NIST GCR 11-917-10

Seismic Design of Composite Steel Deck and Concrete-filled Diaphragms

A Guide for Practicing Engineers

Prepared for
U.S. Department of Commerce
Engineering Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8600

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August 2011

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Cover photo – Steel deck prior to reinforced concrete placement.

How to Cite This Publication

Sabelli, Rafael, Sabol, Thomas A., and Easterling, Samuel W. (2011). “Seismic design of composite steel deck and concrete-filled diaphragms: A guide for practicing engineers,” *NEHRP Seismic Design Technical Brief No. 5*, produced by the NEHRP Consultants Joint Venture, a partnership of the Applied Technology Council and the Consortium of Universities for Research in Earthquake Engineering, for the National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 11-917-10.

1. Introduction

Building structures are typically composed of horizontal spanning elements, such as beams and floor and roof decks; vertical elements, such as columns and walls; and foundation elements. Together these elements comprise an integral system that resists both vertical and lateral loads. Seismic design of building systems entails controlling the building displacements, typically by providing resistance to the inertial forces generated by the acceleration of the building mass. Often the great majority of the load is derived from the mass of the roof and floor systems themselves, and resistance is composed of a continuous lateral load path from these spanning elements to vertical elements that have lateral resistance (e.g., walls, braced frames, moment frames), which in turn deliver the forces to the foundation.

The first segment of this load path is composed of the diaphragm system. This system is typically conceived of as spanning horizontally between the vertical elements of the lateral load-resisting system. Without this element of the load path there would be no resistance to the movement of the distributed building mass, and thus large movements, and perhaps collapse, would result. Thus, diaphragms are a critical component of seismic design and must be properly designed to ensure adequate performance. Additionally, diaphragms serve a number of other functions in providing structural stability and resistance to lateral loads, as discussed in Section 2.

This Guide addresses the design of diaphragms composed of steel beams and steel deck with concrete fill. In passing, the Guide addresses some issues related to the design of diaphragms with non-composite (bare) steel deck, but a future Technical Brief devoted entirely to bare steel-deck diaphragms is anticipated.

The National Earthquake Hazards Reduction Program (NEHRP) Seismic Design Technical Brief No.3, *Seismic Design of Cast-in-Place Concrete Diaphragms, Chords, and Collectors*, includes a great deal of useful information on diaphragm design in general. In order to maximize the utility of this Technical Brief as a stand-alone design reference work, some material is duplicated here, however, this material is integrated with a treatment of conditions beyond the scope of the reinforced concrete diaphragm Technical Brief, such as semirigid and flexible diaphragms.

This Guide covers seismic design issues pertaining to Seismic Design Category B up through Seismic Design Category F. As Seismic Design Category A is exempt from seismic design, it is not specifically addressed, although many of the diaphragm analysis and design methods described herein are applicable to the design of diaphragms to resist wind forces and provide structural integrity in Seismic Design Category A buildings.

Sidebars in the Guide

Sidebars are used in this Guide to illustrate key points and to provide additional guidance on good practices and open issues in analysis, design, and construction.

Items not covered in this document

A number of important issues related to diaphragm design are not addressed in this document; these include:

- Formed concrete diaphragms on steel members (these are addressed in *Seismic Design Technical Brief No.3: Seismic Design of Cast-in-Place Concrete Diaphragms, Chords, and Collectors*);
- Out-of-plane wall support and design of sub-diaphragms;
- Design of open-web joists as chords or collectors;
- Ramp issues in parking garages;
- Saw-tooth roofs and similar discontinuities;
- Detailed treatment of steel-deck only systems;
- Strut-and-tie analysis methods; and
- Expansion joints and seismic separation issues.

The design forces and analysis requirements for diaphragms are contained in ASCE/SEI 7-10 *Minimum Design Loads for Buildings and Other Structures* (ASCE 2010, herein referred to as ACSE 7). ASCE 7-10 is the latest published version of that standard, though in a particular case at the time a reader may consult this Guide, a jurisdiction may reference the previous (2005) edition in its code regulations. The forward-looking approach here in this Guide will facilitate its use over the next several years, because ASCE 7-10 has been adopted into the 2012 edition of the *International Building Code* (IBC 2012, herein referred to as IBC), which establishes general regulations for buildings. The 2012 IBC adoption of ASCE 7-10 has no modifications relevant to composite or concrete-filled steel deck diaphragm design.

Component strengths are determined using ANSI/AISC 360 *Specification for Structural Steel Buildings* (AISC 2010, referred to here as AISC 360) for steel and composite members. ANSI/AISC 341 *Seismic Design Provisions for Structural Steel Buildings* (AISC 2010b, herein referred to as AISC 341) contains additional requirements, including limitations and quality requirements. The IBC adopts both of these standards.

The design in-plane shear strength of concrete-filled or unfilled steel deck can be determined by calculation, or it may be done by testing and subsequent development of an evaluation report. Historically, two approaches have commonly been used to calculate the in-plane shear strength. These approaches are described in the Steel Deck Institute *Diaphragm Design Manual* (SDI 2004, referred to here as SDI DDM, with SDI DDM03 citing the third edition) and the *Seismic Design of Buildings - TI 809-04* (USACE 1998.) Neither is a design code, however IBC recognizes the SDI DDM. Note that TI 809-04 often called the Tri-Services Manual, was superseded by UFC 3-310-04, *Seismic Design for Buildings* in 2007 and updated in 2010 (UFC 2010.) The specific design information that appears in TI 809-04 for diaphragms does not appear in UFC 3-310-04. A consensus standard for steel deck diaphragms that is predominately based on the SDI DDM03 is under development by the American Iron and Steel Institute. In cases where the designer wishes to ignore the presence of steel deck in concrete-filled systems, the in-plane strength of the concrete above the top flange of the deck is evaluated using Building Code Requirements for Structural Concrete and Commentary (ACI 2008, herein referred to as ACI 318). The attachment of the slab to the steel framing would then need to be addressed using one of the other documents, as ACI 318 does not explicitly address this condition. (References to the building code in this Guide refer to the editions cited above.)

Together these documents comprise the building code requirements applicable to composite deck and steel deck diaphragms. While each of these documents has been developed or revised over numerous cycles to work with the others, there nevertheless exist ambiguities, and engineering judgment is required in their consistent application. This Guide is intended to address these ambiguities and to provide guidance on the appropriate design of composite deck and steel deck diaphragms. While numerous respected practitioners, researchers, and other authorities have been consulted, this Guide represents only the opinion of the authors on matters not explicitly defined by building codes, design standards, or design manuals, and other interpretations may be reasonable.

This Guide was written for practicing structural engineers and is intended to provide guidance in the application of code requirements for the design of diaphragms in steel systems. This Guide will also be useful to others wishing to apply building code provisions correctly, such as building officials, and to those interested in understanding the basis of such code provisions and of common design methods, such as educators and students.

This Guide begins by generally discussing the role of diaphragms (Section 2), identifying the components of diaphragms (Section 3), and proceeding to the behavior of diaphragms (Section 4). Next the Guide describes the building analysis necessary to obtain appropriate diaphragm design forces (Section 5), and the analysis of the diaphragm itself (Section 6). The Guide proceeds to detailed guidance on the design of diaphragm components (Section 7). Additional requirements are given in Section 8, and constructability concerns are discussed in Section 9. References are listed in Section 10. Section 11 contains a list of notations, abbreviations, and a glossary. Section 12 provides credits for figures contained within this document.