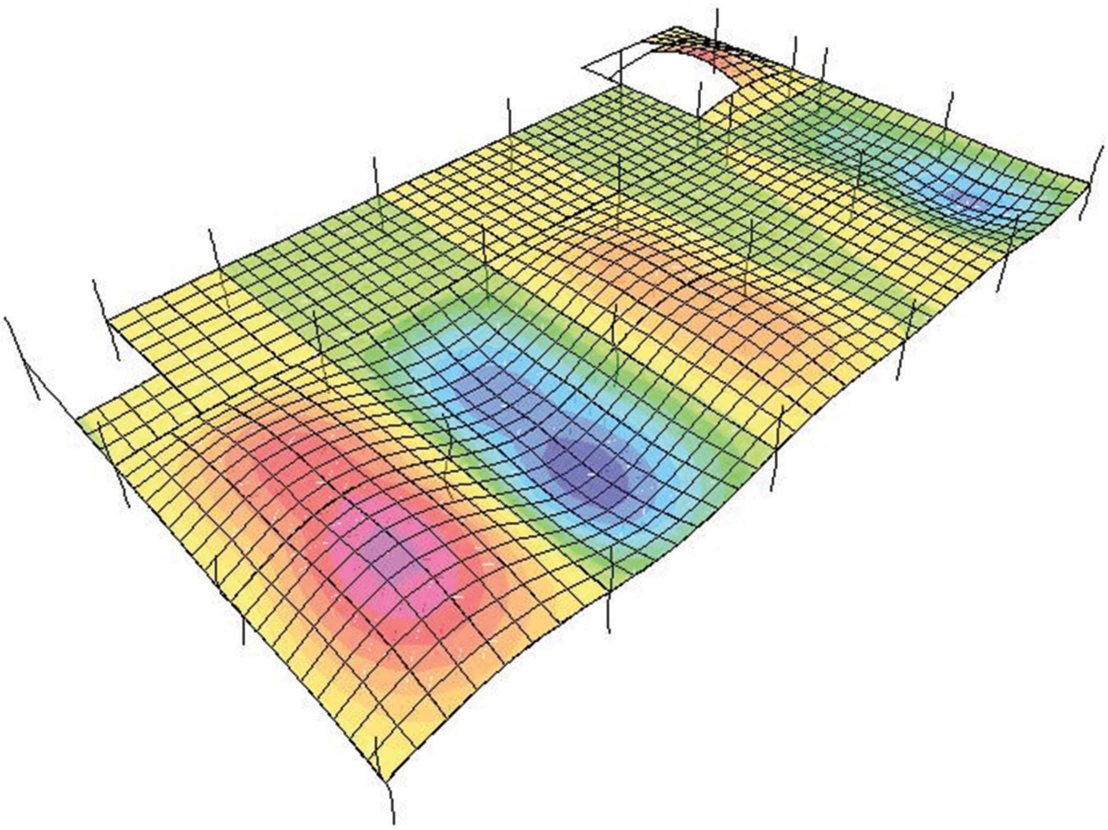
Steel Design Guide

11

Vibrations of Steel-Framed Structural Systems Due to Human Activity

Second Edition



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Vibrations of Steel-Framed Structural Systems Due to Human Activity

Second Edition

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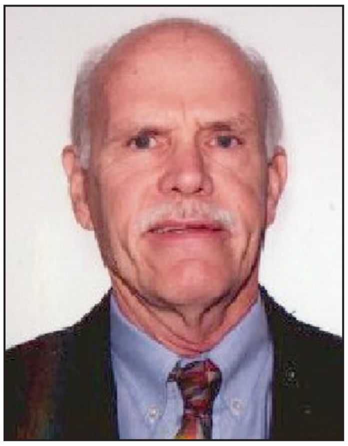
Preface

This is the second edition of Design Guide 11. The first edition was published in 1997 as *Floor Vibrations Due to Human Activity*. The scope of this edition has been broadened as reflected in the new title, *Vibrations of Steel-Framed Structural Systems Due to Human Activity*. Since 1997, a large volume of literature has been published on the response of steel-framed structural systems, including floors, monumental stairs and balconies due to human activity. Some human tolerance and sensitive equipment tolerance limits have been modified, and updated methods to evaluate high-frequency systems have been proposed. The use of the finite element method to analyze structural systems supporting human activity has been refined. Also, simplified methods to evaluate problem floors have been proposed. This second edition of the Design Guide updates design practice in these areas.

DEDICATION



This edition of Design Guide 11 is dedicated to Dr. David E. Allen, retired Senior Research Officer, Institute for Research in Construction, National Research Council Canada. Dr. Allen made outstanding contributions to the first edition of this Guide but was unable to participate in the writing of this second edition because of health reasons. Dr. Allen is known worldwide for his research and writing on floor vibration serviceability. His interest in vibration of structures due to human activity began in the early 1970s, and since then he has written numerous papers on the subject. He has been the major contributor to the vibration provisions in the National Building Code of Canada and is the first author of the Applied Technology Council Design Guide 1, *Minimizing Floor Vibration*. In 2004, Dr. Allen received the Julian C. Smith Medal for Achievement in the Development of Canada. His contributions to the development of guidelines for the evaluation of floor vibration serviceability will be long remembered by the structural engineering profession.

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Chapter 1
Introduction

1.1 OBJECTIVES OF THE DESIGN GUIDE

The primary objective of this second edition remains the same as that of the first edition, i.e., to provide basic principles and simple analytical tools to evaluate vibration serviceability of steel-framed structural systems subjected to human activity. Both human comfort and the need to control the vibration environment for sensitive equipment are considered. Other objectives are to provide guidance on the use of the finite element method and on developing remedial measures for problem floors.

1.2 ROAD MAP

This Design Guide is organized for the reader to move from basic principles of occupant-caused vibration and the associated terminology in Chapter 1; to serviceability criteria for evaluation and design in Chapter 2; to estimation of natural frequency (the most important vibration property) in Chapter 3; to applications of the criteria in Chapters 4, 5, 6 and 7; and finally to possible remedial measures in Chapter 8. Chapter 4 covers walking-induced vibration of building floors, pedestrian bridges and monumental stairs. Chapter 5 concerns vibrations due to rhythmic activities such as dancing, aerobics and spectator crowd movements. Chapter 6 provides guidance on the design of floors supporting sensitive equipment, a topic requiring increased specialization. Chapter 7 provides guidance on the use of the finite element method to predict vibration response of structural systems that cannot be evaluated by the methods in Chapters 4, 5 and 6. Chapter 8 provides guidance on the evaluation of problem floors and the choice of remedial measures. Symbols definitions and References are found at the end of the Design Guide.

1.3 BACKGROUND

Vibration serviceability is a dominant consideration in the design of steel floor framing, monumental stairs, pedestrian bridges and stadia. Modern design specifications, coupled with today's stronger steels and concretes, allow for lighter sections when strength considerations govern. Monumental stairs and pedestrian bridges are longer and more slender than in past years. Balconies and grandstands in stadia have longer cantilevers and lighter seating. Office building build-out has also dramatically changed with the universal use of computers. Virtually paperless offices are lighter and have lower damping than those with large file cabinets, heavy desks, and bookcases. Modern open floor layouts with few partitions, widely spaced demountable partitions or none at all, and light furniture add to the problem. Renovated office spaces with the removal of fixed partitions have resulted in floor vibration complaints that had never been encountered previously. As a result, vibration due to human activity is a significant serviceability concern.

A traditional stiffness criterion for steel floors limits the live load deflection of beams or girders supporting "plastered ceilings" to span/360. This limitation, along with restricting the member span-to-depth ratio to 24 or less, have been widely applied to steel-framed floor systems in an attempt to control vibrations, but with limited success. A number of analytical procedures have been developed in several countries that allow a structural designer to assess a design for occupant comfort for a specific activity and for suitability for sensitive equipment. Generally, these analytical tools require the calculation of the first natural frequency and the maximum amplitude of acceleration or velocity due to a reference excitation. An estimate of damping in the floor is also required. The response is compared to the tolerance limit for human comfort or sensitive equipment, as applicable, to determine whether the system meets serviceability requirements. Some of the analytical tools incorporate limits into a single design formula whose parameters are estimated by the designer.

The analytical tools presented in this Design Guide represent years of research and have been shown to yield useful predictions of the acceptability of vibration response of steel-framed structures subject to human activity.

1.4 BASIC VIBRATION TERMINOLOGY

The purpose of this section is to introduce the reader to terminology and basic concepts used in this Design Guide.

Acceleration ratio. For the purposes of this Design Guide, the vertical acceleration at a location divided by the acceleration of gravity.

Bay. A rectangular plan portion of a floor defined by four column locations.

Beam or joist panel. A rectangular area of a floor associated with movement of its beams or joists. The area is equal to the beam or joist span times an effective width determined from the floor system structural properties.

Damping and critical damping. Damping refers to the loss of mechanical energy in a vibrating system over time. Viscous damping is associated with a retarding force that is proportional to velocity. Damping is usually expressed as the percent of critical damping, which is the ratio of actual damping (assumed to be viscous) to critical damping. Critical damping is the smallest amount of viscous damping for which a free vibrating system that is displaced from equilibrium and released comes to rest without oscillation. For damping that is smaller than critical, the system oscillates freely as shown in Figure 1-1. Damping cannot be calculated and must be determined experimentally, usually using experimental modal analysis techniques that result in detailed identification of modal properties. In some cases, it can be measured using the decay of vibration following an impact such as a heel-drop. Damping ratios for the structural systems considered in this Design Guide are usually between 1% and 8% of critical viscous damping.

Dynamic loadings. Dynamic loadings can be classified as harmonic, periodic, transient and impulsive as shown in Figure 1-2. Harmonic or sinusoidal loads are usually associated with rotating machinery. Periodic loads may be caused by rhythmic human activities such as dancing and aerobics or by machinery that generate repetitive impacts. Transient loads occur from the movement of people and include walking and running. Single jumps and heel-drop impacts are examples of impulsive loads.

Effective impulse. For the purposes of this Design Guide, an effective impulse is a mathematical representation of a human footstep. It is used to scale the unit impulse response of a single-degree-of-freedom system to the response of the system to a human footstep.

Equivalent sinusoidal peak acceleration (ESPA). Amplitude of sinusoidal acceleration that would have approximately the same effect on occupants as that of a walking

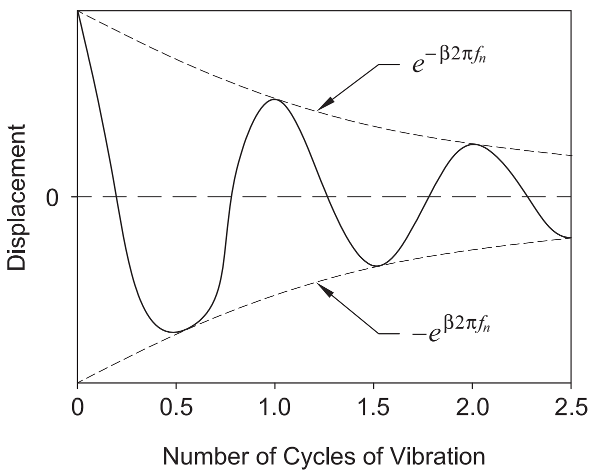

Fig. 1-1. Decaying vibration with viscous damping.

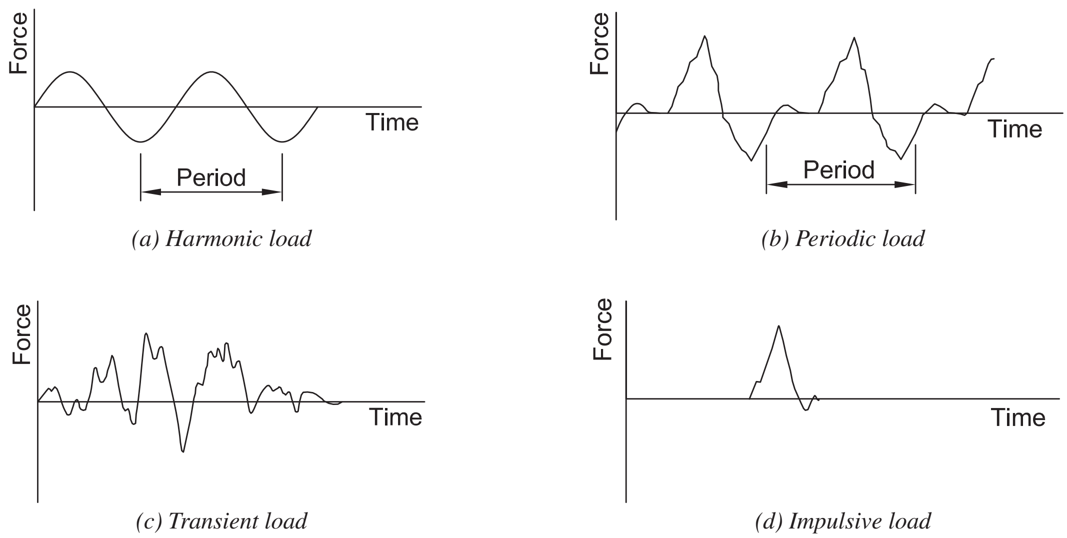

Fig. 1-2. Types of dynamic loadings.