MASONRY INSIGHTS

Masonry - how to account for cracking

Some finite element analysis programs do not account for flexural cracking that occurs when the tension component of a flexural bending moment exceeds the rupture capacity of the masonry. Rupture of the masonry greatly reduces the moment of inertia for additional loading beyond the associated cracking moment. Therefore, a reduction in wall stiffness must be included to correctly model the behavior of the masonry wall. Below is an example of how to adjust the properties within the model to accommodate the reduction in wall stiffness.

Given: 8" normal weight CMU wall with #5 rebar at 32" oc supporting a single bay of steel roof bar joists spanning 20'-0" (assume 4" joist bearing thus e = 7.625/2 - 4/2 = 1.81"
wall weight = 51psf per NCMA TEK 14-13B
A_{net} = 46.0 in^2/ft
S_{net} = 90.1 in^3/ft S_{avg} = 94.6 in^3/ft
I_{net} = 343.7 in^4/ft I_{avg} = 360.5 in^4/ft [NCMA TEK 14-1B]
S_{net}, I_{net} values for strength capacity
S_{avg}, I_{avg} values for stiffness and deflection
f'_m = 2500psi
Roof height = 20'-0" with a 3'-0" parapet
Wind Load: W_u = 30psf; W_s = 0.6(30) = 18psf

1. The cracked moment of inertia is influenced by the factored vertical loads bearing on the wall.

Roof Dead Load: P_f,DL = 15psf (20'/2) = 150plf	P_{uf},DL = 1.2 (150plf) = 180plf
Roof Snow Load: P_f,LL = 35psf (20'/2) = 350plf	P_{uf},LL = 1.6 (350plf) = 560plf
Wall Dead Load: P_w = 51psf (20'/2 + 3') = 663plf	P_{uw} = 1.2 (663) = 796plf
P_f = 150 + 350 = 500plf	P_{uf} = 180 + 560 = 740plf
P = P_w + P_f = 1163plf	P_u = P_{uw} + P_{uf} = 1536plf

2. Calculate distance extreme compression fiber to neutral axis, c

A_s = 0.31in^2 (12/32) = 0.116in^2/ft f_y = 60,000psi

c = ($A_s f_y$ + P_u)/(0.64f'_mb) = [(0.116)(60,000) + 1536] / [0.64(2500)(12)] = 0.443"
[TMS402-13 Equation 9-35]

3. Calculate gross and cracked moments of inertia, I_g, I_{cr}

Em = 900f'_m = 900 (2500) = 2,250,000psi
n = Es/Em = 29,000,000/2,250,000 = 12.9
d = 7.625"/2 = 3.81"

I_g = I_{avg} = 360.5 in^4/ft (For stiffness and deflection, use the average values from NCMA)

$Icr = n(As + Pu/fy)(d-c)^2 + bc^3/3$ (Simplified equation for centered rebar)
I_{cr} = 12.9[0.116 + 1536/60,000)(3.81-0.443)^2+(12)(0.443)^3/3 = 21.1 in^4/ft
[TMS402-13 Equation 9-34]

4. Calculate cracking moment for stiffness, M_{cr} [TMS402-13 Section 9.3.5.4.4]
   f_r = 104 psi [TMS402-13 Table 9.1.9.2]
   $M_{cr} = f_r S_{avg}$ = (104 psi)(94.6 in^3/ft) = 9838 in#/ft < M_{ser}, use TMS402-13 equation 9-30

5. Calculate service deflection, $delta_s$ [TMS402-13 Section 9.3.5.5.1]

   Iteration is required thus start with the assumption: $delta_{s0}$ = 0 in

   $M_{ser1} = w_s h^2/8 + P_f e_u/2 + Pdelta_{s0}$ = (18psf)(20')^2(12)/8 + 500plf(1.81")/2 + 0 = 11,253 in#/ft
   $delta_{s1} = 5M_{cr}h^2/(48E_mI_{avg}) + 5(M_{ser1} - M_{cr})h^2/(48E_mI_{cr})$ = 0.255"

   $M_{ser2} = w_s h^2/8 + P_f e_u/2 + Pdelta_{s1}$ = 11,550 in#/ft
   $delta_{s2} = 5M_{cr}h^2/(48E_mI_{avg}) + 5(M_{ser2} - M_{cr})h^2/(48E_mI_{cr})$ = 0.293"

   $M_{ser3} = w_s h^2/8 + P_f e_u/2 + Pdelta_{s3}$ = 11,593 in#/ft
   $delta_{s3} = 5M_{cr}h^2/(48E_mI_{avg}) + 5(M_{ser3} - M_{cr})h^2/(48E_mI_{cr})$ = 0.298" (within 2% conversion)

   $delta_{s,max}$ = 0.007h = 0.007(240) = 1.68" > 0.298" OK

6. Determine adjusted modulus of elasticity (E_{adj}) for equivalent flexure based on I_{avg}
   (assuming the software accounts for partial grouting)

   Using $delta_{cr}$ and $delta_{s,max}$ calculate a weighted average stiffness for $E_{adj}I_{avg}$

   $delta_{cr} = 5M_{cr}h^2/(48E_mI_{avg})$ = 0.076"
   $delta_{s,max}$ = 0.298"

   $E_{adj}I_{avg} = E_mI_{avg}(delta_{cr} / delta_{s,max}) + E_mI_{cr}(delta_{s,max} - delta_{cr}) / delta_{s,max}$

   Divide each side by I_{avg}

   $E_{adj} = E_m(delta_{cr} / delta_{s,max}) + E_mI_{cr}(delta_{s,max} - delta_{cr}) / (delta_{s,max}I_{avg})$ = 673,979

   To adjust the value of E in the model, typically a multiplier is required, thus
   multiplier = E_{adj} / E_m = 673,979 / 2,250,000 = 0.30

Pros:
- Provides more accurate deflections including Pdelta effects
- Provides more accurate flexural bending moments including Pdelta effects

Cons:
- Reduced modulus of elasticity may adversely affect other portions of the design
- Each masonry wall will require a unique calculation and adjustment factor based on loads
- Separate models may be required for capacity and deflection