

ASCE STANDARD

ASCE/SEI

49-21

# Wind Tunnel Testing for Buildings and Other Structures

Currently in preview, click to buy full version

ASCE STANDARD

ASCE/SEI

**49-21**

# Wind Tunnel Testing for Buildings and Other Structures



PUBLISHED BY THE AMERICAN SOCIETY OF CIVIL ENGINEERS

Library of Congress Cataloging-in-Publication Data

Names: American Society of Civil Engineers, author.

Title: Wind tunnel testing for buildings and other structures.

Description: Reston, Virginia : American Society of Civil Engineers, 2021. | "ASCE/SEI 49-21." | Includes bibliographical references and index. | Summary: "ASCE/SEI 49-21 provides the minimum requirements for conducting and interpreting wind tunnel tests to determine wind loads on buildings and other structures"— Provided by publisher.

Identifiers: LCCN 2021034164 | ISBN 9780784415740 (paperback) | ISBN 9780784483367 (adobe pdf)

Subjects: LCSH: Wind tunnel testing. | Wind-pressure. | Buildings—Aerodynamics. | Structural analysis (Engineering)

Classification: LCC TA654.5 .W575 2021 | DDC 624.1/75—dc23

LC record available at [lcn.loc.gov/2021034164](http://lcn.loc.gov/2021034164)

Published by American Society of Civil Engineers

1801 Alexander Bell Drive

Reston, Virginia, 20191-4382

[www.asce.org/bookstore](http://www.asce.org/bookstore) | [ascelibrary.org](http://ascelibrary.org)

This standard was developed by a consensus standards development process that has been accredited by the American National Standards Institute (ANSI). Accreditation by ANSI, a voluntary accreditation body representing public and private sector standards development organizations in the United States and abroad, signifies that the standards development process used by ASCE has met the ANSI requirements for openness, balance, consensus, and due process.

While ASCE's process is designed to promote standards that reflect a fair and reasoned consensus among all interested participants, while preserving the public health, safety, and welfare that is paramount to its mission, it has not made an independent assessment of and does not warrant the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed herein. ASCE does not intend, nor should anyone interpret, ASCE's standards to replace the sound judgment of a competent professional, having knowledge and experience in the appropriate field(s) of practice, nor to substitute for the standard of care required of such professionals in interpreting and applying the contents of this standard.

ASCE has no authority to enforce compliance with its standards and does not undertake to certify products for compliance or to render any professional services to any person or entity.

ASCE disclaims any and all liability for any personal injury, property damage, financial loss, or other damages of any nature whatsoever, including without limitation any direct, indirect, special, exemplary, or consequential damages, resulting from any person's use of, or reliance on, this standard. Any individual who relies on this standard assumes full responsibility for such use.

ASCE and American Society of Civil Engineers—Registered in US Patent and Trademark Office.

*Photocopies and permissions.* Permission to photocopy or reproduce material from ASCE publications can be requested by sending an email to [permissions@asce.org](mailto:permissions@asce.org) or by locating a title in ASCE's Civil Engineering Database (<https://cedb.asce.org>) or ASCE Library (<https://ascelibrary.org>) and using the "Permissions" link.

*Errata:* Errata, if any, can be found at <http://dx.doi.org/10.1061/9780784415740>.

Copyright © 2021 by the American Society of Civil Engineers.

All Rights Reserved.

ISBN 978-0-7844-1574-0 (soft cover)

ISBN 978-0-7844-8336-7 (PDF)

Manufactured in the United States of America.

27 26 25 24 23 22 1 2 3 4 5

## ASCE STANDARDS

In 2016, the Board of Direction approved revisions to the ASCE Rules for Standards Committees to govern the writing and maintenance of standards developed by ASCE. All such standards are developed by a consensus standards process managed by the ASCE Codes and Standards Committee (CSC). The consensus process includes balloting by a balanced standards committee and reviewing during a public comment period. All standards are updated or reaffirmed by the same process every five to ten years. Requests for formal interpretations shall be processed in accordance with Section 7 of ASCE Rules for Standards Committees, which are available at [www.asce.org](http://www.asce.org). Errata, addenda, supplements, and interpretations, if any, for this standard can also be found at [www.asce.org](http://www.asce.org).

This standard has been prepared in accordance with recognized engineering principles and should not be used without the user's competent knowledge for a given application. The publication of this standard by ASCE is not intended to warrant that the information contained therein is suitable for any general or specific use, and ASCE takes no position respecting the validity of patent rights. The user is advised that the determination of patent rights or risk of infringement is entirely their own responsibility.

A complete list of currently available standards is available in the ASCE Library (<https://ascelibrary.org/page/books/standards>).

This page intentionally left blank

Currently in preview, click buy full version

## DEDICATION



The members of the Wind Tunnel Testing for Buildings and Other Structures Standards Committee of the Structural Engineering Institute respectfully dedicate this standard in the memory of Dr. Jon A. Peterka, P.E., who passed away on May 22, 2017.

Jon was a pioneer and community pillar of wind engineering. He was instrumental in the writing of the first version of ASCE 49 (and its antecedent, ASCE Manual of Practice 7), and was

relied on for thoughtful guidance as the ASCE 7 wind load provisions evolved. This service to our profession was only the tip of the iceberg in his passion for his work. Jon's imprint can be found throughout this standard, certainly in the knowledge and methods he contributed, but also in the spirit in which we strive to provide the information necessary to improve the transparency, consistency, and quality of wind tunnel testing.

This page intentionally left blank

Currently in preview, click buy full version

# CONTENTS

DEDICATION . . . . .	v
PREFACE . . . . .	xi
ACKNOWLEDGMENTS . . . . .	xii
1 GENERAL . . . . .	1
1.1 Scope . . . . .	1
1.2 Report Content . . . . .	1
1.3 Coordinate Systems . . . . .	1
1.4 Definitions . . . . .	1
1.5 Notation . . . . .	3
2 WIND TUNNEL SIMULATIONS. . . . .	5
2.1 General . . . . .	5
2.2 Geometric Scale Considerations . . . . .	5
2.3 Simulation of the Approach Flow . . . . .	5
2.3.1 Atmospheric Boundary-Layer Simulation . . . . .	5
2.3.1.1 Requirements for All Structures . . . . .	5
2.3.1.2 Additional Requirements for Low-Rise Structures . . . . .	6
2.3.1.3 Additional Requirements for Partial Turbulence Simulations. . . . .	6
2.3.2 Considerations for Tornadoes, Downbursts, and Other Nonsynoptic Winds. . . . .	6
2.4 Proximity Models . . . . .	6
2.5 Topographic Modeling. . . . .	6
2.6 Appurtenances to Buildings and Other Structures. . . . .	6
3 WIND LOADS FOR RIGID STRUCTURES. . . . .	7
3.1 General . . . . .	7
3.2 Models . . . . .	7
3.3 Reference Wind Velocity . . . . .	7
3.4 Measurement Techniques . . . . .	7
3.4.1 Pressure Measurement . . . . .	7
3.4.1.1 Pressure Integration . . . . .	7
3.4.1.2 Internal Pressures. . . . .	7
3.4.1.3 Calculation of Peak Pressures . . . . .	8
3.4.2 Direct Load Measurement . . . . .	8
3.4.2.1 Rigid Section Models . . . . .	8
3.5 Wind Loads on Products. . . . .	8
4 WIND LOADS AND EFFECTS FOR FLEXIBLE STRUCTURES . . . . .	9
4.1 General . . . . .	9
4.2 Measurement Techniques . . . . .	9
4.2.1 High-Frequency Force Balance . . . . .	9
4.2.2 Pressure Integration . . . . .	9
4.3 Analysis Techniques . . . . .	9
4.3.1 Calculation of Wind Loads and Effects . . . . .	9
4.3.2 Results and Presentation . . . . .	9
4.4 Inertial Wind Loads on Products . . . . .	9
5 WIND LOADS AND EFFECTS FOR AEROELASTIC STRUCTURES . . . . .	11
5.1 General . . . . .	11
5.2 Aeroelastic Models. . . . .	11

5.2.1	Dynamic Similarity Requirements . . . . .	11
5.2.1.1	Structural Damping . . . . .	11
5.2.1.2	Reynolds Number Similarity . . . . .	11
5.2.1.3	Froude Number Similarity . . . . .	11
5.2.1.4	Velocity and Time/Frequency Scaling . . . . .	11
5.2.2	Types of Aeroelastic Models . . . . .	11
5.2.2.1	Section Models . . . . .	11
5.2.2.2	Partial Aeroelastic Models . . . . .	11
5.2.2.3	Full Aeroelastic Models . . . . .	11
5.3	Test Conditions for Aeroelastic Models . . . . .	11
5.4	Analysis Techniques for Aeroelastic Model Tests . . . . .	12
5.5	Additional Reporting Requirements . . . . .	12
6	WIND CLIMATE ANALYSIS AND MODELING . . . . .	13
6.1	General . . . . .	13
6.2	Analysis of Historical Wind Velocity Data . . . . .	13
6.3	Tropical Cyclones . . . . .	13
6.4	Extratropical Storms . . . . .	13
6.5	Thunderstorms . . . . .	13
6.6	Tornadoes . . . . .	13
6.7	Orographic Winds . . . . .	13
6.8	Development of the Wind Climate Model and Combination with Wind Tunnel Data . . . . .	13
7	SNOW LOAD MODEL STUDIES . . . . .	15
7.1	Snow Load Model Studies . . . . .	15
8	MEASUREMENT REQUIREMENTS AND QUALITY ASSURANCE . . . . .	17
8.1	Instrumentation and Test Requirements . . . . .	17
8.2	Measurement Uncertainty . . . . .	17
8.3	Quality Assurance . . . . .	17
C1	GENERAL . . . . .	19
C1.1	Scope . . . . .	19
C1.2	Report Content . . . . .	19
C1.4	Definitions . . . . .	20
C2	WIND TUNNEL SIMULATIONS . . . . .	21
C2.1	General . . . . .	21
C2.2	Geometric Scale Considerations . . . . .	21
C2.3	Simulation of the Approach Flow . . . . .	21
C2.3.1	Atmospheric Boundary-Layer Simulation . . . . .	21
C2.3.1.1	Requirements For All Structures . . . . .	21
C2.3.1.2	Additional Requirements for Low-Rise Structures . . . . .	26
C2.3.1.3	Additional Requirements for Partial Turbulence Simulations . . . . .	26
C2.3.2	Considerations for Tornadoes, Downbursts, and Other Nonsynoptic Winds . . . . .	26
C2.4	Proximity Models . . . . .	28
C2.5	Topographic Modeling . . . . .	29
C2.6	Appurtenances to Buildings and Other Structures . . . . .	29
C3	WIND LOAD FOR RIGID STRUCTURES . . . . .	31
C3.1	General . . . . .	31
C3.2	Models . . . . .	31
C3.3	Reference Wind Velocity . . . . .	31
C3.4	Measurement Techniques . . . . .	31
C3.4.1	Pressure Measurement . . . . .	31
C3.4.1.1	Pressure Integration . . . . .	32
C3.4.1.2	Internal Pressures . . . . .	32
C3.4.1.3	Calculation of Peak Pressures . . . . .	32
C3.4.2	Direct Load Measurement . . . . .	33

	C3.4.2.1	Rigid Section Models . . . . .	33
C3.5		Wind Loads on Products. . . . .	33
C4		WIND LOADS AND EFFECTS FOR FLEXIBLE STRUCTURES . . . . .	35
	C4.1	General . . . . .	35
	C4.2	Measurement Techniques . . . . .	35
	C4.2.1	High-Frequency Force Balance . . . . .	35
	C4.2.2	Pressure Integration . . . . .	36
	C4.3	Analysis Techniques . . . . .	37
	C4.3.1	Calculation of Wind Loads and Effects . . . . .	37
	C4.3.2	Results and Presentation . . . . .	37
	C4.4	Inertial Wind Loads on Products . . . . .	37
C5		WIND LOADS AND EFFECTS FOR AEROELASTIC STRUCTURES . . . . .	39
	C5.1	General . . . . .	39
	C5.2	Aeroelastic Models. . . . .	40
	C5.2.1	Dynamic Similarity Requirements . . . . .	40
	C5.2.1.1	Structural Damping. . . . .	40
	C5.2.1.2	Reynolds Number Similarity. . . . .	40
	C5.2.1.3	Froude Number Similarity . . . . .	41
	C5.2.1.4	Velocity and Time/Frequency Scaling. . . . .	41
	C5.2.2	Types of Aeroelastic Models . . . . .	41
	C5.2.2.1	Section Models. . . . .	41
	C5.2.2.2	Partial Aeroelastic Models . . . . .	42
	C5.2.2.3	Full Aeroelastic Models . . . . .	42
	C5.3	Test Conditions for Aeroelastic Models . . . . .	43
	C5.4	Analysis Techniques for Aeroelastic Model Tests . . . . .	43
C6		WIND CLIMATE ANALYSIS AND MODELING. . . . .	45
	C6.1	General . . . . .	45
	C6.2	Analysis of Historical Wind Velocity Data . . . . .	45
	C6.3	Tropical Cyclones . . . . .	45
	C6.4	Extratropical Storm Systems. . . . .	45
	C6.5	Thunderstorms . . . . .	46
	C6.6	Tornadoes . . . . .	46
	C6.7	Orographic Winds . . . . .	46
	C6.8	Development of Wind Climate Model and Combination with Wind Tunnel Data . . . . .	46
C7		SNOW LOAD MODEL STUDIES . . . . .	49
	C7.1	Snow Load Model Studies . . . . .	49
C8		MEASUREMENT REQUIREMENTS AND QUALITY ASSURANCE. . . . .	53
	C8.1	Instrumentation Requirements . . . . .	53
	C8.2	Measurement Uncertainty . . . . .	54
	C8.3	Quality Assurance . . . . .	55
		REFERENCES . . . . .	57
		INDEX . . . . .	65

This page intentionally left blank

## PREFACE

Prepared by the Wind Tunnel Testing for Buildings and Other Structures Standards Committee of the Codes and Standards Activities Division of the Structural Engineering Institute of ASCE

*Wind Tunnel Studies for Buildings and Other Structures*, Standard ASCE/SEI 49-12, provides the minimum requirements for conducting and interpreting wind tunnel tests to determine wind loads on buildings and other structures. Wind tunnel tests are used to predict the wind loads and responses of a structure, structural components, and cladding to a variety of wind conditions. This standard includes commentary that elaborates on the background and application of the requirements.

Topics include simulation of wind in boundary-layer wind tunnels, local and area-averaged wind loads, overall wind effects, aeroelastically active structures, extreme wind climate, and snow load model studies.

New to this version are requirements for wind loads on products. Wind loads are a critical design consideration for many mass-produced products that are constructed or installed at many different sites and in many different situations. Such products can be building-mounted (sunshades, solar racking, HVAC units, screen walls) or freestanding (ground-mounted

solar trackers, gazebos, fences, communication towers). In addition, commentary guidance is provided for determining wind loads on buildings and other structures in tornadoes, which is an area of current active research.

The requirements outlined in this standard satisfy requirements for wind tunnel testing set out in *Minimum Design Loads for Buildings and Other Structures*, Standard ASCE 7. The loads produced by these tests are suitable for use in building codes and standards.

The material presented in this standard has been prepared in accordance with recognized engineering principles. This standard should not be used without first securing competent advice with respect to its suitability for any given application. The publication of the material contained herein is not intended as a representation or warranty on the part of ASCE, or of any other person named herein, that this information is suitable for any general or particular use or promises freedom from infringement of any patent or patents. Anyone making use of this information assumes all liability from such use.

This standard will be useful to those who design, conduct, and interpret wind tunnel tests for buildings, including structural engineers, architects, and building code officials.

This page intentionally left blank

## ACKNOWLEDGMENTS

ASCE acknowledges the work of the Wind Tunnel Testing for Buildings and Other Structures Standards Committee of the Codes and Standards Activities Division of the Structural Engineering Institute (SEI). This group comprises individuals from many backgrounds representing consumers, producers, and general interest individuals; included were wind engineers, consulting engineers, professors, and an insurance company representative. This standard was prepared through the consensus standards process by balloting in compliance with procedures of ASCE's Codes and Standards Committee.

The following individuals serve on the Wind Tunnel Testing Standards Committee:

### **Committee members**

Gregory A. Kopp, Ph.D., P.Eng., M.ASCE, *Chair*  
Christopher Letchford, Ph.D., P.E., F.ASCE, *Vice Chair*  
Frederick Haan, Ph.D., M.ASCE, *Secretary*  
Ryan Catarelli, Ph.D., A.M.ASCE, *Balloteer*  
David Banks, Ph.D., M.ASCE  
DongHun Yeo, Ph.D., P.E., M.ASCE  
Melissa Burton, Ph.D., CEng, Aff.M.ASCE  
Lakshmana Doddipatla, Ph.D., A.M.ASCE  
Brad Douglas, M.ASCE  
Peter Iglesias, P.E., M.ASCE  
John Kilpatrick, Ph.D., M.ASCE  
Franklin T. Lombardo, Ph.D., A.M.ASCE  
Forrest Masters, Ph.D., M.ASCE

Murray J. Morrison, Ph.D., A.M.ASCE  
Ted Stathopoulos, Ph.D., F.ASCE  
Peter Vickery, Ph.D., F.ASCE  
Bradley Young, P.E., M.ASCE

### **Associate members**

Peter A. Irwin, Ph.D, P.E., F.ASCE  
Ahsan Kareem, Ph.D., Dist.M.ASCE  
Thomas Mara, Ph.D., P.E., M.ASCE  
Patrick McCarthy, M.ASCE  
Mark Sterling, Ph.D.  
Teng Wu, Ph.D., M.ASCE  
Ioannis Zisis, Ph.D., A.M.ASCE

This page intentionally left blank

# CHAPTER 1

## GENERAL

### 1.1 SCOPE

This standard provides minimum requirements for wind tunnel tests to determine wind loads on, and responses of, buildings and other structures. Loads considered in this standard are wind loads for main wind-force-resisting systems (MWFRS) and for individual structural components and cladding (C&C) of buildings and other structures. Loads produced by tests meeting the specifications of this standard are suitable for use as design wind loads in applicable building codes and standards.

Provisions of this standard satisfy the requirements for wind tunnel testing of ASCE 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. Wind tunnel testing has the capability to perform measurements beyond those specifically addressed in this standard, including pedestrian wind evaluations, dispersion of airborne pollutants, fugitive particulates, and wind energy siting studies. Although these studies are not included in the scope of this document, they shall be permitted to be included within the test report addressing wind loads.

The flowchart in Figure 1-1 illustrates the organization of this standard; it is intended to assist the user in navigating the relevant chapters and to identify the scoping considerations therein.

### 1.2 REPORT CONTENT

The wind tunnel test report (hereinafter referred to as the report) shall be prepared to document the wind tunnel test setup, procedure, and results.

The report, including any appendixes, shall be auditable and contain sufficient information that any party reviewing or performing a peer review of the wind tunnel tests can clearly understand all testing methods, assumptions, and results. At a minimum, the report shall include the following material directly or this information shall be documented and be made promptly available to the sponsor on request:

1. Description of the test setup, objectives, and test methodology, including
  - (a) Similarity parameters for geometric (length), velocity, and time scaling;
  - (b) Characteristics of the target upwind exposure, terrain, and proximity features;
  - (c) Description of the measurement technique utilized; and
  - (d) Any other basic characteristics of the test setup.
2. Description of the properties of the simulated wind field for each wind direction considered, including
  - (a) Simulated and target mean velocity profiles,
  - (b) Simulated and target longitudinal turbulence intensity profiles, and
  - (c) Simulated and target turbulence spectra and longitudinal length scales.

3. Description of the development and application of the wind climate analysis, including
  - (a) Basic wind climate characteristics and a description of data set(s) used, and
  - (b) A description of the statistical method used to combine the climatological data with the aerodynamic response results.
4. Results of the tests
  - (a) The specific type of test results to be included in the report and the format in which they are to be used shall be based on the agreement between the sponsor and the wind tunnel laboratory.
5. Quantification of the uncertainty
  - (a) This shall include uncertainties associated with the testing process and techniques: structural property assumptions, the wind climate data, measurement devices, approach flow, and any other sources contributing to the overall uncertainty.

Time histories of the loads, pressures, and reference velocities shall be stored for future reference and quality control purposes.

Where wind tunnel test conditions vary from those specified in this standard, a justification for the variance shall be included in the report.

### 1.3 COORDINATE SYSTEMS

The following coordinate system with mean and fluctuating velocities is defined:

- $x, y, z$  = Right-hand coordinate axes,  $z$  is vertical;
- $U, V, W$  = Mean velocities in the  $x$ -,  $y$ -, and  $z$ -directions; and
- $u, v, w$  = Fluctuating portion of velocity vector in the  $x$ -,  $y$ -, and  $z$ -directions.

### 1.4 DEFINITIONS

Unless specified in this section, all terms used in this standard are consistent with definitions of the ASCE 7 wind load provisions.

**Aeroelastic Feedback:** Process by which motion of a body in the wind causes changes in applied wind pressures.

**Aeroelastic Model:** Model that simulates the stiffness, mass, and damping of the full-scale structure.

**Aeroelastic Structure:** Flexible building or other structure for which the aerodynamic forces are affected by the motion of the structure itself.

**Approved:** Acceptable to the Authority Having Jurisdiction.

**Atmospheric Boundary Layer (ABL):** Lower part of the atmosphere, typically 3,000 to 13,000 ft (1,000 to 4,000 m) thick