# FIRE DESIGN OF COLUMNS AS 3600 & EC2









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## OVERVIEW

- AS 3600 2009 & 2018 Incl. AMDT No. 1 & 2
  - Deemed to comply fire tables
    - Table 5.6.3, 5.6.4, 5.7.2
  - FRP equation introduced in 2018
    - Eqn. 5.6.3(2)
  - Practical considerations and limitations.
  - Fully implemented in RCB and RCC software
- Eurocode 2
  - 500°C Isotherm Method
  - Theory and example
  - Coming early 2023 to RCB and RCC



### FIRE DESIGN OF COLUMN TO AS 3600

- 5.3 Design Performance Criteria
  - 5.3.1 General Performance Criteria
    - A) determined using tabulated data and figures
    - B) predicted by methods of calculation
      - Eurocode 2 Part 1.2
        - 500°C Isotherm Method coming to INDUCTA RCC and RCB in early 2023!
        - Zone Method

### • 5.6 Fire Resistance Periods (FRPs) For Columns

- Table 5.6.3
  - Eqn. 5.6.3(2) as an alternative (2018)
- Table 5.6.4
- Table 5.7.2 if aspect ratio > 4:1 wall



### AS 3600 - TABULATED FIRE DATA

- AS 3600 2009 and AS 3600 2018: Tables 5.6.3, 5.6.4, 5.7.2
- Deemed to comply approach
- Derived from empirical tests
  - Limiting Criteria to use these clauses represents the scope of the tests.
- Key Limiting Criteria:
  - Braced Column
  - Effective length under fire:  $I_{o.fi} < 3 \text{ m} \text{Table 5.6.3}$
  - Eccentricity under fire conditions (e)
    - $e \le 0.15b Table 5.6.3$
    - e/b < 0.25 and  $e \le 100$  mm Table 5.6.4
    - Slenderness under fire condition  $\lambda_f \leq 30$  Table 5.6.4
  - Aspect Ratio  $\geq 4$  Table 5.7.2



### Difficult to get fix-fix columns working using the tables due to eccentricity limits

TABLE 5.6.3 - EXAMPLE





- FRP = 90 min
- a<sub>s</sub> = 54 mm
- $L_{u} = 3 m$
- $I_{o.fi} = 1.5 \text{ m} < 3 \text{ m}$
- $N_{f}^{*} = 800 \text{ kN}$
- φN<sub>u.f</sub>= 2,158 kN
- $\mu_{fi} = 0.37$
- e = 20 mm < 0.15b

90

### **TABLE 5.6.3**

### FIRE RESISTANCE PERIODS (FRPs) FOR STRUCTURAL ADEQUACY OF COLUMNS

	Minimum dimensions, mm						
Combinations for column exposed on more than one side							
$\mu_{\mathrm{fi}} = 0.2$		$\mu_{\mathrm{fi}} = 0.5$		$\mu_{\mathrm{fi}} = 0.7$			
as	b	as	b	as	b		
31	200	45	300	53	350		
25	300	38	400	40(1)	450 <sup>(1)</sup>		

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FILE HOME HELP			
Title AS 3600 - 2018 AMI - Solve A <sup>+</sup> Title Design Code Run	Lock M-N Curve Ultimate Loading Fire	□ Show Tension □ Plot Cl10.6.3 ☑ Grid ☑ ΦM at N*	Confinement Zone Direction Section Points Fire Table M - N Interaction
	3.000	0-	
	2,800 2,600 2,400 2,200 (N¥ 1,800 1,600 1,600 1,600 1,000 800 600 400 200	D D D D D D D D D D D D D D	μ, ΦΝυ , 1916) ΦΜ (11;
400		0 10 20 30 40 50 60 70 Moment - ΦΜx	) 80 90 100 110 12 y(kNm)
Geometry	Longitudinal Steel	№ of laterally restrained longitudinal bars	Design Load: Ultimate
Section Type Circle 🔹	Bars Diameter, mm 🗌 24 🔹	Total: 4	Тор
Braced, X   Braced, Y  Column Height: Lu, m  Graced, Y  Column Height: Lu, m  Graced, Y  Graced, Y	Yield Stress, MPa □ 500 • № of bars - total 4 •	Rest Spc: 292 mm Tie Diameter: 328 mm	N*, kN ? 1000 M*x, kNm ? 0 M*y, kNm ? 0 V*x, kN ? 0
Diameter mm 400	Centreline Snc: 229 mm	Material Area	V*y, kN ? 0
	Steel Ties	Gross: 125,664 mm <sup>2</sup>	V* < 0.001
Concrete	Bar Diameter, mm 🗌 12 🔹	Long, Bars: 1.800 mm <sup>2</sup> 1.43 %	$\beta d = G / (G + Q)$ 0.8
f'c, MPa 32 - Cover, mm ? 30	Yield Stress, MPa     500       Rest. of long steel to 10.7.4.1     Image: Compare the state of the stat	Single Set Ties: 220 mm² W:310 kg/m (Total: 9 kN)	<ul> <li>Apply Min Moment, N x</li> <li>Force Bending in Single C</li> <li>Reversal of Loads: Vuc =</li> </ul>
Strength reduction factor due to spalling Core concrete strength multiplier due to 1.00	№ of Legs 2 Use Helix Ties		Mmin xy, kNm : 20.0 M*xy, kNm: 20.0
confinement	Min. Tie Spacing, mm 50		Go To





## AS 3600 - EQN. 5.6.3(2)

- Introduced to 2018 version of AS 3600
  - Has been amended twice since release.
- Provided as an alternative to the tabulated data
- No limits on eccentricity
- Limits on effective length (lo.fi) and dimensions.
- Provides more flexibility than tables
  - Can cap values to back limits (conservative)
    - $I_{o fi}$  can be taken as 2 m when  $I_{lo,fi}$  < 2m
    - b' taken as 450 mm when b' > 450 mm



The FRP for structural adequacy for columns outside the limits defined for Table 5.6.3 and within the limits defined in the variables below may be assessed using Equation 5.6.3(2):

$$FRP = 120 \left( \frac{(R_{\eta.fi} + R_a + R_l + R_b + R_n)}{120} \right)^{1.8} \dots 5.6.3(2)$$

where

- $R_{\eta,\text{fi}} = 83(1.0 \mu_{\text{fi}} (1 + \omega)/(.945 + \omega))$   $R_{\text{a}} = 1.60 (a_{\text{s}} 30)$   $R_{1} = 9.60 (5 10.\text{fi})$   $R_{\text{b}} = 0.09 b'$   $R_{\text{n}} = 0 \text{ for 4 (corner bars only)}$  = 12 for greater than 4 bars  $a_{\text{s}} = \text{ the axis distance to the longitudinal steel bars (mm); 25 mm \le a_{\text{s}} \le 80 \text{ mm}}$
- $l_{o.fi}$  = the effective length of the column under fire conditions; 2 metres  $\leq l_{o.fi} \leq 6$  metres

When  $l_{o.fi} < 2$  m, it is conservative to take  $l_{o.fi} = 2$  m in Equation 5.6.3(2)

- $b' = 2A_g / (y + x)$  for rectangular cross-sections
  - = the diameter of circular cross-sections within the limits

 $200 \text{ mm} \le b' \le 450 \text{ mm} \text{ and } y \le 1.5x$ 

 $\omega = 1.3 A_s f_{sy} / A_g f'_c$  denotes the mechanical reinforcement ratio at normal temperature conditions



- INDUCTA would treat these as "hard" limits and stop calculations if they were violated.
- I<sub>o.fi</sub> limit was clarified with AMDT No. 2
- b' geometry limit capped in a recent update to RCC and RCB



- Tests have shown blade columns have larger FRP than columns of same thickness but less width.
- If y > 1.5 x then y should be limited to:
  - y = 1.5x ...then
  - b' = 2x . 1.5x / (x + 1.5 x) = 1.2 x
- Similar for a circular columns
  - 500 mm column would fail b' but 450 mm passes?
  - Makes sense to cap back to lower value (conservative)

N\*f = 800 kN M\*fx unmagnified = -24 kNm Effective length under fire (lo.fi\_x): 2000 mm Reinf. ratio: 0.01 Min. Dimension (b): 200 mm Axis distance (as): 45 mm

$$\Phi N_{ux} = 2,559 \text{ kN}$$
  
 $\mu_{fi} = N_f^* / \Phi N_u = 0.31$   
 $A_{gross}: 120,000 \text{ mm}^2$   
 $\omega = 1.3 \text{ A}_s f_{sy} / A_g f_c' = 0.162$   
 $b' = 240 \text{ mm}$   
 $x = 200 \text{ mm}$   
 $y = 300 \text{ mm} - \text{capped to } y = 1.5x$ 

$$R_{\eta.fi} = 55.76$$
  
 $R_a = 24.00$   
 $R_1 = 28.80$   
 $R_b = 21.60$   
 $R_n = 12$ 

FRP = 163 min ... Eqn 5.6.3(2)



## FIRE DESIGN OF COLUMNS TO AS 3600

- 5.3.1 b) predicted by methods of calculation
  - Eurocode 2 Part 1-2
    - 500°C Isotherm Method Annex B1
    - Zone Method Annex B<sub>2</sub>
  - Zone Method
    - More accurate but difficult to implement and check.
    - Concrete is divided into zones (at least 3) and considers reduced concrete strength.
    - There is also a zone of concrete that is ineffective.
    - Reduced reinforcement capacity is considered.
    - Section is checked using this cross section with varying concrete grades and reduced reinforcement.
    - Will not be done with the INDUCTA Software.



## 500°C ISOTHERM METHOD

- Assume concrete with temperature > 500°C is ineffective.
- Assume all other concrete has same properties normal temperature.
- Reinforcement has reduced strength even if outside the reduced section. ullet
- Isotherm is rationalised to a rectangle with same area and aspect ratio or original section.



### 500°C ISOTHERM METHOD





### **CALCULATION PROCEDURE**

- Determine the 500°C isotherm for the chosen Fire Resistance Class (R or FRP)
  - Figure A.15 (rectangular) & Figure A.20 (circular and complex)
- Determine the reduced concrete section
  - Create an equivalent rectangle that has same area is reduced 5000C Isotherm but maintains aspect ratio of original section. (rect. only)
- Determine the temperature of the reinforcing bars for the relevant temperature profile
  - Figure A11 A14 (rectangular) & Figure A16 A 19 (circular and complex)
- Determine reduced strength of the reinforcement to 4.2.4.3 •
  - Reinforcement yield stress (f<sub>sv</sub>) will vary for compression and for tension
  - Elastic Modulus (E<sub>s</sub>) is reduced
- Check the section using conventional calculation methods
  - Reduced concrete section has normal, unreduced properties
  - Reinforcement has reduced properties.







R = 90











### SECTION CAPACITY - R90





### CIRCULAR SECTIONS



Figure A.17: Temperature profiles (°C) for a circular column - R60





Figure A.20: 500 °C isotherms for a circular column

### COMPLEX SECTIONS





Figure A.18: Temperature profiles (°C) for a circular column - R90





Figure A.20: 500 °C isotherms for a circular column

### CLOSING REMARKS

- EC2 500°C Isotherm Method
  - Coming as a free update to INDUCTA RCB and RCC software early 2023.
- Fully automated as per existing column calculations.
- Will provide complete solution for column fire design using the INDUCTA Software.



C software early 2023. ations.

### REFERENCES

- Concrete structures AS 3600 2018 Incl. AMDTs No 1 & No 2
- Concrete structure commentary (supplement 1 to AS) 3600:2018)
- Concrete Design Guide, No. 6: Fire design of concrete columns and walls to Eurocode 2
- Eurocode 2: Design on concrete structure Part 1-2: General rules – Structural fire design

