An ACI/TMS Standard

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Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies

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Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies (metric)

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Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies

An ACI and TMS Standard

Reported by ACI Committee 216 joint with TMS

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Fire resistance of building elements is an important consideration in building design. While structural design considerations for concrete and masonry at ambient temperature conditions are addressed by ACI 318M and TMS 402/ACI 530/ASCE 5, respectively, these codes do not consider the impact of fire on concrete and masonry construction. This standard contains design and analytical procedures for determining the fire resistance of concrete and masonry members and building assemblies. Where differences occur in specific design requirements between this standard and ACI 318M and TMS 402/ACI 530/ASCE 5, as in the case of cover protection of steel reinforcement, the more stringent of the requirements shall apply.

Keywords: beams; columns; compressive strength; concrete slabs; fire endurance; fire ratings; fire resistance; fire tests; masonry walls; modulus of elasticity; prestressed concrete; prestressing steels; reinforced concrete; reinforcing steel; structural design; temperature distribution; thermal properties; walls.

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PREFACE

This standard provides requirements for determining fire resistance of concrete and masonry elements and assemblies. Calculation procedures for determining fire resistance are provided for concrete walls, floors, roofs, and columns and masonry walls, lintels, and columns. Procedures are also included for determining requirements for concrete cover, protection of structural steel columns using concrete or masonry, and for hollow structural steel columns filled with concrete. Procedures for determining the contribution of additional fire resistance provided by finish materials on concrete or masonry assemblies are also included.

CHAPTER 1—GENERAL

1.1—Scope

This standard describes acceptable methods for determining the fire resistance of concrete and masonry building assemblies and structural elements, including walls, floor and roof slabs, beams, columns, lintels, and masonry fire protection for structural steel columns. These methods shall be used for design and analysis purposes and shall be based on the fire exposure and applicable end-point criteria of ASTM E119. This standard does not apply to composite metal deck floor or roof assemblies.

The primary intended use of this standard is for determining the design requirements for concrete and masonry elements to resist fire and provide fire protection. Tolerance compliance to the provisions for concrete shall be based on information provided in ACI 117M. Masonry construction shall comply with TMS 402/ACI 530.1/ASCE 6.

The provisions of this standard establish fire resistance based on calculations. The fire resistance associated with an element or assembly shall be deemed acceptable when established by the calculation procedures in this standard or when established in accordance with 1.2.

1.2—Alternative methods

Methods other than those presented in this standard shall be permitted for use in assessing the fire resistance of concrete and masonry building assemblies and structural elements if the methods are based on the fire exposure and applicable end-point criteria specified in ASTM E119. Computer models, when used, shall be validated and supported by published literature to substantiate their accuracy. Alternative methods include:

Qualification by testing—Materials and assemblies of materials of construction tested in accordance with the requirements set forth in ASTM E119 shall be classified for fire resistance in accordance with the results and conditions of such tests.

Approval through past performance—The application of fire resistance ratings to elements and assemblies that have been applied in the past and have been proven through performance shall be permitted.

Other methods—The provisions of this standard are not intended to prevent the application of new and emerging technology for predicting the life safety and property protection implications of buildings and structures.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A_1, A_2, and A_n = air factor for each continuous air space having a distance of 13 to 90 mm between wythes
A_{ps} = cross-sectional area of prestressing tendons, mm^2
A_s = cross-sectional area of nonprestressed longitudinal tension reinforcement, mm^2
A_{st} = cross-sectional area of the steel column, mm^2
a = depth of equivalent rectangular concrete compressive stress block at nominal flexural strength, mm
a_θ = depth of equivalent concrete rectangular stress block at elevated temperature, mm
B = least dimension of rectangular concrete column, mm
b = width of concrete slab or beam, mm
b_f = width of flange, mm
C = compressive force due to unfactored dead load and live load, kN
c_c = ambient temperature specific heat of concrete, kJ/(kg·K)
d = effective depth, distance from centroid of tension reinforcement to extreme compressive fiber or depth of steel column, mm
D = for hollow structural steel columns, outside diameter for circular columns, mm; outside dimension for square columns, mm; and least outside dimension for rectangular columns, mm
D_c = oven-dried density of concrete, kg/m^3

d_{ef} = distance from centroid of tension reinforcement to most extreme concrete compressive fiber at which point temperature does not exceed 760°C, mm
d_l = thickness of fire-exposed concrete layer, mm
d_{st} = column width, mm
f_c = measured compressive strength of concrete test cylinders at ambient temperature, MPa
f_c' = specified compressive strength of concrete, MPa
$f_{c\theta}'$ = reduced compressive strength of concrete at elevated temperature, MPa
f_{ps} = stress in prestressing steel at nominal flexural strength, MPa
$f_{ps\theta}$ = reduced stress of prestressing steel at elevated temperature, MPa
f_{pu} = specified tensile strength of prestressing tendons, MPa
f_y = specified yield strength of nonprestressed reinforcing steel, MPa
$f_{y\theta}$ = reduced yield strength of nonprestressed reinforcing steel at elevated temperature, MPa
H = specified height of masonry unit, mm
H_s = ambient temperature thermal capacity of steel column, kJ/(m·K)
h = average thickness of concrete cover, mm
KL = column effective length, m
k_c = thermal conductivity of concrete at room temperature, kcal/(m·hr·°C)
k_{cm} = thermal conductivity of concrete masonry at room temperature, kcal/(m·hr·°C)
L = specified length of masonry unit or interior dimension of rectangular concrete box protection for steel column, mm
ℓ = clear span between supports, m
M = moment due to full service load on member, N·m
M_n = nominal moment capacity at section, N·m
$M_{n\theta}$ = nominal moment capacity of section at elevated temperature, N·m
$M_{n\theta}^+$ = nominal positive moment capacity of section at elevated temperature, N·m
$M_{n\theta}^-$ = nominal negative moment capacity of section at elevated temperature, N·m
M_{x1} = maximum value of redistributed positive moment at some distance x_1, N·m
m_c = equivalent moisture content of the concrete by volume, percent
p = inner perimeter of concrete masonry protection, mm
p_s = exposed perimeter of steel column, mm
R = fire resistance of assembly, hours
R_m = fire resistance of assembly, minutes
R_0 = fire resistance at zero moisture content, minutes
R_1, R_2, R_n = fire resistance of layer 1, 2,...n, respectively, hours
s = center-to-center spacing of items such as ribs or undulations, mm
t = time, minutes
t_e = equivalent thickness of a ribbed or undulating concrete section, mm
t_{e2} = equivalent thickness t_e calculated by dividing the net cross-sectional area by the panel width
t_{min} = minimum thickness, mm
t_{tot} = total slab thickness, mm
t_w = thickness of web, mm
T = specified thickness of concrete masonry and clay masonry unit, mm
T_e = equivalent thickness of concrete, concrete masonry and clay masonry unit, mm
T_{ea} = equivalent thickness of concrete masonry assembly, mm
T_{ef} = equivalent thickness of finishes, mm
u = average thickness of concrete between the center of main reinforcing steel and fire-exposed surface, mm
u_{ef} = an adjusted value of u to accommodate beam geometry where fire exposure to concrete surfaces is from three sides, mm
V_n = net volume of masonry unit, mm³
W = average mass of the steel column, kg/m
w = sum of unfactored dead and live service loads, N/m
w_c = density of concrete, kg/m³
w_{cm} = density of masonry protection, kg/m³
x_0 = distance from inflection point to location of first interior support, measured after moment redistribution has occurred, m
x_1 = distance at which maximum value of redistributed positive moment occurs measured from: (a) outer support for continuity over one support; and (b) either support where continuity extends over two supports, m
x_2 = in continuous span, distance between adjacent inflection points, m
θ = subscript denoting changes of parameter due to elevated temperature
ρ = reinforcement ratio (A_s/bd)
ρ_g = ratio of total reinforcement area to cross-sectional area of column
ω_p = reinforcement index for concrete beam reinforced with prestressing steel
$\omega_{p\theta}$ = reinforcement index for concrete beam reinforced with prestressing steel at elevated temperature
ω_r = reinforcement index for concrete beam reinforced with nonprestressed steel
ω_θ = reinforcement index for concrete beam at elevated temperature
ψ = modification factor reflecting type of column infill

2.2—Definitions

The following terms are defined for general use in this code.

bar, high-strength alloy steel—reinforcement conforming to the requirements of ASTM A722M.

barrier element—a building member that performs as a barricade to the spread of fire (for example, walls, floors, and roofs).

beam—a structural member subjected to axial load and flexure but primarily to flexure.