R.C. Beam Design to ACI 318
User Manual

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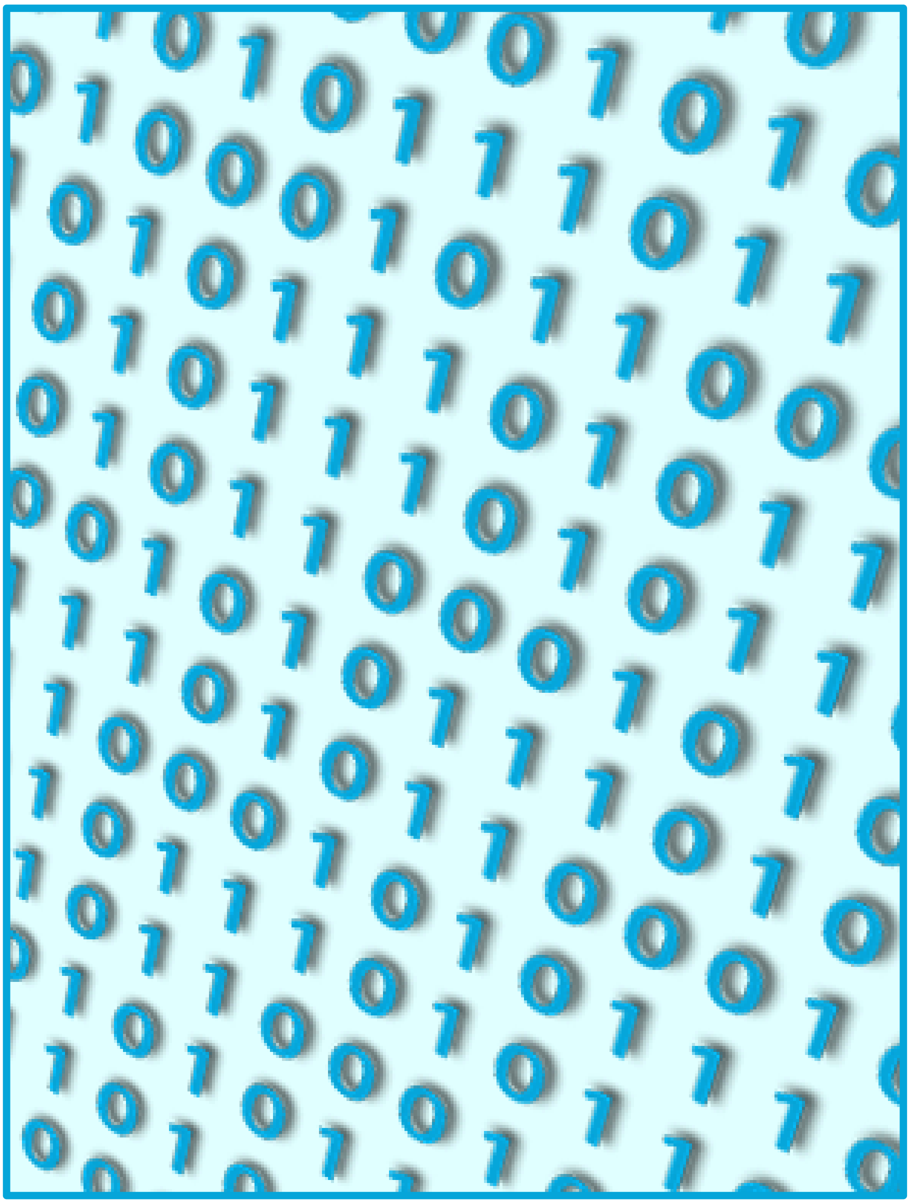

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1 Introduction

This Excel spreadsheet has been written to facilitate the detailed design of singly reinforced rectangular concrete beams, subject to co-existent or separate shear force and bending moments, with a single layer of reinforcement in accordance with the Structural Concrete Building Code ACI 318M-11. It may also be used, with engineering judgement, for the design of reinforced concrete beams with multiple layers of tensile reinforcement and reinforced concrete slabs.

By inputting the design load effects, concrete outline and reinforcement details for any given section the user is presented with the design moment and shear capacity together with a clear alert should either capacity be exceeded. Details of the concrete and reinforcement stresses and strains are also provided together with relevant compliance criteria in order that the results may be more easily understood and verified by the user, or assist with a more comprehensive analysis.

The worksheet has been arranged such that it generally represents the logical flow of a manual calculation, with design references listed in the left margin, and will fill a single A4 sheet when printed at 100%. All cells that do not require input have been protected in order to prevent accidental changes.

It is expected that the user has a good understanding of reinforced concrete design and the appropriate design assumptions, general principles and requirements expressed in ACI 318M-11, and accepts full responsibility for using this spreadsheet.

2 Non Technical Data Input

2.1 Calculation Sheet Header

The header sheet layout as shown (Fig 2-1) below is drawn from a typical calculation pad layout, with the company logo in the top right hand corner. The current web-site reference may be deleted and replaced with the user's preference.

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project:	page	of
section:	file/ref no:	
designed:	date:	
checked:	date:	

Fig 2-1; Header Layout

The remaining elements allow entry of specific details such as project title, structure or section, file reference and design and checking engineer's name etc. These may be entered in the spreadsheet or hand written on the printed sheet.

2.2 Calculation Sheet Body

The non technical data cells which may be edited in the remainder of the worksheet are limited to those to the right of the "BEAM NUMBER" text where a suitable reference may be added, and those section numbers currently shown as 1.0 to 1.6.

3 Calculation Data

3.1 General

All calculation data cells that require user input have been provided with a pale green background for clear identification. The input data comprises the design bending moment and coexistent shear force; concrete strength, density factor, beam height, width and reinforcement cover; reinforcement strength, elastic modulus, tensile reinforcement diameter and quantity; vertical shear reinforcement diameter quantity and spacing; and shear strength reduction factor.

3.2 Design Load Effects

The design bending moment and co-existent shear force acting on the beam section resulting from the application of load factors specified in ACI 318M-11 chapter 9.2 should be entered in the appropriate cells as shown below (Fig 3-1). The required units are specified adjacent to the input cells.

Factored Design Load Effects			
Bending Moment	M_u =	350	kNm
Shear Force	V_u =	450	kN

Fig 3-1; Factored Design Load Effects

3.3 Material Properties

The concrete strength and density factor should be entered here in accordance with ACI 318M-11 chapters 4.1.1 and 8.6.1 respectively (Fig 3-2).

Material Properties				
Concrete:	Strength	f'_c =	35	N/mm^2
	Density	λ =	1	
	Max Strain	ε_{cu} =	0.003	
	Modulus	E_c =	27806	N/mm^2
	Block factor	β_1 =	0.8	
Rebar:	Strength	f_y =	420	N/mm^2
	Link	f_{yt} =	420	N/mm^2
	Modulus	E_s =	200000	N/mm^2

Fig 3-2; Material Properties

It should be noted that the density factor should generally be left as 1.0 given that the spreadsheet assumes normal weight (2400kg/m^3) concrete. The maximum usable strain at the extreme concrete compression fibre is specified in the spreadsheet as 0.003, and the modulus of elasticity is calculated assuming normal weight concrete in accordance with ACI 318M-11 chapters 10.2.3. and 8.5.1 respectively.

Main tension and vertical shear reinforcement yield strength and modulus of elasticity should be provided by the user in accordance with ACI 318M-11 chapters 3.5.3. and 8.5.2 respectively. The same modulus of elasticity is assumed for both the shear and main tension reinforcement.

3.4 Geometry

In this section the user provides details of the beam height, width and concrete cover to reinforcement. The latter depends on class of structural member and reinforcement detail, and should be measured from the concrete surface to the outermost surface of the steel, whether this be main reinforcement or enclosing stirrups etc., in accordance with ACI 318M-11 chapter 7.7. The quantity of reinforcement is specified by providing the bar diameter and number of bars for both main tension and vertical shear link (stirrup) reinforcement. In the case of shear link the number of bars specifies the number of links (two vertical legs) within spacing (*s*). This proposed spacing of the shear reinforcement links should also be provided.

Geometry										
Concrete:	Height	h =	600	mm		Width	b =	300	mm	
	Cover	c_c =	50	mm						
Main rebar:	Dia.	d_b =	25	mm		No	n =	5	no.	
Vertical link:	Dia.	d_b =	12	mm		No	n =	1	no.	
	Spacing	s =	125	mm						
		s_{max} =	131	mm	O.K.					
Effective depth		d =	525.5	mm						
Tension steel area reqd:		$A_{s\,reqd}$ =	1980	mm^2						
Tension steel area provd:		A_s =	2454	mm^2			$A_{s\,min}$ =	555	mm^2	O.K.
Tension steel ratio		ρ =	0.0156							
Shear steel area:		A_{sv} =	226	mm^2			$A_{v\,min}$ =	46	mm^2	O.K.

Fig 3-3; Beam Geometry

It is suggested that the initial values entered for the beam height are based on the deflection limiting span to depth ratios specified in ACI 318M-11 table 9.5(a), with a width of approximately 50% of the height. Initial tension reinforcement may also be estimated by providing a value that is equal to or greater than the stated tension steel area required ($A_{s\ reqd}$) which is further explained below.

At this stage the user is provided with useful feed back in terms of beam effective depth and a check on maximum shear link spacing, areas of tension reinforcement provided, and required to satisfy the minimum requirements of ACI 318M-11 chapter 10.5; together with the area of shear reinforcement provided and required to satisfy the minimum requirements of ACI 318M-11 chapter 11.4.6.

The effective depth is a straight forward derivative of the beam height, diameters of the main tension and shear link reinforcement, and the concrete cover. The stated required tension steel area ($A_{s\ reqd}$) is derived from the following:

$$A_{s\ reqd} = \frac{M_u}{\varphi f_y z}$$

where: $$z = \left[1 - \frac{A_s}{1.7bd}\frac{f_y}{f_c'}\right] d$$

but; $$z > \left[1 - \frac{\beta_1}{2\left(1+\frac{0.004}{\varepsilon_C}\right)}\right] d$$

The latter condition ensures a minimum lever arm z by enforcing the minimum steel strain required by ACI 318M-11 chapter 10.3.5.

Although the required tension steel area is shown, there is no automated check against the provided tension steel area (A_s) as this has been made redundant by the more relevant comparison of design strength and factored bending moment provided later. A purpose of computing $A_{s\ reqd}$ is to check whether the minimum tension steel requirements ($A_{s\ min}$) of ACI 318M-11 chapter 10.5.1 are negated by subsequent chapter 10.5.3 provision that the minimum tensile reinforcement criteria need not be applied should A_s exceed $A_{s\ reqd}$ by at least 33.3%. *If* $A_{s\ min}$ is not satisfied then the user is either prompted to increase A_s (Fig 3-4) or notified that A_s exceeds $1.33A_{s\ reqd}$ (Fig 3-5).

Tension steel area reqd:	$A_{s\ reqd}$ =	1749	mm²				
Tension steel area provd:	A_s =	157	mm²	$A_{s\ min}$ =	563	mm²	
Tension steel ratio	p =	0.0010		*Increase tensile reinforcement to satisfy As min*			
Shear steel area:	A_{sv} =	226	mm²	$A_{v\ min}$ =	46	mm²	*O.K.*

Fig 3-4; Prompt to Increase Tensile Reinforcement

Tension steel area reqd:	$A_{s\ reqd}$ =	50	mm²				
Tension steel area provd:	A_s =	157	mm²	$A_{s\ min}$ =	563	mm²	
Tension steel ratio	p =	0.0010		*As prov > 1.33 As req. O.K.*			
Shear steel area:	A_{sv} =	226	mm²	$A_{v\ min}$ =	46	mm²	*O.K.*

Fig 3-5; Notification that A_s exceeds $1.33A_{s\ reqd}$

The checks on shear reinforcement comprise whether the maximum spacing is exceeded and the minimum area of reinforcement is satisfied in accordance with ACI 318M-11 chapters 11.4.5 and 11.4.6 respectively (Fig 3-6). It should be noted however that the spreadsheet does not currently implement the exemptions of 11.4.6.1

(a) through (f) for minimum shear reinforcement therefore minimum steel warnings may be ignored if any of these conditions are satisfied.

Spacing	s =	500	mm				
	s_{max} =	264	mm	*Exceeded*			
Effective depth	d =	527.5	mm				
Tension steel area reqd:	$A_{s\,reqd}$ =	1971	mm^2				
Tension steel area provd:	A_s =	2454	mm^2	$A_{s\,min}$ =	557	mm^2	*O.K.*
Tension steel ratio	p =	0.0155					
Shear steel area:	A_{sv} =	157	mm^2	$A_{v\,min}$ =	184	mm^2	*Not Satisfied*

Fig 3-6; Shear Reinforcement Warnings

The user should note the maximum spacing criteria of ACI 318M-11 chapter 11.4.5.3 which halves the maximum spacing (S_{max}) when the nominal shear strength of the reinforcement (V_s) exceeds a stated threshold. As the strength V_s is also a function of the shear reinforcement spacing (s) this can sometimes result in the counter intuitive effect of S_{max} doubling when a spacing value larger than the currently shown S_{max} is entered.

3.5 Nominal Tension Steel Condition

This section provides details of the concrete stress block together with the tensile steel stress and strain for either the steel elastic or yielded condition as appropriate (Fig 3-7). The analysis assumes an equivalent rectangular concrete stress distribution in accordance with ACI 318M-11 chapter 10.2.7. Much of this information is not needed to conclude the design however it does provide the designer with data that may be used for validation purposes.

Nominal Tension Steel Condition

Stress block depth	a =	115	mm	Rebar strain limits (ref. cl. 10.3.3 - 5):-			
Neutral axis depth	c =	144	mm	Comp. Controlled	$\varepsilon_t \leq$	0.0021	
Steel strain	ε_t =	0.0079		Tension Controlled	$\varepsilon_t \geq$	0.005	
Steel stress	f_s =	420	N/mm^2	Minimum	ε_t =	0.004	*O.K.*
Concrete compression	C =	1031	kN				
Steel tension	T =	1031	kN				
Moment capacity	M_n =	482	kNm				

Fig 3-7; Tension Steel Condition

The main intent of this section is to avoid over reinforcing the beam, and potential brittle failure, by checking against the minimum steel strain requirements of ACI 318M-11 chapter 10.3.5. Should this occur the user is prompted to reduce the tension steel (Fig 3-7), or increase the beam section size.

Stress block depth	a =	189 mm	Rebar strain limits (ref. cl. 10.3.3 - 5):-			
Neutral axis depth	c =	237 mm		Comp. Controlled	$\varepsilon_t \leq$	0.0021
Steel strain	ε_t =	0.0036		Tension Controlled	$\varepsilon_t \geq$	0.005
Steel stress	f_s =	420 N/mm^2		Minimum	ε_t =	0.004 *
Concrete compression	C =	1689 kN				* Reduce tension steel
Steel tension	T =	1689 kN				

Fig 3-8; Minimum Steel Strain not Satisfied

3.6 Flexural Design Strength

The design moment capacity is presented, based on the calculated strength reduction factor, and compared with the factored bending moment provided by the user. Notification is provided whether or not the moment capacity is exceeded.

Flexural Design Strength				
Strength Reduction Factor	ϕ =	0.9	*Tension Controlled*	
Design Moment Capacity	*O.K.*			**M_r = 434 kNm**

Fig 3-9; Flexural Design Strength

3.7 Shear Design Strength

The final data to be input is the shear strength reduction factor which would normally be 0.75 in accordance with ACI 318M-11 chapter 9.3.2.3 unless the seismic requirements of chapter 9.3.4 dictate. The spreadsheet informs whether the shear capacity of the concrete alone is sufficient to resist the design shear in accordance with ACI 318M-11 chapter 11.2.2.1 or whether designed shear reinforcement is required. The design shear capacity of the beam section is then presented together with notification whether this is exceeded by the factored shear force.

Shear Design Strength				
Strength Reduction Factor	ϕ =	0.75		
Nominal Concrete Strength	V_c =	251 kN	*Designed shear reinf. required*	
Nominal Reinforcement Strength	V_s =	399 kN		
Design Strength	*O.K.*			**V_r = 488 kN**

Fig 3-10; Shear Design Strength