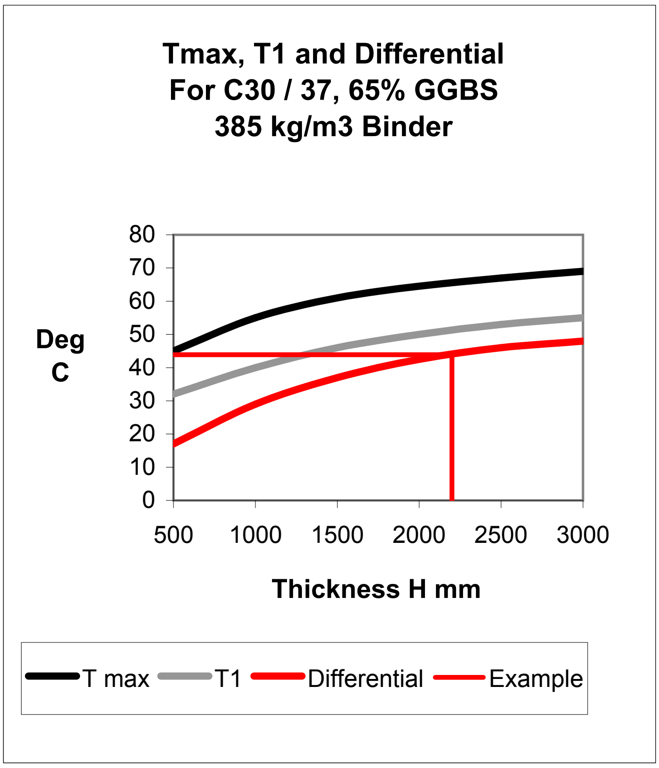
Internal Restraint Ref CIRIA C660

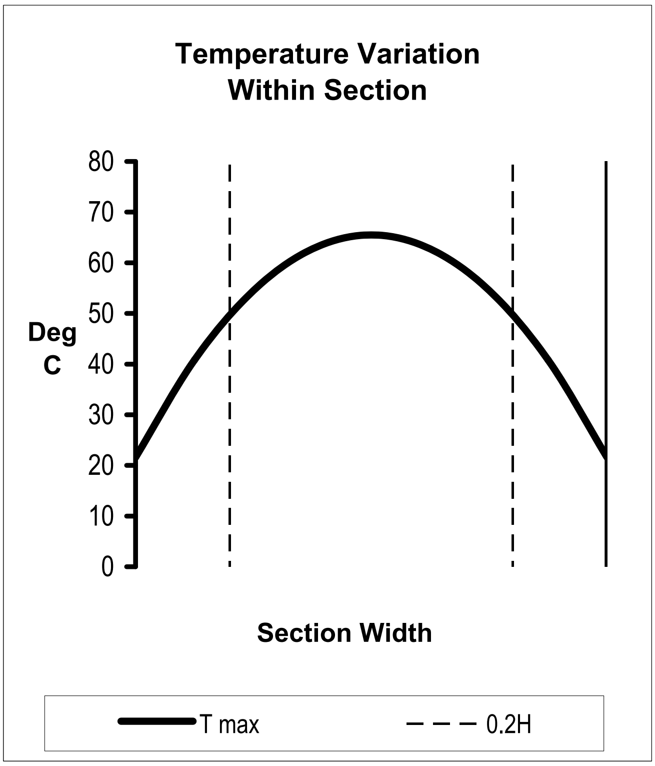
The restrained strain is due to the difference in temperature rise at the centre and surfaces at 3 days.

R in all cases	=	0.42	Sect 4.7.4	Coefficient of Expansion	=	12	x 10E-6	Values
K1 = Creep Factor	=	0.65	Sect 4.9.1	3D Tensile Strain Cap	=	76	με	From
Autogenous	=	N/A	Sect 4.6.1	3D Tensile Strength Cap	=	1.73	N/mm²	Main Sheet

Temperature Differential ΔT

This is best calculated using the software provided with CIRIA C660. Appendix A2
A graph showing values for a typical GGBS blended mix design (Ref Table 4.2) is included below.
The values are similar between 50% & 70% GGBS as more binder is required with higher GGBS% to maintain strength.





Section Thickness	2200	mm	Max	65.5	° C	Surface	21.6	° C	Differential	43.9	° C		
Restrained Strain	=	0.42	x	0.65	x	43.9	x	12	=	143.8	με	Equ 3.7	
Crack Inducing Strain	=	143.8	- (	76	x	0.5	)		=	105.8	με	Equ 3.5	

As1 Reinforcement Table 3.1, Equs 3.12, 3.13, 3.14, Sect 3.4, Sect 4.13

Internal Restraint Dominant kc = 0.5 k = 1.0 0.2H = 0.2 x 2200 = 440 mm

As1min = 0.5 x 1.0 x 440 x 1000 x 1.73 / 500 = 762.4 mm²

Note: - % As1min / Act = 0.173 This is 50% of the general value because kc is normally 1.0

Crack Spacing k1 = 1.14 Cover = 50 φ = 16.0 Ctrs = 250 As1 = 804.2 mm²

heff = 2.5 x (Cov + φ/2) = 145 Aceff = 145000 mm² ρp,eff = As1/Aceff 0.006

Srmax = 3.4 x 50 + 0.425 x 1.14 x 16.0 x 0.006 = 1568 mm

Crack Width = 1568 x 105.8 / 1000000 = 0.166 mm

Also Check As1 Provided against:- 0.151 % x 1000 x d1 d1 = 2142 mm = 3226 mm²

Calculation of T1 Temperature Drop Using the C660 Adiabatic Program

Whereas it is possible to use the C660 T1 charts to get an accurate value according to the mix used, these values are only appropriate when the Mean Daily Temperature (MT) = 15 deg and the Placing Temperature (PT) = 20 deg.
In order to take account of variations in MT and PT the C660 Adiabatic spreadsheet must be used.

One of the features of this HAC program is its ability to automatically calculate T1. So a considerable amount of effort has been expended to devise a viable way of embedding key results from the C660 Adiabatic program into this program so they can be combined to suit the mix and MT and PT values. The aim is + / - 1 degree of accuracy.

Ranges Considered

The wall thickness H can vary from 200mm to 2200mm with ply or steel formwork. Slabs use steel with H = 1.3 x Depth.
The Mean Temperature can vary from 20 deg down to 5 deg and up to 35 deg
The Placing Temperature can vary from 15 deg down to 5 deg and up to 35 deg
PFA% can vary from 0% up to 55% although the minimum addition would normally be 35%
GGBS% can vary from 0% up to 80% although the minimum addition would normally be 35%.

Values Calculated Over the Range of H

The T1 values for a Control Mix of 350 kg of CEM1 with MT = 15 deg and PT = 20 deg
The effect of varying PT between 5 deg & 35 deg in 5 deg steps.
The effect of varying MT between 5 deg & 35 deg.
The effect of a varying % of PFA for MT = 15 and PT varying between 5 deg and 35 deg.
The effect of a varying % GGBS for MT = 15 and PT varying between 5 deg and 35 deg.
The effect of a varying the kg of CEM1 for MT = 15 and PT varying between 5 deg and 35 deg.
The equivalent extra kg of CEM1 within a total of additional kg when PFA or GGBS blended mixes are used.

Observations

The results were interrogated to see how they varied. Some values diverge between H = 400mm and H = 200mm.
The results can be considered as linear and symmetrical for an MT increase or decrease about the 15 deg Control value.

Varying PT causes slightly different linear changes in T1 between the 5 degree steps from PT = 5 deg to PT = 35 deg.
Varying PT causes a linear change in T1 due to Extra CEM1 kg which lessens as H increases.
Varying PT causes a linear change in T1 due to PFA which lessens as H increases.
Varying PT causes a nearly linear change in T1 due to GGBS up to H 1000mm and increasingly polynomial thereafter.

Varying CEM1 kg causes a linearly proportional increase in T1.
Increasing PFA% causes a linearly proportional decrease in T1.
Increasing GGBS% causes a non linear decrease in T1 which is more pronounced as H increases.

Varying MT causes a linearly proportional change in T1 whatever the value of PT or other variations.

Method

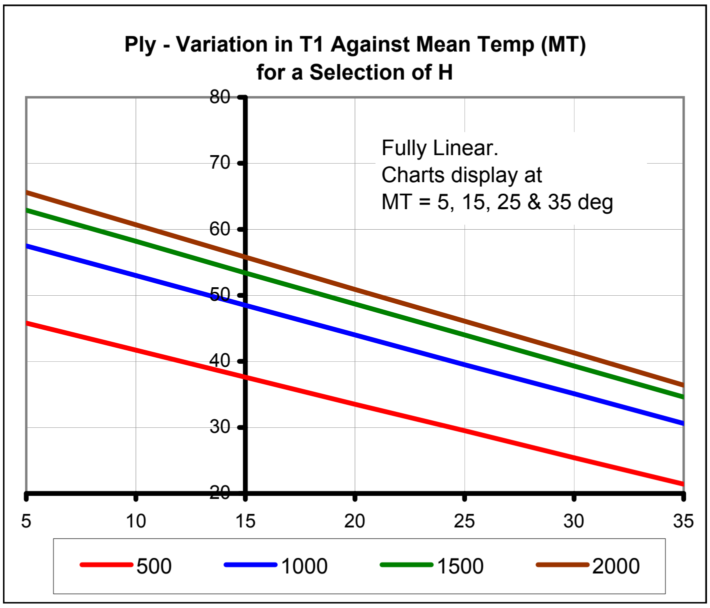
The HAC program uses a sophisticated Excel Lookup procedure coupled with interpolation and extrapolation of linearly varying data to add the variation effects to the control design values and derive a value of T1.
The GGBS% variation between PT20 and PT35 is taken as linear as this is suficiently accurate and slightly conservative.
The values are shown on composite charts which cover Ply and Steel formwork. The charts show:-

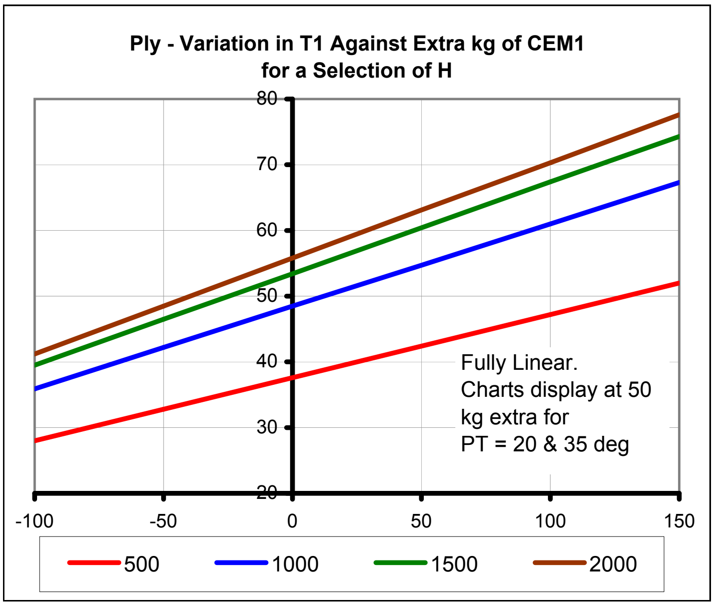
T1 variation due to Extra CEM1 kg between PT = 20 deg & 35 deg - use equiv kg value and interpolate or extrapolate.
T1 variation due to PFA% between PT = 20 deg & 35 deg - interpolate or extrapolate and factor % values as it is linear.
T1 variation due to GGBS between PT 20 deg lines and PT = 35 deg lines and % GGBS lines - interpolate or extrapolate.
T1 variation due to MT between 5 deg & 35 deg - interpolate in between MT = 5 & 15 deg and 15 & 35 deg as it is linear.
T1 variation due to PT between 5 deg & 35 deg - interpolate in between PT = 5, 10, 20, 25, 30 & 35 lines.
The T1 values for the Control parameters.
The T1 values for the Design which combines all of the above.

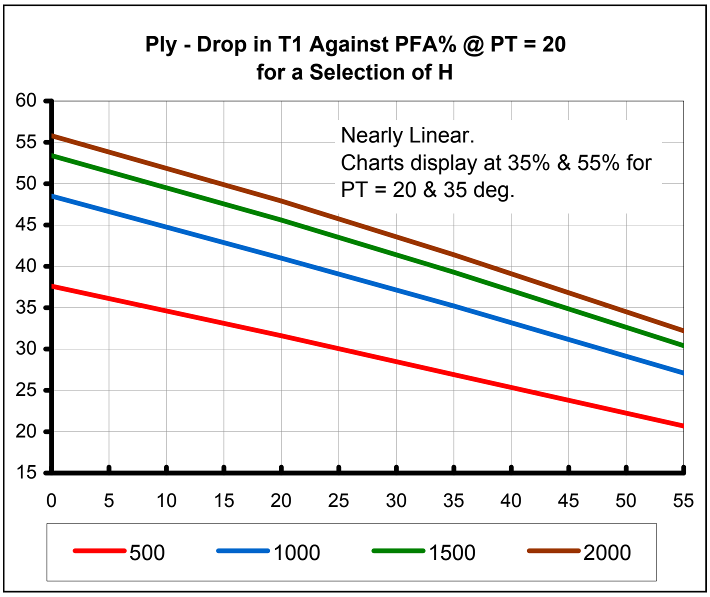
The charts can be used without a computer as all of the information and ranges of the varying data are shown.
The charts provide a graphical view of what is happening in the program and the program's Auto results are displayed with an example of how the variables are taken from the chart and deducted from the control value to give a similar value.
The author has tested numerous results against the CIRIA C660 values and believes the program is accurate enough to use.

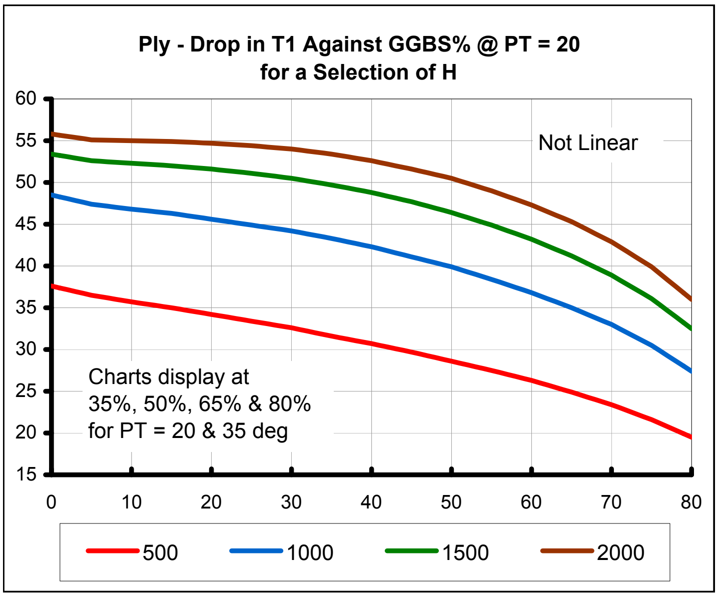
Variations in T1

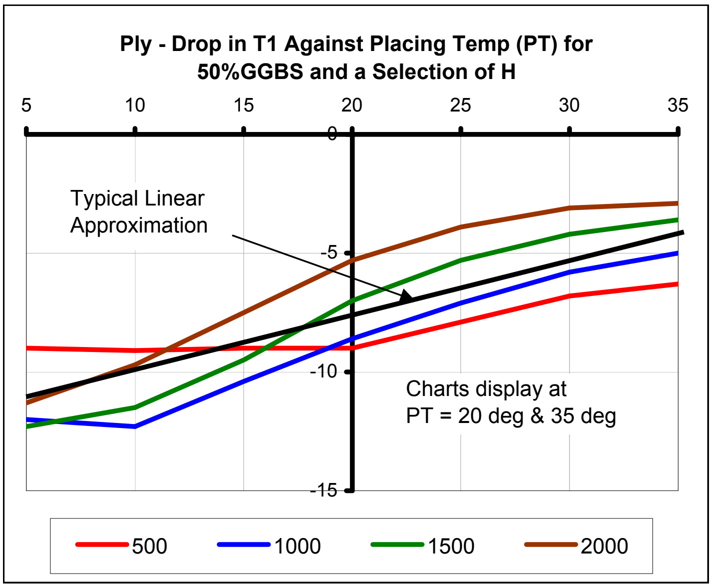
The following charts show the variations from the Control design as described in the previous page for a wall with ply fmwk

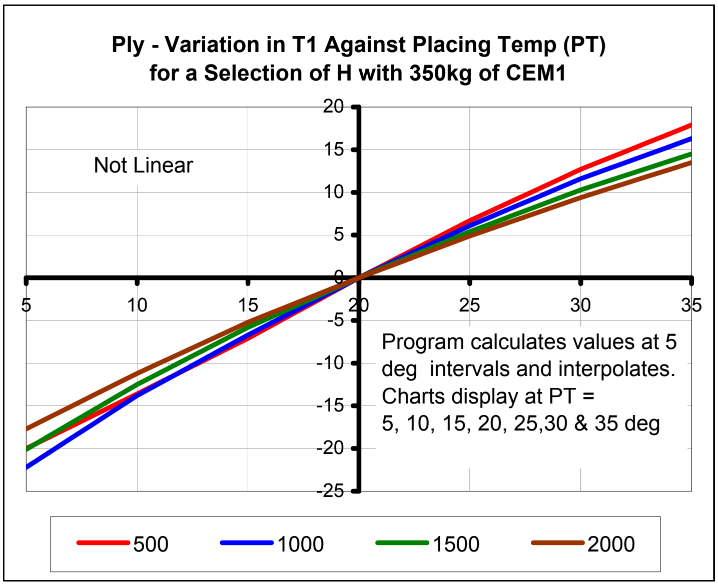












Calculation of T1 Temperature Drop Using the Following Charts

Manual Method

1 Select correct chart according to Ply or Steel formwork.

2 Print out the example before deleting any values. Note the values are displayed on the charts in bold colour.

3 Delete the H value in the input box. This will blank out all of the values.

4 Print out as many master sheets as you need.

5 Define H, Total kg, %GGBS or %PFA , Mean Temp (MT) & Placing Temp (PT).

Draw a vertical line against H on all 4 charts.

6 Calculate the equivalent Extra CEM1 kg and enter on sheet.

Equivalent Extra CEM1 kg = (Total - 350) x (1 - (0.0075 x %PFA) or (0.0025 x %GGBS))

7 Use Chart 1 to calculate the T1 effects of Extra CEM1 kg, %PFA or %GGBS at 20 deg PT (PT20).

Use the Equivalent CEM1 kg value and the Actual % of PFA or GGBS

Note that for %GGBS you will have to interpolate in between the 35%, 50%, 65% & 80% lines.

8 Repeat using Chart 2 for 35 deg PT (PT35).

9 Enter the above T1 variations into the spaces in the formulae to calculate the T1 according to the Design PT.

The formulae are arranged as follows.

T1 Variation = Variation at PT20 + ((Variation at PT35 - Variation at PT20) x (Design PT - 20) / 15)

10 Use Chart 3 to calculate T1 variations due to Design MT and Design PT

11 Sum up the T1 variations due to Extra CEM1 kg, %PFA or %GGBS, MT & PT to get total T1 Variation.

12 Use Chart 4 to calculate T1 for the Control parameters.

13 Design T1 value = Control T1 value + T1 Variation

Note The Excel charts are fully interactive and the blue values will adjust as the input parameters are changed.

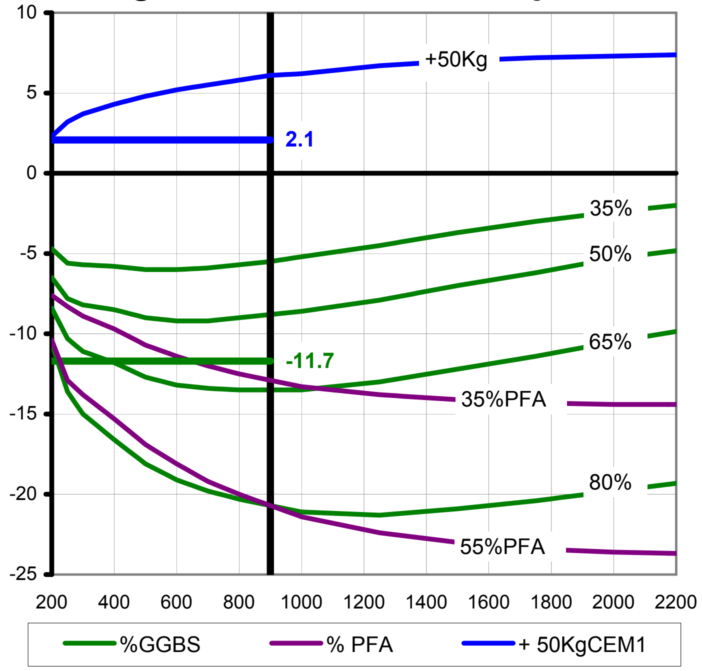
However, there may be occasions when it is not practical or possible to use Excel and in these conditions it is possible to derive good results manually.

It may appear complex and slow at first but it becomes faster with practice!

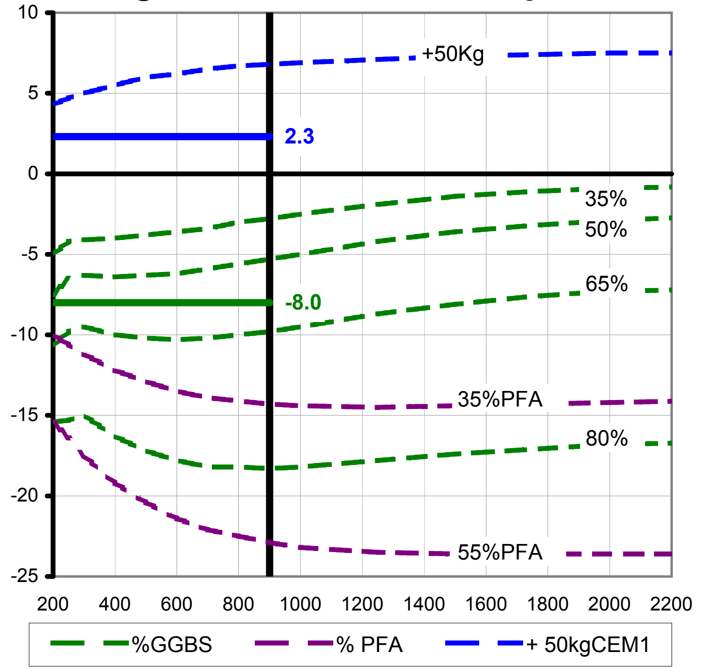
Ply Fmwk Wall T1 Drop for Changes in Mix, Placing Temp and Mean Temp **Ref C660 Adiabatic Prog**

Control = 350 kg CEM1, Mean T = 15º, Placing T = 20º **For Slabs See Steel Formwork Chart**

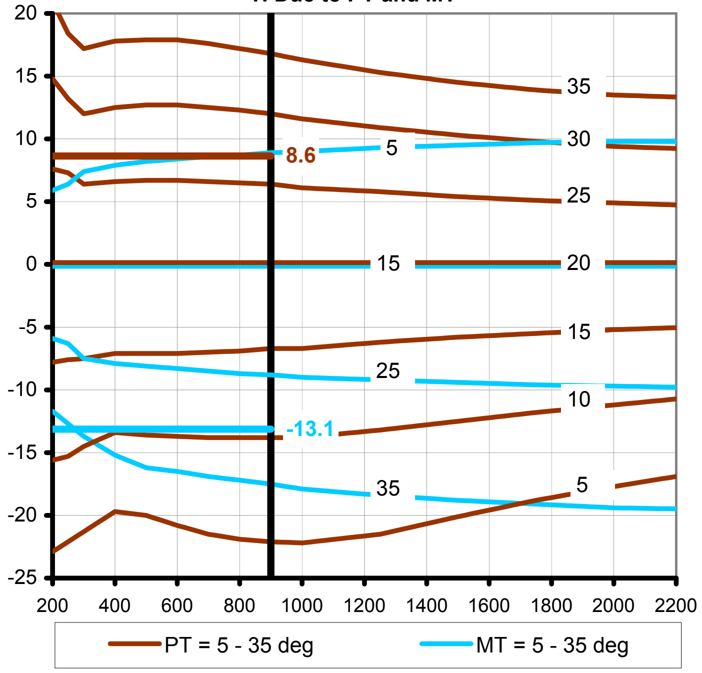
1 - Ply - Variation in Wall T1 Against Control and H @PT20 Due to GGBS or PFA and + 50KgCEM1



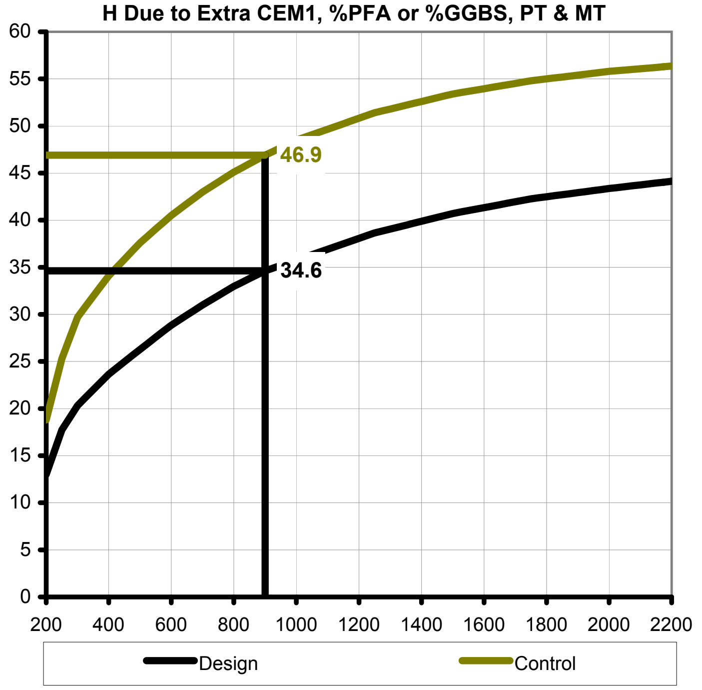
2 - Ply - Variation in Wall T1 Against Control and H @PT35 Due to GGBS or PFA and +50kgCEM1



3 - Ply - Variation in Wall T1 Against Control and H Due to PT and MT



4 - Ply - Variation in Wall T1 Against Control and H Due to Extra CEM1, %PFA or %GGBS, PT & MT



Design H 900 kg 370 %GGBS 60 %PFA 0 MTº 30 PTº 27 Auto T1 34.6 deg

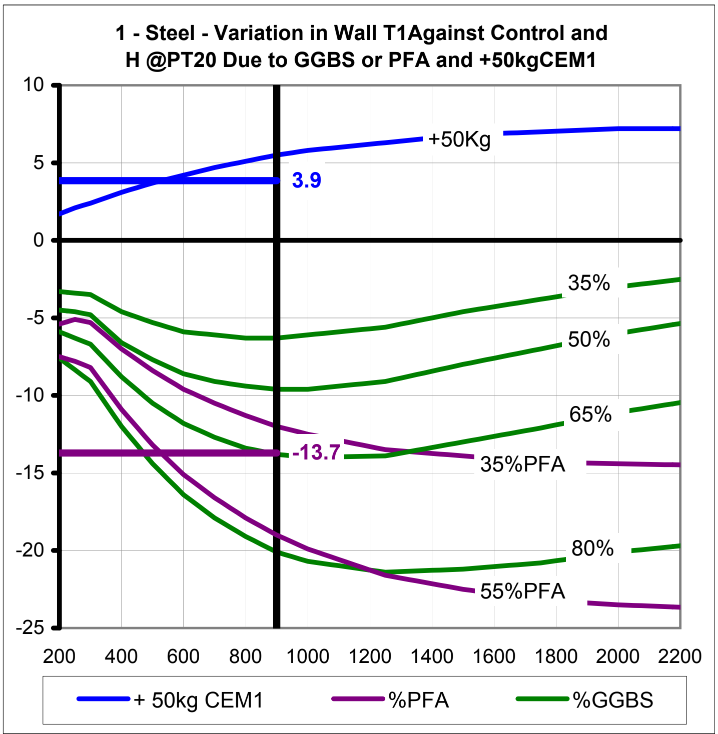
Equivalent Extra CEM1 kg = (370 - 350) x (1 - (0.0075 x %PFA) or (0.0025 x %GGBS)) = 17.0 kg

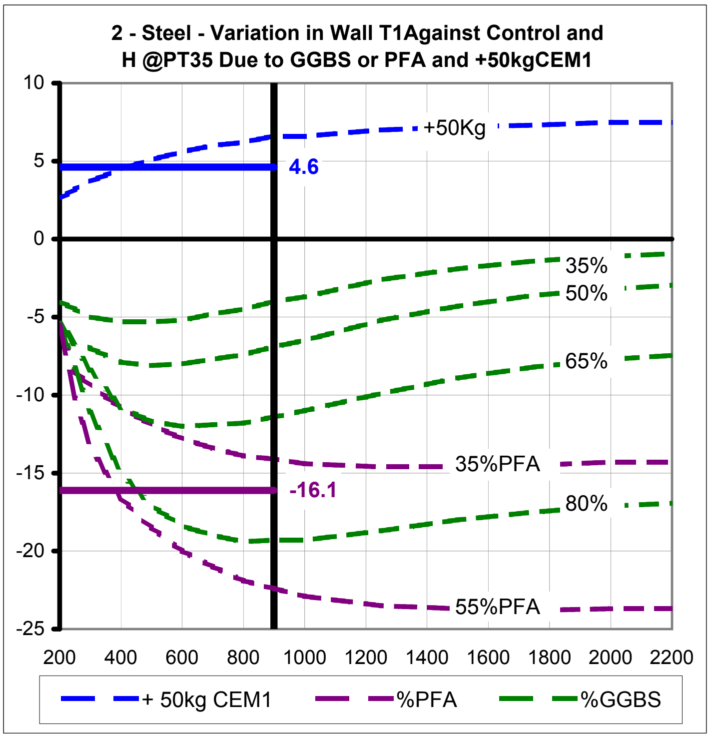
Extra kg	(2.1 + ((2.3 - 2.1) x (27 - 20) / 15))	=	2.2			
PFA %	(0.0 + ((0.0 - 0.0) x (27 - 20) / 15))	=	0.0	Control T1	46.9	deg
GGBS% =	-11.7 + ((-8.0 - -11.7) x (27 - 20) / 15)	=	-10.0	Variation	-12.3	deg
MT > or < 15 deg	Directly from Chart 3	=	-13.1	Design T1	34.6	deg
PT > or < 20 deg	Directly from Chart 3	=	8.6			
	Total T1 Variation	=	-12.3 deg			

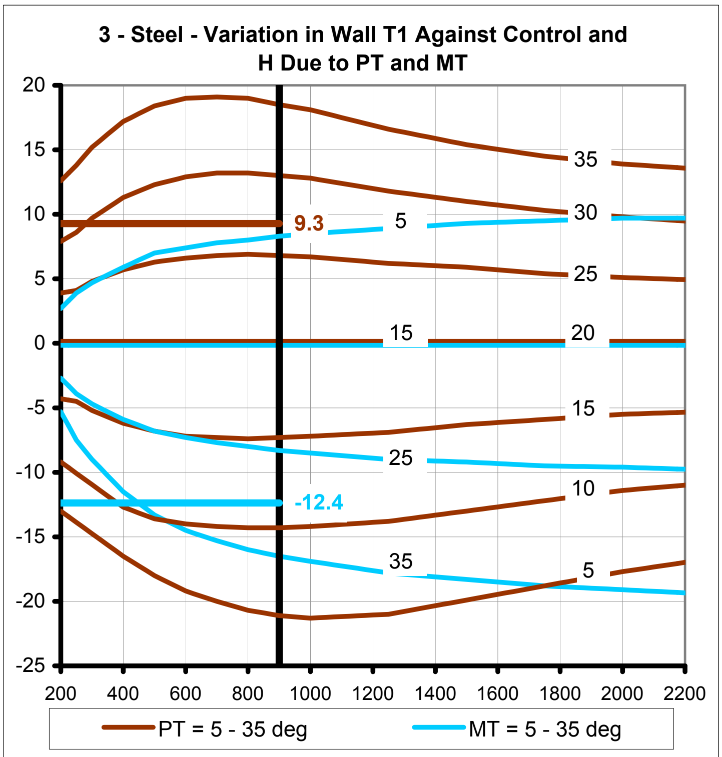
	EC2 INTERACTIVE DESIGN TOOL THERMAL, SHRINKAGE, RESTRAINT & CREEP HAC-PRO 1 - 5 - 2 REST 17	HAC Howes Atkinson Crowder LLP Copyright © 2009 HAC

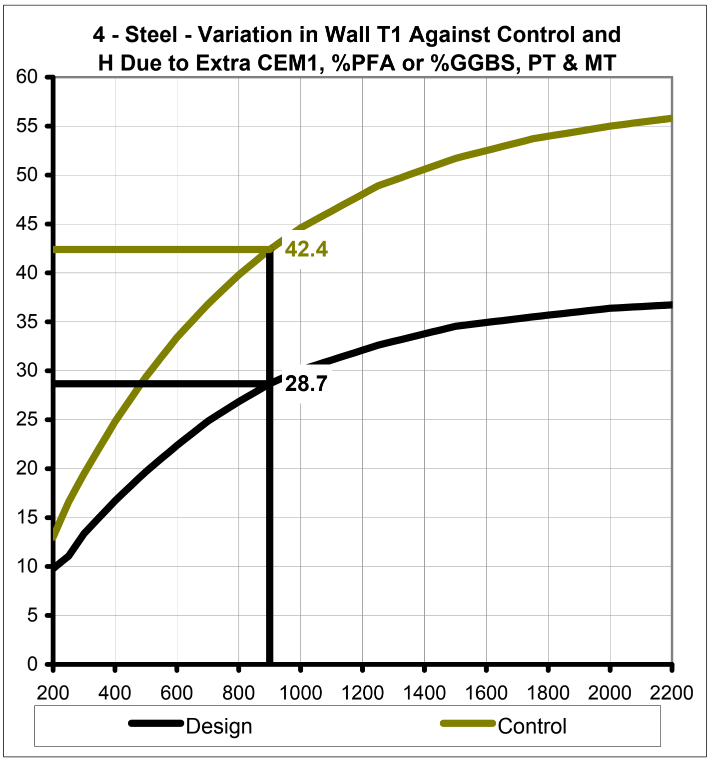
Steel Fmwk T1 Drop for Changes in Mix, Placing Temp and Mean Temp **Ref C660 Adiabatic Prog**

Control = 350 kg CEM1, Mean T = 15º, Placing T = 20º **For Slabs H = Depth x 1.3**









Design H 900 kg 400 %GGBS 0 %PFA 40 MTº 30 PTº 27 Auto T1 28.7 deg

Equivalent Extra CEM1 kg = (400 - 350) x (1 - (0.0075 x %PFA) or (0.0025 x %GGBS)) = 35.0 kg

Extra kg	(3.9	+ ((4.6	- 3.9	) x (27	- 20) / 15))	= 4.2		
PFA %	(-13.7	+ ((-16.1	- -13.7	) x (27	- 20) / 15))	= -14.8	Control T1	42.4 deg
GGBS% =	0.0	+ ((0.0	- 0.0	) x (27	- 20) / 15)	= 0.0	Variation	-13.7 deg
MT > or < 15 deg		Directly from Chart 3				= -12.4	Design T1	28.7 deg
PT > or < 20 deg		Directly from Chart 3				= 9.3		
			Total T1 Variation			= -13.7 deg		

Reinforcement Layout and Quantities

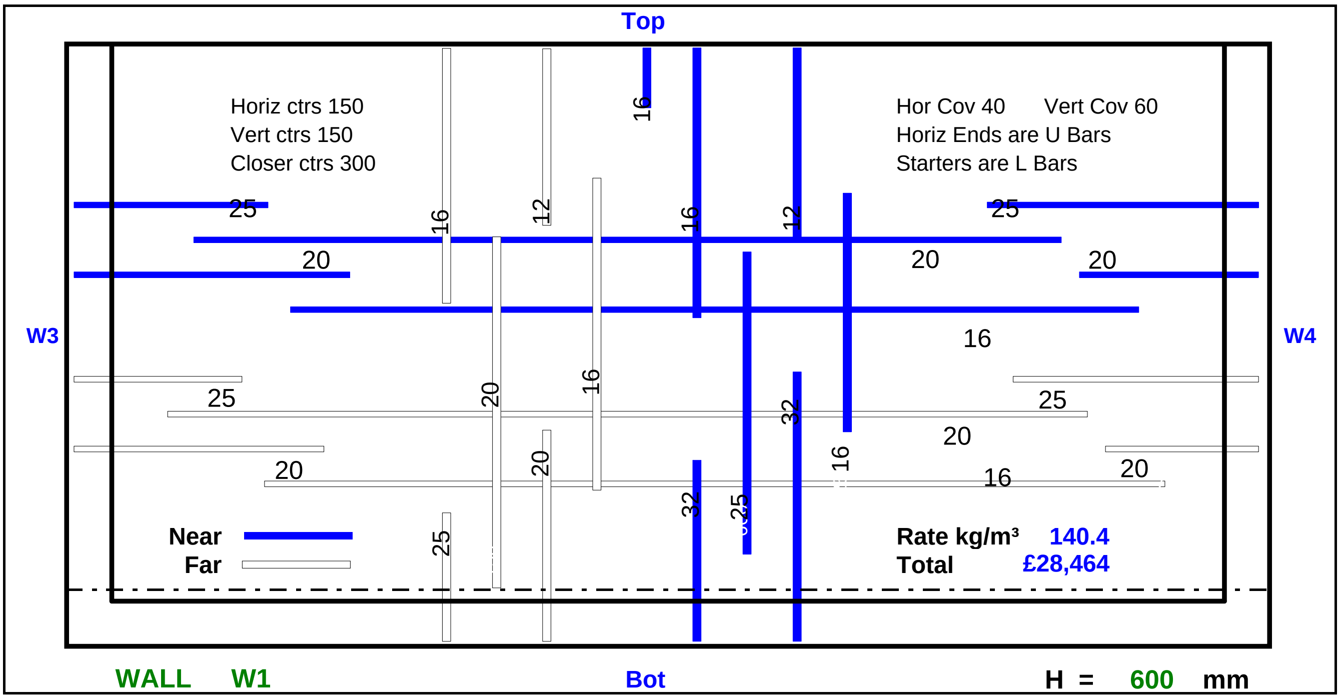
The following method allows the design reinforcement requirements to be displayed in a manner that is suitable for briefing for detailing. It also demonstrates the concepts of staggered and alternate bars. It is good practice to stagger bars to even out the bond transfer. The use of alternate diameters allows more economy and the diagram shows how the lap length is always based on the smaller bar dia. The sequence should be large dia followed by small dia to avoid too much bar size variation at laps.

The method also allows the cost of an element to be estimated. The current rates for the reinforcement, concrete and formwork are entered. The program calculates the tonnage of reinforcement allowing for laps based on the specified maximum bar lengths. This is a guide only, as reinforcement and concrete rates depend on the total project quantities and formwork rates depend on the method and amount of re-use.

PANEL 1 **Walls W1 & W2**

Key Data **Reinforcement** **Parameters and Data**

HOR Ctrs	150	W3		Span		W4		O/A		16000	Lap = Dia x	50	Horiz	Cov	40
								H	W3	600	Stag = Diax	65	H	W4	600
Near Face	Dia	25	20	20	16	25	20	Cov	W3	40	End Bars =	U	Cov	W4	40
								Near Gap		1050	Max Bar L	9000	Near Gap		1050
Far Face	Dia	25	20	20	16	25	20	Far Gap		700	Min Gap =	40	Far Gap		700
Vertical Top U Bar Closers Dia				16		Ctrs	300	Gap Denotes Bar Offset Distance From Face or Top							
VERT Ctrs	150	Bot		Span		Top		O/A		8000	Lap = Dia x	50	Vert	Cov	60
								H	Bot	600	Stag = Diax	65	H	Top	0
Near Face	Dia	32	32	25	16	16	12	Cov	Bot	40	Starter Bars	L	Cov	Top	50
								Near Gap		600	Max Bar L	5000	Near gap		2000
Far Face	Dia	25	20	20	16	16	12	Far Gap		150	Kicker =	150	Far Gap		1800



COSTING DATA										
Reinf Dia	10		12		16	20	25	32	40	
Tonne	0.0		0.2		2.3	3.5	2.5	2.3	0.0	
Reinft Wt	10.8	Tonne	@	£800	/ T =	£8,624	Steel £60	/ m²	Ply £40	/ m²
Conc Vol	77	m³	@	£125	/ m³ =	£9,600	Formwork	Ply		
Fmk Area	256	m²	@	£40	/ m² =	£10,240	Rate kg/m³ 140.4		Total	£28,464

Reinforcement Layout and Quantities Cont.

Cost of Structural Elements

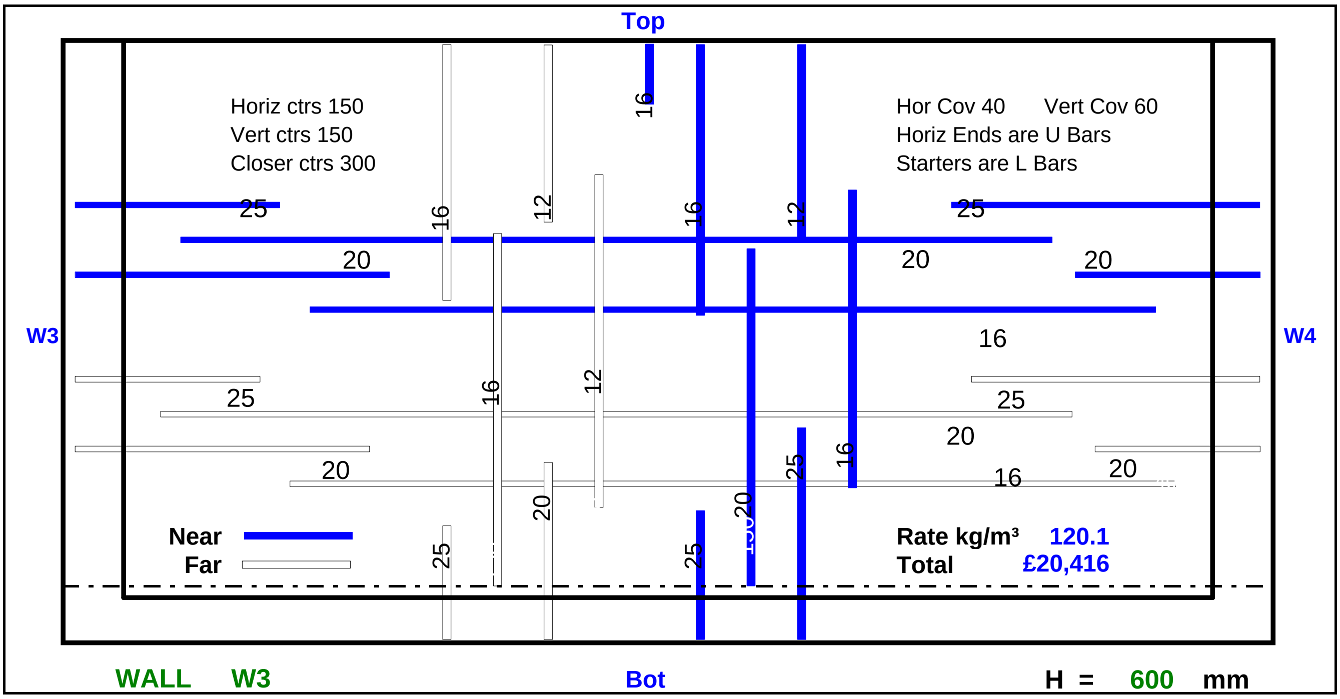
Generally, there will be 2 similar long panels, 2 similar short panels, a base slab and possibly a roof slab and columns.

		Reinf £	Conc £	Fmwk £	Total £
Wall 1		8,624	9,600	10,240	**28,464**
Wall 2		8,624	9,600	10,240	**28,464**
Wall 3		5,536	7,200	7,680	**20,416**
Wall 4		5,536	7,200	7,680	**20,416**
Base Slab		17,496	14,400	1,344	**33,240**
Columns	N/A	0	0	0	**0**
Roof Slab	N/A	0	0	0	**0**
		45,816	**48,000**	**37,184**	**131,000**

PANEL 2 **Walls W3 & W4**

Key Data **Reinforcement** **Parameters and Data**

HOR	**Ctrs**	**150**	**W3**		**Span**		**W4**		**O/A**	12000	**Lap = Dia x**	50	**Horiz Cov**	40
Near Face		**Dia**	**25**	**20**	**20**	**16**	**25**	**20**	**H W3**	600	**Stag = Diax**	65	**H W4**	600
									Cov W3	40	**End Bars =**	U	**Cov W4**	40
Far Face		**Dia**	**25**	**20**	**20**	**16**	**25**	**20**	**Near Gap**	500	**Max Bar L**	9000	**Near Gap**	500
									Far Gap	300	**Min Gap =**	40	**Far Gap**	300
Vertical Top U Bar Closers Dia					**16**		Ctrs	**300**	Gap Denotes Bar Offset Distance From Face or Top					
VERT	**Ctrs**	**150**	**Bot**		**Span**		**Top**		**O/A**	8000	**Lap = Dia x**	50	**Vert Cov**	60
Near Face		**Dia**	**25**	**25**	**20**	**16**	**16**	**12**	**H Bot**	600	**Stag = Diax**	65	**H Top**	0
									Cov Bot	40	**Starter Bars**	L	**Cov Top**	50
Far Face		**Dia**	**25**	**20**	**16**	**12**	**16**	**12**	**Near Gap**	150	**Max Bar L**	5000	**Near gap**	2000
									Far Gap	150	**Kicker =**	150	**Far Gap**	1800



COSTING DATA							
Reinf Dia	**10**	**12**	**16**	**20**	**25**	**32**	**40**
Tonne	0.1	0.3	1.7	2.6	2.2	0.0	0.0

Reinft Wt	6.9	Tonne	@	£800	/ T =	£5,536	**Steel**	£60	/ m²	**Ply**	£40	/ m²	
Conc Vol	58	m³	@	£125	/ m³ =	£7,200	**Formwork**	Ply					
Fmk Area	192	m²	@	£40	/ m² =	£7,680	**Rate kg/m³**	**120.1**		**Total**		**£20,416**	

Reinforcement Layout and Quantities Cont.

BASE SLAB

The bottom base slab reinforcement for a flat slab is often practically taken as the same across the slab. The top reinforcement must resist the wall moment and tension at the edges and peak moments over the piles or columns. A common way of detailing the support reinforcement is to provide a blanket top mat that will satisfy thermal and general support moments with extra bars bundled over the support over a width = pile spacing / 4.

Extra Bars Over Supports

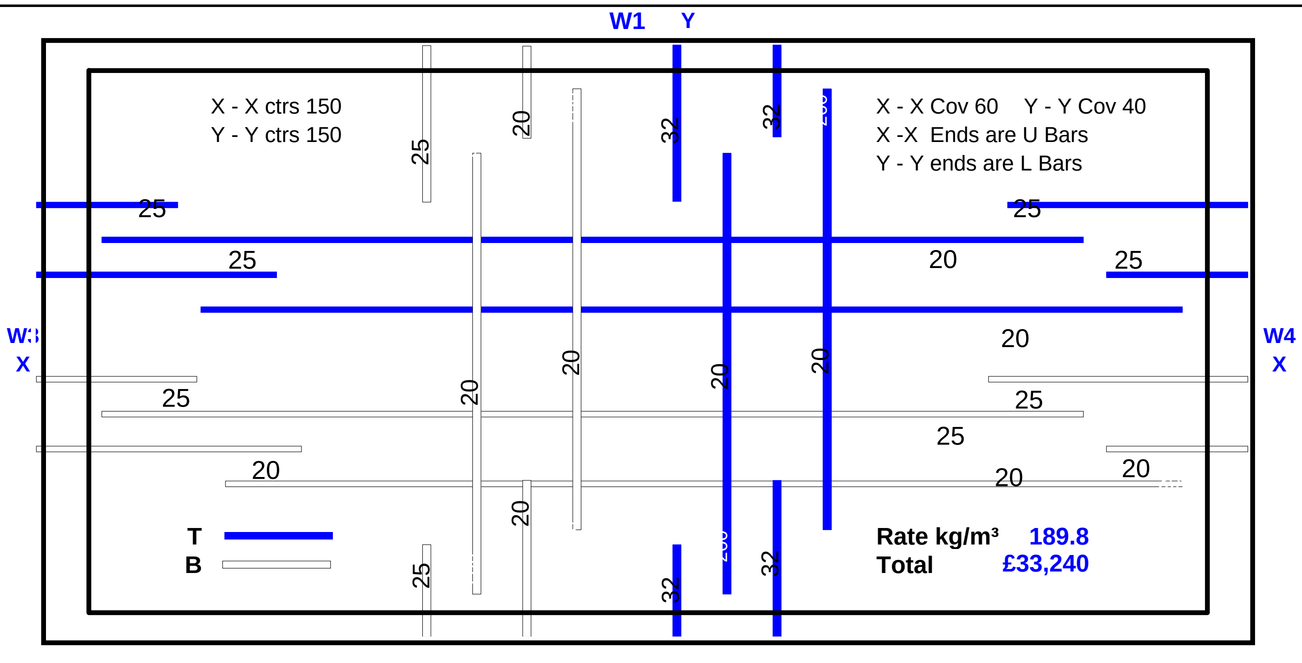
	Dia 1	Dia 2	Ctrs	L	Width	Tonne	
X - X Dir	25	25	150	4000	1200	0.138	
Y - Y Dir	25	25	150	4000	1200	0.138	0.276 T

Locations 6 Total Wt 1.654 T

Key Data **Reinforcement** **Parameters and Data**

X - X	Ctrs	150	W3		Span		W4	
Top		Dia	25	25	20	20	25	25
Bottom		Dia	25	20	25	20	25	20
Chairs Dia and Centres Each Way			20		Ctrs	1000		
Y - Y	Ctrs	150	W2		Span		W1	
Top		Dia	32	32	20	20	32	32
Bottom		Dia	25	20	20	20	25	20

O/A		16000	Lap = Dia x	50	X - X	Cov	60	
H	W3	600	Stag = Diax	65	H	W4	600	
Cov	W3	40	End Bars =	U	Cov	W4	40	
Top Gap		300	Max Bar L	9000	Top Gap		300	
Bot Gap		300	Min Gap =	40	Bot Gap		300	
Gap Denotes Bar Offset Distance From Face								
O/A		12000	Lap = Dia x	50	Y - Y	Cov	40	
H	W2	600	Stag = Diax	65	H	W1	600	
Cov	W2	40	End Bars =	L	Cov	W1	40	
Top Gap		300	Max Bar L	5000	Top Gap		300	
Bot Gap		300	Min Gap =	150	Bot Gap		300	



COSTING DATA								
Reinf Dia	10	12	16	20	25	32	40	Chairs & Supp
Tonne	0.0	0.0	0.0	10.2	5.7	3.8	0.0	2.2

Reinft Wt	21.9	Tonne	@	£800	/ T =	£17,496	Steel	£60	/ m²	Ply £40	/ m²
Conc Vol	115	m³	@	£125	/ m³ =	£14,400	Formwork	Grnd	&	Ply	Edges
Fmk Area	34	m²	@	£40	/ m² =	£1,344	Rate kg/m³	189.8		Total	£33,240

Reinforcement Layout and Quantities Cont.

ROOF SLAB

Extra Bars Over Supports

	Dia 1	Dia 2	Ctrs	L	Width	Tonne	
X - X Dir	16	16	150	4000	1200	0.056	
Y - Y Dir	16	16	150	4000	1200	0.056	0.113 T
Locations	6					Total Wt	0.677 T

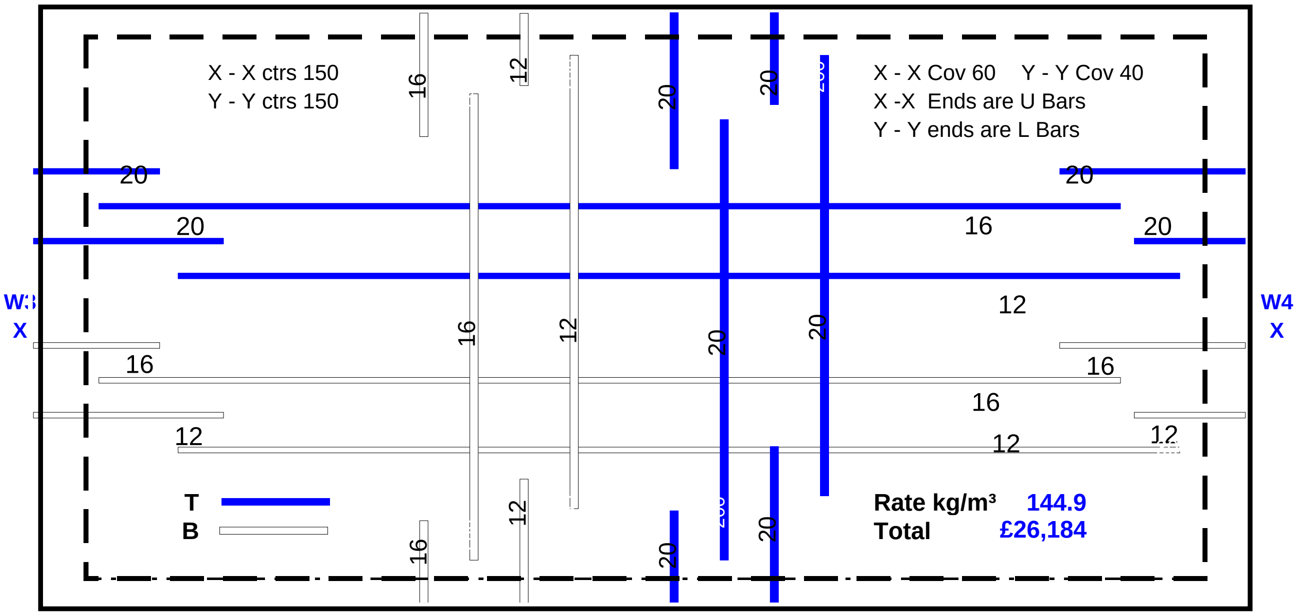
Columns

	Dia 1	Nr	Link	Ctrs	Ht	H	Reinf T	Conc m³	Fmk m²
Data	25	8	10	300	8000	500	0.402	2.0	16
Locations	6					Totals	2.414	12	96

Key Data **Reinforcement** **Parameters and Data**

X - X	Ctrs	150	W3		Span		W4		O/A	16000	Lap = Dia x	50	X - X	Cov	60
Top	Dia		20	20	16	12	20	20	H W3	600	Stag = Diax	65	H	W4	600
									Cov W3	40	End Bars =	U	Cov	W4	40
Bottom	Dia		16	12	16	12	16	12	Top Gap	300	Max Bar L	9000	Top Gap		300
									Bot Gap	300	Min Gap =	40	Bot Gap		300
Chairs Dia and Centres Each Way					20		Ctrs	1000	Gap Denotes Bar Offset Distance From Face						
Y - Y	Ctrs	150	W2		Span		W1		O/A	12000	Lap = Dia x	50	Y - Y	Cov	40
Top	Dia		20	20	20	20	20	20	H W2	600	Stag = Diax	65	H	W1	600
									Cov W2	40	End Bars =	L	Cov	W1	40
Bottom	Dia		16	12	16	12	16	12	Top Gap	300	Max Bar L	5000	Top Gap		300
									Bot Gap	300	Min Gap =	150	Bot Gap		300

W1 Y



SLAB Roof Slab W2 Y H = 400 mm

COSTING DATA								
Reinf Dia	10	12	16	20	25	32	40	Chairs & Supp
Tonne	0.3	1.7	3.2	4.7	0.0	0.0	0.0	1.2

Reinft Wt	11.1	Tonne	@	£800	/ T =	£8,904	Steel	£60	/ m²	Ply	£40	/ m²
Conc Vol	77	m³	@	£125	/ m³ =	£9,600	Formwork	Ply				
Fmk Area	192	m²	@	£40	/ m² =	£7,680	Rate kg/m³	144.9		Total		£26,184

Typical BS & EC2 0.2mm Crack Width Service Moment Capacity Curves

EC2 gives a higher relative capacity as the moment increases and the section depth reduces and the cover increases

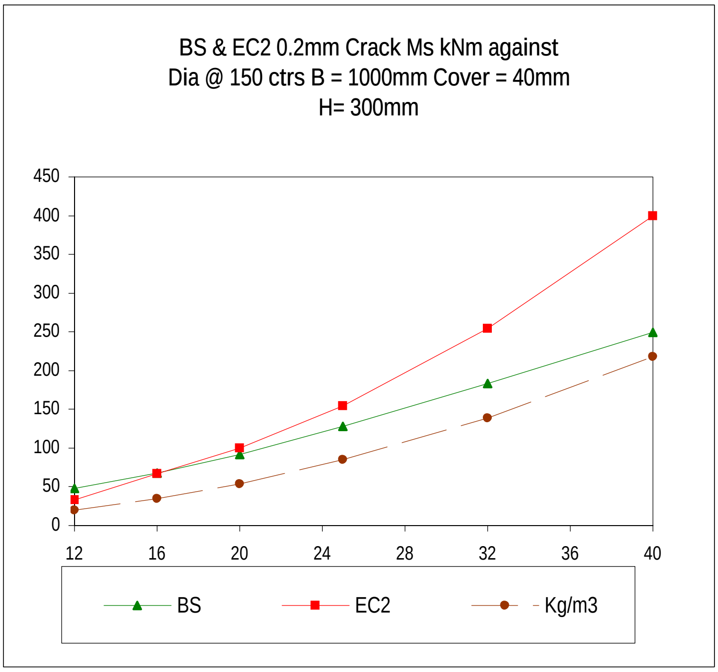
B	1000	Cov	40	ctrs	150	fcu	40	fck	32	CR	1.5

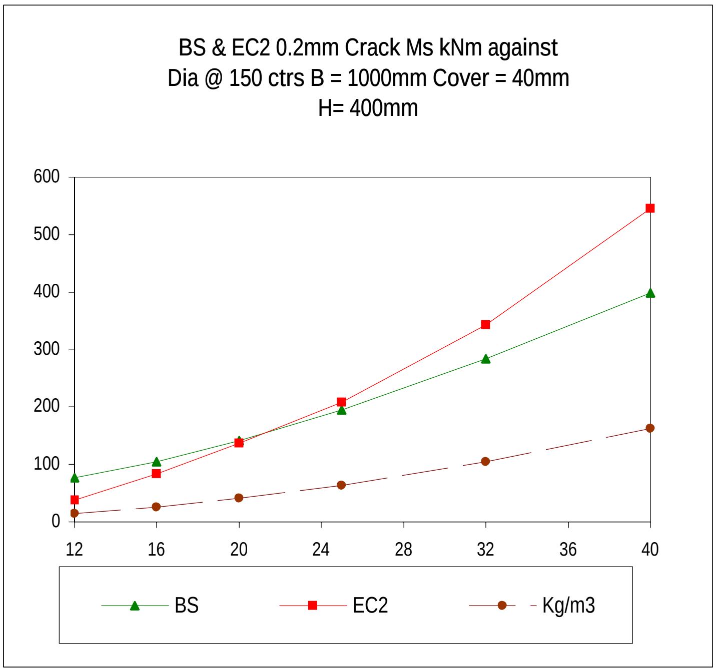
	H						
Dia	300	12	16	20	25	32	40
M kNm BS		48	68	92	128	183	249
M kNm EC2		33	67	100	154	254	400
Kg / m3		20	35	54	85	139	218

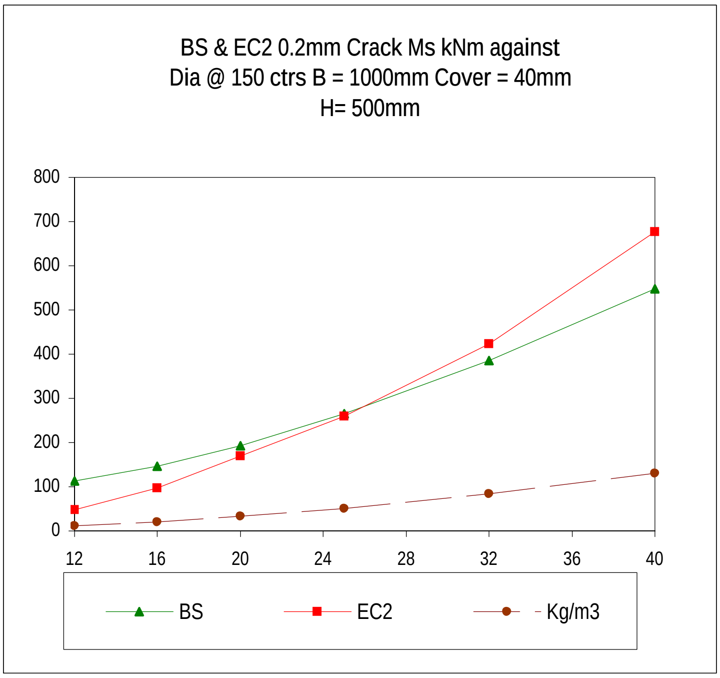
	H						
Dia	400	12	16	20	25	32	40
M kNm BS		77	105	141	195	284	398
M kNm EC2		38	84	137	208	343	545
Kg / m3		15	26	41	64	105	163

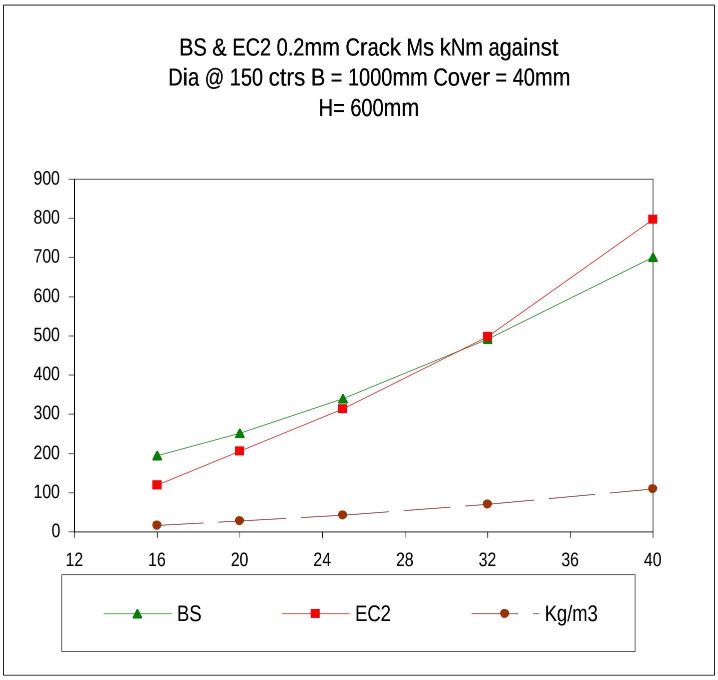
	H						
Dia	500	12	16	20	25	32	40
M kNm BS		113	147	193	265	385	548
M kNm EC2		48	97	170	259	423	677
Kg / m3		12	21	33	51	84	131

	H						
Dia	600	16	16	20	25	32	40
M kNm BS		195	195	251	339	491	700
M kNm EC2		120	120	205	313	499	797
Kg / m3		17	17	27	43	70	109









	EC2 DESIGN TOOL SERVICE MOMENT CAPACITY COMPARISON HAC-PRO 1 - 5 - 2 MC 2	Howes Atkinson Crowder LLP Copyright © 2009 HAC

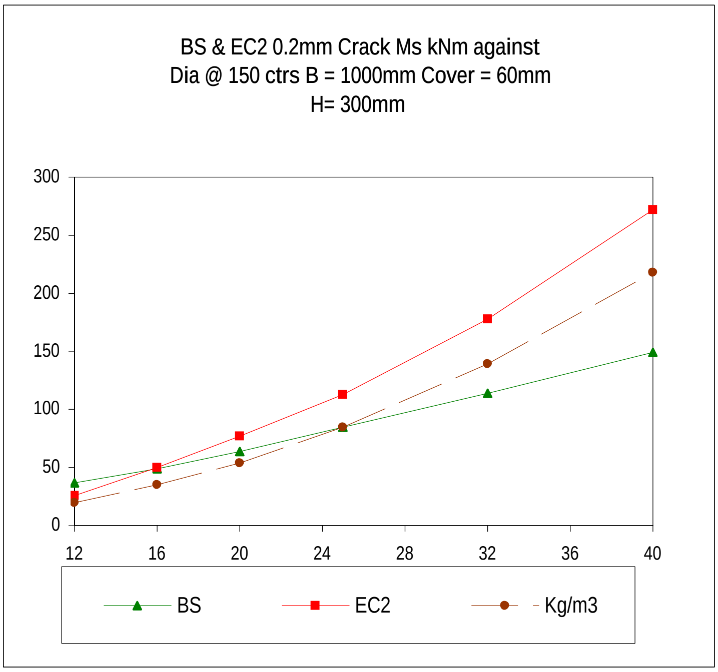
Typical BS & EC2 0.2mm Crack Width Service Moment Capacity Curves

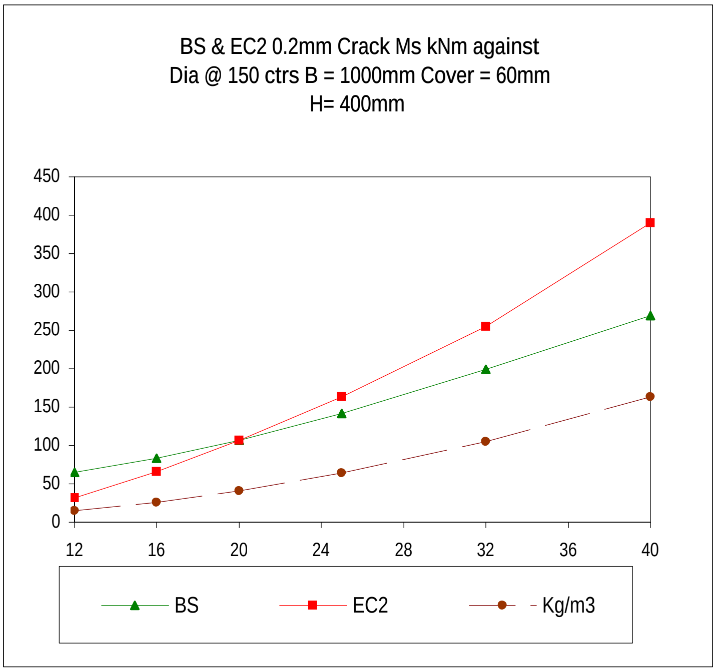
EC2 gives a higher relative capacity as the moment increases and the section depth reduces and the cover increases

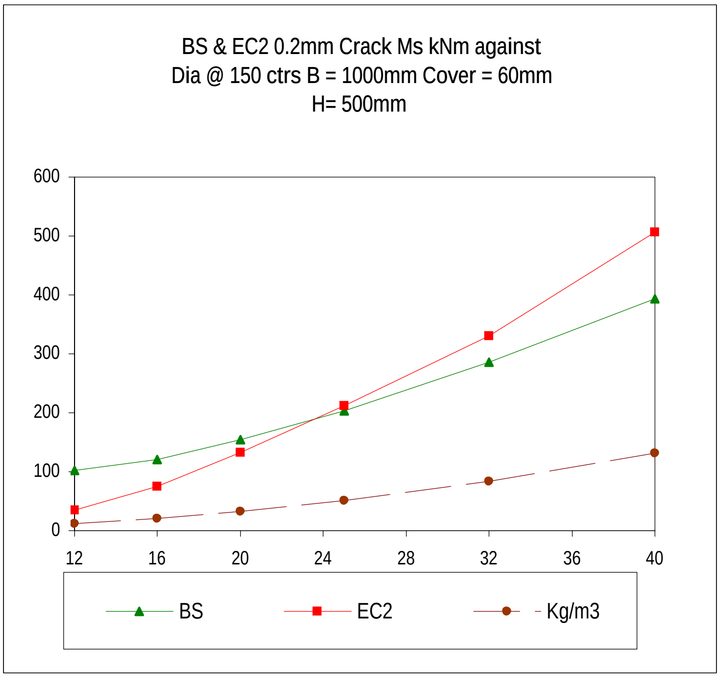
B	1000	Cov	60	ctrs	150	fcu	40	fck	32	CR	1.5

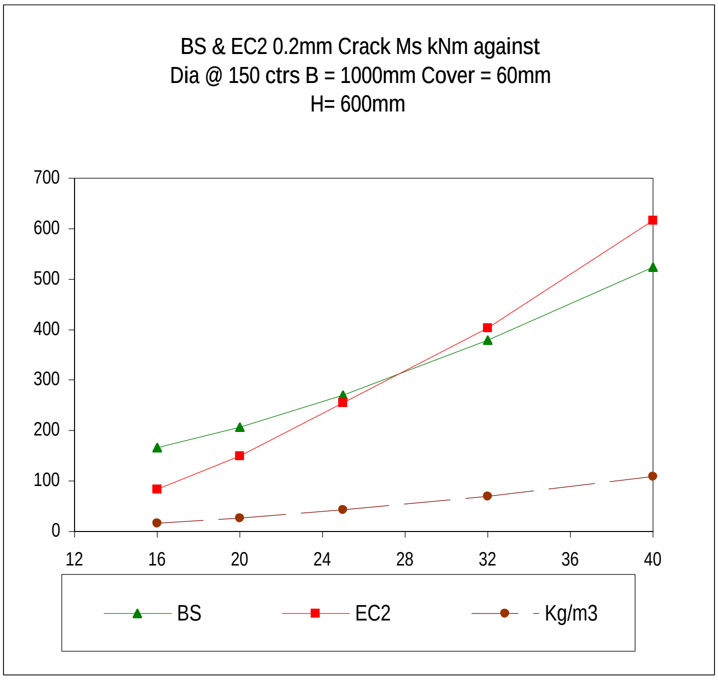
	H							H						
Dia	300	12	16	20	25	32	40	400	12	16	20	25	32	40
M kNm BS		37	49	64	85	114	149		65	83	107	142	199	269
M kNm EC2		26	50	77	113	178	272		32	66	107	163	255	390
Kg / m3		20	35	54	85	139	218		15	26	41	64	105	163

	H							H						
Dia	500	12	16	20	25	32	40	600	16	16	20	25	32	40
M kNm BS		102	121	154	203	286	393		166	166	207	270	379	524
M kNm EC2		35	75	133	212	330	506		84	84	150	255	403	616
Kg / m3		12	21	33	51	84	131		17	17	27	43	70	109









Fatigue

Concrete demonstrates a loss of strength which depends on the number of Cycles N and the ratio between the maximum and minimum values of the cyclical stress range.

N is defined in multiples of a million and the loss of strength for a given Min / Max stress ratio R relates linearly to Log N. This is presented in Wohler diagrams as below where Log 1 million = 6 and log 10 million is 7 and so on.

Ref. Fatigue of Normal Weight Concrete and Lightweight Concrete by EuroLightCon
http://www.sintef.no/static/bm/projects/eurolightcon/be3942r34.pdf

All codes give equations for a Wohler-diagram. For comparison of the codes the following values of parameters are used:

R $= 0.2$;

$f_{c;c}$ $= 45$ [MPa]

This results in the diagram of Figure 33.

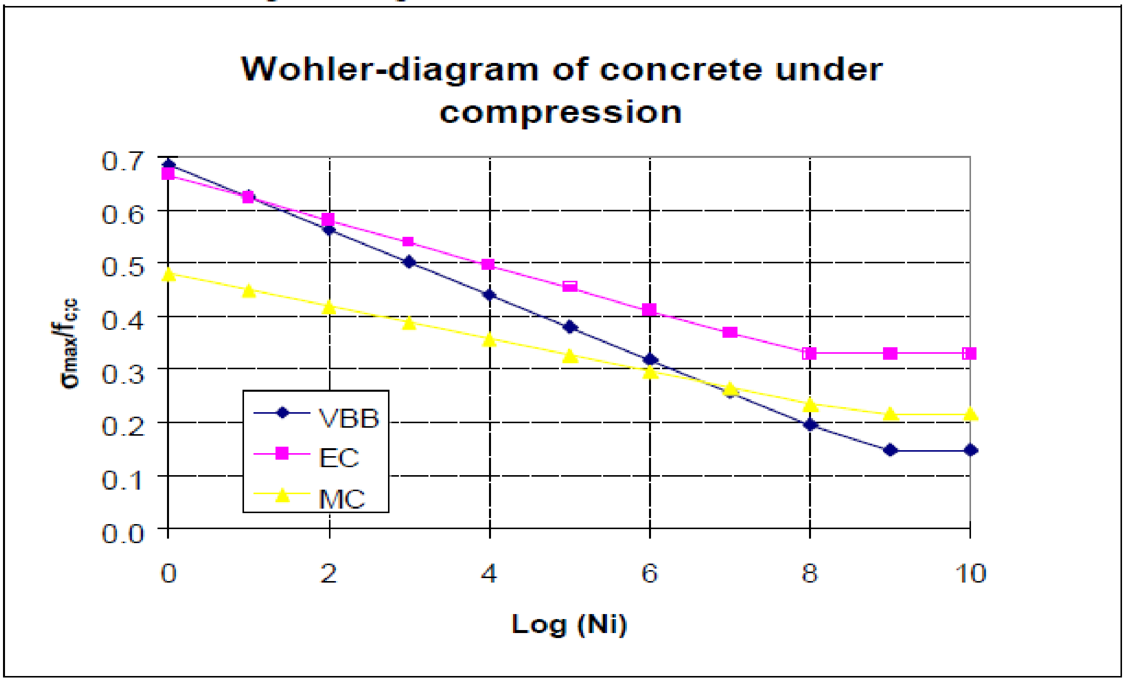


Figure 33: Wohler-diagram according of the codes for concrete under compression

By comparing the σmax / fc,c values at Log N =6 against the EC2 k1 value of 0.85 we can derive k1 for log N = 8 & 7

k1 at Log N = 8	=	0.85	x	0.33	/	0.42	=	0.67
k1 at Log N = 7	=	0.85	x	0.375	/	0.42	=	0.76

This is compared with a 2nd reference.

Ref. **Fracture and fatigue behaviour of high strength limestone concrete as compared to gravel concrete**

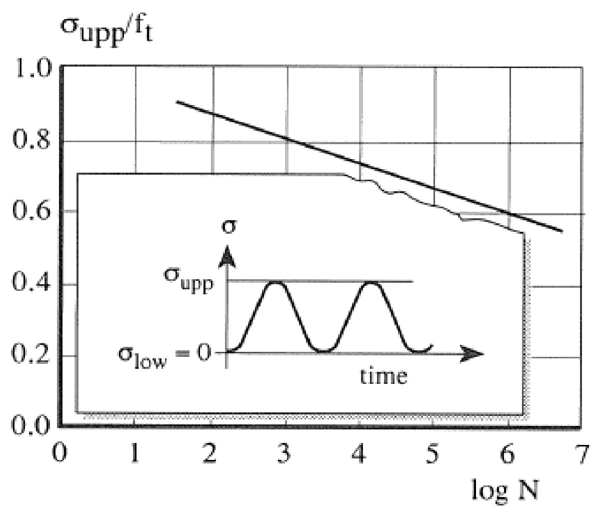
by **Hordijl, Wolsink, de Vries**
TNO Building & Research

By Extrapolating line

k1 at Log N = 7

= 0.85 x 0.535 / 0.6 = 0.76

Therefore a consistent value of k1 at N = 10 million is derived



	EC2 DESIGN TOOL **FATIGUE** HAC-PRO 1 - 5 - 2 FAT 2	**Howes Atkinson Crowder LLP** **Copyright © 2009 HAC**

Fatigue

The following sheets demonstrate the process used in the program

Ref EC2 part 1-1 Section 6.8
& Ref 20 by Hendy and Smith

Concrete in Compression

Normal αcc = 0.85 However as K1 is deemed to include for Long Term Effects αcc,fat = 1

Grade C **35** / 45 N Using the insitu strength at loading and setting (to) at 28 days

fcd - non fatigue = αcc fck / γm = 0.85 x **35** / 1.5 = **19.833** N/mm2

K1 at N = 1 Million Cycles = 0.85 National Annex Varies logarithmically to a
100 = 0.67 See Fat 1 Fatigue Limit at 100 Million
Design Value 10 = **0.76** Derived from above as per Wõhler diagrams

βcc (to) = exp (s (1 - (28 / to) ^ 0.5)) For Class N Cement s = **0.25**

= **1** Age at time of loading (to) = 28 Days

Strength Factor = 1 - (fck / 250) = 1 - (**35** / 250) = **0.86**

fcd, fat = k1 βcc (to) (αcc,fat / αcc) (1 - (fck / 250) fcd = **0.7689** x **19.833** = **15.251** N/mm2

Verification Methods

Ratio For Requ = 50 / 382 = **0.1309**

Equ 6.72 Ecd, max, equ + (Log N / 6) x 0.43 ((1 - Requ) ^ 0.5) < = 1

Ecd, max, equ = σcd max, equ / fcd,fat Where Log N / 6 x 0.43 = **0.5017**

Requ = (σcd min, equ / fcd,fat) / (σcd, max / fcd,fat) = σcd min / σcd, max

Ecd, max, equ = 1 - **0.5017** x ((1 - Requ) ^ 0.5)

Ecd, max, equ = 1 - **0.5017** x ((1 - 0.1309) ^ 0.5) = **0.5323**

σcd max, equ = **0.5323** fcd,fat = **0.5323** x **15.251** = **8.1182** N/mm2

σcd max, equ / fcd = **8.1182** / **19.833** = **0.4093** Fatigue Factor

fck, fat = **0.4093** x **35** = **14** N/mm2 fcu, fat = **0.4093** x **45** = **18** N/mm2

Equ 6.77 σc, max / fcd,fat < = 1 + 0.45 x (σc, min / fcd, fat) < = 0.9

σc, max < = 0.5 fcd, fat + (0.45 x σc, min) < = 0.9 fcd, fat

σc, max < = 0.5 fcd,fat + 0.45 x R,equ x σc,max < = 0.9 fcd, fat

σc, max < = fcd,fat x 0.5 / (1 - (0.45 x R,equ)) < = 0.9 fcd, fat

σc, max < = **15.251** x **0.5313** **8.1026** N/mm2

σcd max, equ / fcd = **8.1026** / **19.833** = **0.4085** Fatigue Factor

fck, fat = **0.4085** x **35** = **14** N/mm2 fcu, fat = **0.4085** x **45** = **18** N/mm2

Note Equ 6.72 factor for LogN > 6 taken from EC2 part 2: Concrete Bridges. For LogN =7, value matches equ 6.77
Equ 6.77 does not include an N term and from above it appears it is based on 10 million cycles.

Concrete in Shear

The EC2 shear design approach differs from BS8110 in that it utilises a strut and tie system when links are required.

Therefore, for EC2 designs utilising a compressive strut, the compression values from Equ 6.7.7 may be used but with the additional strength reduction factor v for concrete cracked in shear as per 6.2 (6).

Where v = 0.6 x (1 - (fck / 250)) = **0.516**

For members not requiring shear reinforcement, the EC2 method is similar to the BS8110 method, see example below.

Equ 6.78 VED,max / VRd,c < = 0.5 + 0.45 x (VED,min / VRd,c) < = 0.9

EC2 VRd,c = (CRd,c k (100 ρ1 fck) ^ (0.333)) bw d / 1000 kN Ignoring Axial Load

& VRd,c min = (vmin) bw d / 1000 kN

CRd,c = 0.18 / γm = 0.18 / 1.5 = **0.12**

vmin = 0.035 x k ^ (3/ 2) x fck ^ (1/ 2) Appliies where Asl is very low or zero

For d = **540** mm bw = **1000** mm Asl = **3272** mm2

k = Depth Factor = 1 + ((200 / d) ^ 0.5)) <= 2 = **1.6086**

100 ρ1 = 100 x As l / (bw d) = 100 x **3272** / (**1000** x **540**) = **0.6059**

VRd,c = (0.12 x **1.6086** x (**0.6059** x **35**) ^ 0.3333) x 1000 x **540** / 1000 = **288.52** kN

VRd,c min = 0.035 x (**1.6086** ^ 1.5) x (**35** ^ 0.5) x 1000 x **540** / 1000 = **228.12** kN

BS8110 Vc = ((0.79 / 1.25) (400 / d) ^ 0.25) ((100 ρ1 fcu / 25) ^ 0.333) bw d / 1000 kN

= (**0.632** x **0.9277** x (**0.6059** x **1.6**) ^ 0.3333) x 1000 x **540** / 1000 = **313.36** kN

BS gives an equivalent capacity to EC2 fcu max = 40 N /mm2

Both methods include ρ1 and fck or fcu terms ^ 0.333

Where Vequ = VED, min / VED, max = **50** / **382** = **0.1309** > = 0

VED,max < = VRd,c x 0.5 + (0.45 x VED,min) < = 0.9 VRd,c

VED,max < = VRd,c x 0.5 + (0.45 x V,equ x VED,max) < = 0.9 VRd,c

VED,max < = VRd,c x 0.5 / (1 - (0.45 x V,equ)) < = 0.9 VRd,c

VED,max < = VRd,c x 0.5 / (1 - (0.45 x **0.1309**)) = VRd,c x **0.5313**

Shear Fatigue Factor = **0.5313** VRd,c = **153.29** kN Vc = **166.48** kN

The EC2 Design Tool spreadsheet uses fck,fat and fcu,fat values throughout. So, in order to give the correct values for shear the spreadsheet program needs to multiply the concrete shear capacity components by the following factors

EC2	VRd,c	Shear Fatigue Factor	x	(Fck / Fck, fat) ^ 0.333	=	**0.7155**
	VRd,c min	Shear Fatigue Factor	x	(Fck / Fck, fat) ^ 0.5	=	**0.8304**
BS	Vc	Shear Fatigue Factor	x	(Fcu / Fcu, fat) ^ 0.333	=	**0.688**

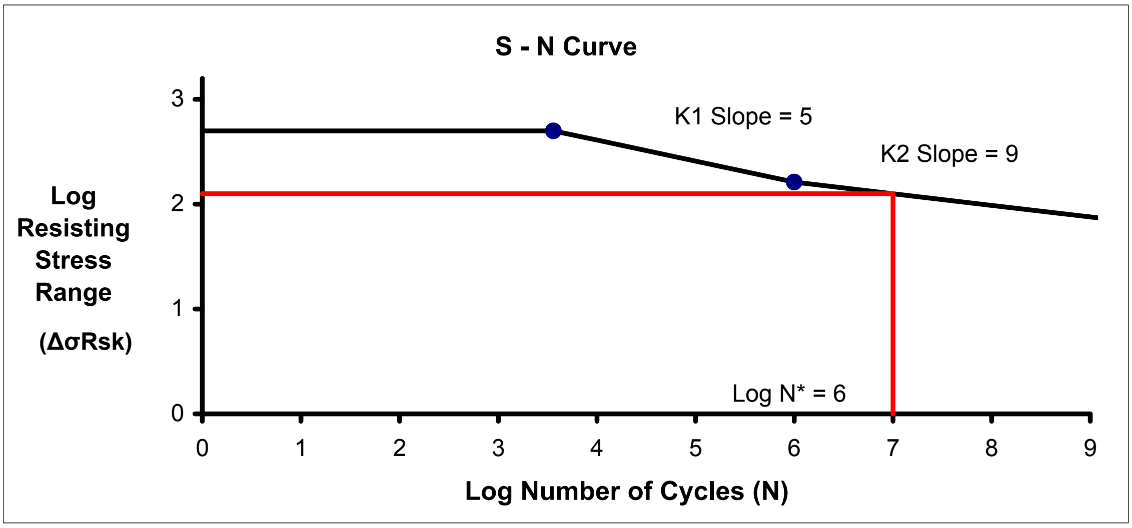
EC2 DESIGN TOOL

FATIGUE

HAC-PRO 1 - 5 - 2 FAT 4

Reinforcement

The damage caused by a single stress amplitude Δσ is determined from the S - N curves in EC2 Fig 6.30 as below
Values are based on yield and do not include γs,fat, which must be applied at the end of the process.



Straight Bars N* = 1 Million Cycles & ΔσRsk = 162.5 N/mm2

Bent - mandrel = 7 φ N* = 1 Million Cycles & ΔσRsk = 0.532 x 162.5 = 86.5 N/mm2

Below N*, the graph relates to the slope where Log ΔσRsk = k1 Log N = 5 Log N
Beyond N*, the graph relates to the slope where Log ΔσRsk = k2 Log N = 9 Log N

At Log (1 Million) = 6 Log (ΔσRsk) = 2.2109

At Log (10 Million) = 7 Log (ΔσRsk) = 2.2109 - 1 / 9 = 2.100

10 ^ 2.0997423 = 125.82 N/mm2 Reinf yield stress fyk = 500 N/mm2

The fyd value of resisting stress range of the cyclical loading = 125.82 / γm = 1.15 = 109.41 N/mm2

R = Min Action / Max Action = 50 / 382 = 0.1309

Max fyd value = 500 / γs,fat = 1.15 = 434.78 N/mm2 R at Max Stress = 0.7484

Straight Bars Max Stress = 109.41 / (1 - R) = 126 N/mm2 Factor = 0.2895

Bent Bars Max Stress = 0.532 x 125.88 = 67 N/mm2 Factor = 0.154