IN-LB Inch-Pound Units

Design of Nuclear Safety-Related Structures for Impactive and Impulsive Loads using ACI CODE-349 and ASME Section III, Division 2 Provisions—Guide

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Reported by ACI Committees 349 and 359

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CONTENTS

PREFACE

This guide is the work of the ACI 349/359 Task Group on Impulsive and Impactive Loading that established a proposal of updated design provisions for both ACI CODE-349 and ASME BPVC Section III, Division 2. The provisions of this guide are nonbinding on ACI CODE-349-23 Appendix F or ASME BPVC Section III, Division 2:2011 and may change if implemented.

This guide gives the genesis of the provisions that are proposed to be incorporated into these code documents and further explains why these provisions were adopted. Furthermore, the primary mandate of this guide was to align both aforementioned codes and to bring these codes up to date with current industry practices, using current references for the provisions of both code documents. This guide serves as an independent report of the task group's work to the code committees. This guide is issued as a detailed commentary to the provisions of ACI CODE-349-23 Appendix F or ASME BPVC Section III, Division 2. The language of ACI CODE-349-13 and ASME BPVC Section III, Division 2:2011 form the starting point for the proposed nonbinding revisions already incorporated in the first two columns of this guide. The last column does not provide proposed changes but provides explanations of why such changes are proposed.

Keywords: blast; hard impact; impact; impulse; nuclear structure; perforation; scabbing; soft impact; structural analysis; structural design.

NOTATION AND DEFINITIONS

Notation

A_d = area of diagonal reinforcement
A_g = gross area of concrete section
A_s = area of steel reinforcement
A_{sh} = area of hoop reinforcement
a_g = aggregate size of concrete
b = width of compression face of member
c = distance from extreme compression fiber to neutral axis
c_r = reinforcing bar spacing
D = effective missile diameter
d = distance from extreme compression fiber to centroid of longitudinal tension reinforcement (Section F.2.3); effective diameter or the diameter of the hard/rigid part if the missile contains flexible part (Section RF.7.2.1)
d_e = distance between the front face and reinforcement
d_{load} = diameter of loaded area
e_b = eccentricity corresponding to balanced strain conditions
$\bar{F}$ = impact force demand for high-mass, low-velocity impact (Section F.6.3); average value of the time-dependent force resultant of the missile (Section RF.6.4)
F_1 = maximum impulsive loading
F_2 = approximately constant impulse loading during Δt
F_e = effective load for a single degree of freedom (SDOF) model (Section RF.6.1)
F_p = static punching capacity of a slab
F_t = resultant force
f_c' = concrete compressive strength
f_{dc} = dynamic compressive strength
f_{ds} = dynamic stress capacity of steel reinforcement
f_u = ultimate strength
f_y = specified yield strength of reinforcement
H_0 = target thickness
h = overall thickness or height of member
I = total impulse
I_{cr} = moment of inertia of cracked section transformed to concrete
I_g = moment of inertia of gross concrete section about centroidal axis, neglecting reinforcement
K = value of F_t to cause unit deflection at point of application of resultant force (Section RF.6.1); concrete penetrability factor (Section RF.7.2.1)
K_e = elastic stiffness
k = stiffness of impactor (Section F.6.3)
L_d = development length
ℓ_h = unsupported length
M = mass of missile
M_e = equivalent mass
m = mass per unit area (Section RF.6.1); mass of the impactor (Section F.6.3)
N = missile nose shape factor
P_b = nominal axial strength at balanced strain conditions
$P_{n(max)}$ = design axial strength
p = pressure (Section RF.6.1); perimeter of missile cross section (Section RF.7.2.1)
R_{avail} = available resistance
R_{DL} = dead load resistance
R_{m1} = resistance required at F_1
R_{m2} = resistance required at F_2
R_u = ultimate resistance
r = percentage of reinforcement described by the percentage each way in each face
r_θ = rotational capacity/support rotation (refer to Fig. RF.3.3)
s_h = spacing of hoops
t = total section thickness
t_d = impact duration
t_p = perforation thickness
t_s = scabbing thickness
$\dot{u}$ = reference velocity
$\dot{u}_{max}$ = impact velocity
V_d = direct shear capacity
V_u = factored shear force at section
v = missile impact velocity
W = weight of missile
X_m = maximum acceptable displacement
X_y = effective yield point
x = penetration depth of missile
Y_j = jet impingement load, or related internal moments and forces, on the structure generated by a postulated pipe break
Y_m = missile impact load, or related internal moments and forces, on the structure generated by a postulated pipe break, such as pipe whip
Y_r = loads, or related internal moments and forces, on the structure generated by the reaction of the broken pipe during a postulated break
α = angle defining orientation of reinforcement
Δt = time interval
ε_{cu} = maximum concrete compression strain
ϕ = strength reduction factor
$\phi(x,y)$ = deformed shape function
μ = ductility ratio
μ_d = permissible ductility ratio
ρ = ratio of A_s to bd (Section F.4.2); concrete density (Section RF.7.2.1)
ρ_p = average percentage of reinforcement on the tensioned face
σ = principal stress
σ_e = effective stress
ψ = cross-section curvature (Attachment B)

Definitions

abnormal, extreme environmental, and abnormal and extreme environmental load categories—structural members designed to resist impactive and impulsive loads and dynamic effects are structures in the abnormal, extreme environmental, and abnormal and extreme environmental categories, which can have permanent, plastic deformations.

component damage levels—acceptable damage levels in F.3.3 and F.3.4 as invoked either by the ACI CODE-349 or