GUIDE TO THE DESIGN OF BUILDING SYSTEMS FOR SERVICEABILITY

IN ACCORDANCE WITH THE 2012 IBC® AND ASCE/SEI 7-10

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NCSEA
National Council of Structural Engineers Associations

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Guide to the Design of Building Systems for Serviceability
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Preface

As the building design industry continues to move toward full acceptance of ultimate strength design and looks toward performance based design, it is vital that designers are provided a clear understanding of serviceability limit states. However, the structural engineering profession resists the idea of standardizing or codifying serviceability design for buildings. As a result, serviceability performance has not been rigorously addressed in building codes and standards. Therefore, the responsibility for determining appropriate serviceability design limit states in many situations lies with the individual professional. The breadth and disparity of information concerning serviceability limit states allows the professional freedom and creativity in developing design; however, the lack of a minimum working standard for serviceability design also yields undue conservatism on the one hand and neglect on the other. In addition, the breadth of opinions results in unnecessary disagreement between professional engineers. This disagreement and lack of a standard of practice in serviceability design leads to confusion on the part of owners, architects and contractors concerning the expected performance of structural systems. The final result is lost time and funds as project teams sort out or resolve the coordination of claims concerning unacceptable performance of architectural elements, finishes and building equipment.

The purpose of this design guide is to provide practical information and examples for the design professional to use when evaluating a structural building design for serviceability performance. It is the hope of the author that this design guide may lead to the development of a consensus standard for serviceability design. The challenges in applying the provisions of the code and recommendations of referenced standards are clearly shown and discussed in the example problems.

One special feature of this guide is its almost total reliance on the *International Building Code®* (IBC®), commentary and code referenced standards, and publications. To date, most available references on serviceability have been based on individual research publications and reports whose main purpose was to accurately predict serviceability behavior. This guide, by design, is limited to the use of information included in the IBC and code referenced standards as well as their commentaries. Whenever appropriate, the author utilized publications specifically cited by the IBC, its referenced standards and their commentaries to supplement the code provisions.

The guide's broad scope of materials, building systems, and building components is fairly unique. Most serviceability references or guides deal with a limited number of structural materials, or structural systems/components, or specific serviceability limit states. This guide attempts to cover the majority of structural materials, systems, components and limits states encountered in the design of significant common building types. The design guide does not include discussions related to bridges, industrial facilities, high rise buildings, long span systems, or special building loads. Finally, the example problems included in the guide are presented in a holistic fashion using realistic building projects. The format includes 26 examples of serviceability design or evaluation taken from various portions of seven building structures. Given this wide range of examples, the design engineer can appreciate a systems level approach to serviceability.

We anticipate that the guide will be used primarily by practicing design professionals. In addition, the guide is organized to lend itself to use by educators teaching upper level structural system based classes. The guide may also be used by others in the construction industry, such as architects and legal professionals, as a reference to code requirements governing the serviceability performance of buildings.

About NCSEA

The National Council of Structural Engineers Associations (NCSEA) is comprised of 43 structural engineering associations throughout the United States. NCSEA serves to advance the practice of structural engineering and, as the autonomous national voice for practicing structural engineers, protect the public's right to safe, sustainable and cost effective buildings, bridges, and other structures. NCSEA generates and responds to code changes, promotes structural engineering certification and separate licensure, and promotes the practice of structural engineering to students and the general public. Members also include structural engineering firms, as well as companies who provide structural engineering products and services.

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About the International Code Council

The International Code Council is a member-focused association. It is dedicated to developing model codes and standards used in the design, build and compliance process to construct safe, sustainable, affordable and resilient structures. Most U.S. communities and many global markets choose the International Codes. ICC Evaluation Service (ICC-ES) is the industry leader in performing technical evaluations for code compliance fostering safe and sustainable design and construction.

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Figures

Tables

Variables

Variable	Definition (unless noted otherwise in text)
a	Depth of equivalent rectangular stress block as defined in ACI 318-11 10.2.7.1
A	Gross cross-sectional area of a structural element
A_{ps}	Area of prestressed steel reinforcing
A'_s	Area of longitudinal compression reinforcement
A_s	Area of nonprestressed longitudinal tension reinforcement
A_T	Tributary element of structural element or connection
b	Structural element width
B_e	Effective width used in vibration analysis
b_{eff}	Effective compression flange width
b_w	Width of beam web
C_d	Seismic deflection modification factor
d	Depth of structural element; for concrete element distance from compression face to centroid of tensile reinforcement
D_e, d_e	Effective depth used in vibration analysis
DL	Dead load
d_p	Dimension from compression face of concrete element to centroid of post-tensioning reinforcement
E_c	Modulus of elasticity of concrete
E_s	Modulus of elasticity of steel
f'_c	28-day concrete compression strength as defined by ACI 318-10
f_c	Compression stress in a structural element
f'_{ci}	Concrete compression strength at time of initial stressing
f_r	Modulus of rupture of concrete
f_t	Tensile stress in concrete structural element
h	Structural concrete element depth
h_i	Vertical height of a building story, i

Variable	Definition (unless noted otherwise in text)
H_i	Reference elevation for level i of the building; assumed to be building height if subscript is omitted
I_{cr}	Moment of inertia of cracked section transformed to concrete
I_e	Effective moment of inertia for computation of deflection
I_{eff}	Effecting moment of inertia for steel beam designed to act compositely with a concrete slab
I_g	Moment of inertia for gross or uncracked concrete section, neglecting the contribution of reinforcing steel
I_j	Moment inertia for open-webbed structural steel joist
I_{jg}	Moment of inertia for open webbed joist girder
I_P	Moment of inertia for primary framing used in ponding analysis
I_s	Moment of inertia for secondary framing used in ponding analysis
K_{cr}	Time dependent deformation (creep) factor
K_{LL}	Live load element factor
LL	Reduced design live load
LL_o	Unreduced design live load
LL_s	Sustained live load
LL_t	Transient live load
M_a	Applied bending moment for the element or section being analyzed
M_{cr}	Cracking moment of structural element
MRI	Mean Return Interval
n	Ratio of modulus of elasticity of steel to modulus of elasticity of concrete
p	Wind pressure
P	Concentrated load
P_{sh}	Compression force in the compression flange of a composite steel beam caused by shrinkage of the concrete portion of the beam
R	Seismic response modification factor
t	Slab thickness
V_i	Wind speed in mph for MRI i
w	Wind load applied as a line load; Uniform floor or roof load
W_a	Serviceability level wind load
W_c	Unit weight of concrete

Variable	Definition (unless noted otherwise in text)
W_{LL}	Live load applied as a line on an element
Wt	Weight of structural steel element per linear foot
X_{na}	Distance to neutral axis of structural element from reference point
y_t	Distance from neutral axis of structural element to tensile face
β	Aspect ratio of structural bay; ratio of long to short dimensions
Δ_{APP}	Deflection that occurs after the application of a specific element or system of elements
Δ_{DL+LL}	Deflection that occurs as a result of the application of dead loads and live loads combined
Δ^{i}_{DL+LL}	Immediate deflection that occurs as a result of the application of dead loads and live loads combined
Δ_{LL}	Deflection that occurs as a result of the application of live loads
Δ^{i}_{LL}	Immediate deflection that occurs as a result of the application of live loads
Δ_{LT}	Immediate deflection due to long-term loads
Δ_{S}	Deflection that occurs as a result of the application of snow loads
Δ_{SD}	Deflection that occurs as a result of the application of superimposed dead loads
Δ^{i}_{SD}	Immediate deflection that occurs as a result of the application of superimposed dead loads
Δ_{sh}	Deflection in a composite steel beam caused by shrinkage of the concrete compression flange
Δ_{sw}	Deflection of a structural element or system that occurs as a result of the structure's own self-weight
Δ^{i}_{sw}	Immediate deflection that occurs as a result of the self-weight of the structural elements
Δ_{W}	Story drift or element deflection that occurs as a result of the application of wind load
δ_{W}	Horizontal deflection that occurs as a result of application of wind load
ξ	Time dependent factor for sustained loads for concrete elements
λ_{Δ}	Long-term deflection multiplier
λ^{SD}_{Δ}	Long-term deflection multiplier for superimposed dead loads

Variable	Definition (unless noted otherwise in text)
λ_{Δ}^{SW}	Long-term deflection multiplier for member self-weight
ρ'	Ratio of compression reinforcement
ε_{sh}	Stain due to shrinkage of concrete