

**691**<sup>TM</sup>

# IEEE Guide for Transmission Structure Foundation Design and Testing

## IEEE Power Engineering Society

Sponsored by the  
Transmission and Distribution Committee

*and the*

## American Society of Civil Engineers

Sponsored by the  
Transmission Structure Foundation Design Standard Committee



Published by  
The Institute of Electrical and Electronics Engineers, Inc.  
3 Park Avenue, New York, NY 10016-5997, USA

26 December 2001

Print: SH94786  
PDF: SS94786

# IEEE Guide for Transmission Structure Foundation Design and Testing

Sponsor

**Transmission and Distribution Committee**

of the

**IEEE Power Engineering Society**

and

**Transmission Structure Foundation Design Standard Committee**

of the

**American Society of Civil Engineers**

Approved 6 December 2000

**IEEE-SA Standards Board**

**Abstract:** The design of foundations for conventional transmission line structures, which include lattice towers, single or multiple shaft poles, H-frame structures, and anchors for guyed structures is presented in this guide.

**Keywords:** anchor, foundation, guyed structure, H-frame structure, lattice tower, multiple shaft pole, single shaft pole, transmission line structure

---

The Institute of Electrical and Electronics Engineers, Inc.  
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2001 by the Institute of Electrical and Electronics Engineers, Inc.  
All rights reserved. Published 26 December 2001. Printed in the United States of America.

*Print:* ISBN 0-7381-1807-9 SH94786  
*PDF:* ISBN 0-7381-1808-7 SS94786

*No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.*

**IEEE Standards** documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information contained in its standards.

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied “**AS IS.**”

The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

In publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board  
445 Hoes Lane  
P.O. Box 1331  
Piscataway, NJ 08855-1331  
USA

Note: Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

IEEE is the sole entity that may authorize the use of certification marks, trademarks, or other designations to indicate compliance with the materials set forth herein.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; (978) 750-8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

# Introduction

(This introduction is not part of IEEE Std 691-2001, IEEE Guide for Transmission Structure Foundation Design and Testing.)

This design guide is intended for the use of the practicing professional engineer engaged in the design of foundations for electrical transmission line structures. This guide is not to be used as a substitute for professional engineering competency, nor is it to be considered as a rigid set of rules. Of all building materials, soil is the least uniform and most unpredictable; therefore, the methods described in this guide may not be the only methods of design and analysis, nor may they be appropriate in all situations. Design and analysis must be based upon sound engineering principles and relevant experience.

This design guide is the result of a major effort to consolidate the results of published reports and data, ongoing research, and experience into a single document. It is also an outgrowth of the previously published efforts of a joint committee of the American Society of Civil Engineers and the Institute of Electrical and Electronic Engineers, which combined the knowledge, expertise, and experience of both organizations in the field of transmission line structure foundation design. Electrical transmission line structures are unique when compared with other structures, primarily in that no human occupancy is involved and the loading requirements are different from other structure types. The primary loading of most conventional structures or buildings is a dead load or sustained live load and lateral wind forces or seismic loads. The primary loading of a transmission line structure is caused by meteorological loads, such as wind and ice, or combinations thereof [B68].<sup>1</sup> Under normal weather or operating conditions, the loads may be only a fraction of the ultimate capacity of tangent structures, but the application of the design load is short term and sometimes violent as nature unleashes its fury. In addition, a finite probability exists that the design load could be exceeded.

Foundations for transmission line structures are called on to resist loading conditions consisting of various combinations. Lattice tower foundations typically experience uplift or compression and horizontal shear loads. H-frame structures experience combinations of uplift or compression and horizontal shear and moment loads. Single pole structures experience horizontal shear loads and large overturning moments. Foundations for transmission structures must satisfy the same fundamental design criteria as those for any other type of structure—adequate strength and stability, tolerable deformation, and cost-effectiveness. In addition, transmission line structures may be constructed hundreds or thousands of times in a multitude of subsurface conditions encountered along the same route. Therefore, optimization and standardization for cost-effectiveness is highly desirable.

This design guide addresses fundamental performance criteria and the design methods associated with transmission line structure modes of loading, much of which is not found in geotechnical engineering textbooks.

Many alternative approaches can be used for the geotechnical design of foundations for transmission line structures. It is the intent of this design guide to provide several approaches to the design of various foundation types that are consistent with the present state of geotechnical engineering practice. Where several methods are presented for the design of a particular type of foundation, the design engineer should exercise sound engineering judgment in determining which method is most representative of the situation.

---

<sup>1</sup>The numbers in brackets correspond to those of the bibliography in Annex A.

## Participants

At the time this guide was completed, the Foundation Design Standard Task Group of the Line Design Methods Working Group; Towers, Poles, and Conductors Subcommittee; and Transmission and Distribution Committee had the following membership:

**Anthony M. DiGioia, Jr., IEEE Co-Chair**

Fred Dewey  
Yen Huang

Jake Kramer

Bob Peters  
Pete Taylor

At the time this guide was completed, the Transmission Structure Foundation Design Standards Committee of the ASCE had the following membership:

**Paul A. Tedesco, ASCE Co-Chair**

Wesley W. Allen, Jr.  
David R. Bowman  
Kin Y. C. Chung  
Samuel P. Clemence  
Dennis J. Fallon  
Safdar A. Gill

Adel M. Hanna  
Thomas O. Keller  
Fred H. Kulhawy  
S. Bruce Langness  
Robert C. Latham  
Edwin B. Lawless III  
Donald D. Oglesby

Marlyn G. Schepers  
Wayne C. Teng  
Charles H. Trautmann  
Dale E. Welch  
Robert M. White  
Harry S. Wu

When the IEEE-SA Standards Board approved this standard on 6 December 2000, it had the following membership:

**Donald N. Heirman, Chair**

**James T. Carlo, Vice Chair**

**Judith Gorman, Secretary**

Satish K. Aggarwal  
Mark D. Bowman  
Gary R. Engmann  
Harold E. Epstein  
H. Landis Floyd  
Jay Forster\*  
Howard M. Frazier  
Ruben D. Garzon

James H. Gurney  
Richard J. Holleman  
Lowell G. Johnson  
Robert J. Kennelly  
Joseph L. Koepfinger\*  
Peter H. Lips  
L. Bruce McClung  
Daleep C. Mohla

James W. Moore  
Robert F. Munzner  
Ronald C. Petersen  
Gerald H. Peterson  
John B. Posey  
Gary S. Robinson  
Akio Tojo  
Donald W. Zipse

\*Member Emeritus

Also included is the following nonvoting IEEE-SA Standards Board liaison:

Alan Cookson, *NIST Representative*

Donald R. Volzka, *TAB Representative*

Andrew D. Ickowicz  
*IEEE Standards Project Editor*

# Contents

1.	Overview .....	1
1.1	Scope .....	1
1.2	System design considerations .....	1
1.3	Other considerations .....	2
2.	Loading and performance criteria .....	3
2.1	Loading .....	3
2.2	Foundation performance criteria and structure types.....	5
3.	Subsurface investigation and selection of geotechnical design parameters.....	10
3.1	General .....	10
3.2	Phases of investigation.....	10
3.3	Types of boring samples .....	13
3.4	Soil and rock classification .....	15
3.5	Engineering properties .....	18
4.	Design of spread foundations.....	23
4.1	Structural applications .....	23
4.2	Analysis.....	31
4.3	Traditional design methods.....	66
4.4	Construction considerations.....	73
4.5	General foundation considerations .....	74
5.	Design of drilled shaft and direct embedment foundations .....	77
5.1	Types of foundations.....	77
5.2	Structural applications .....	79
5.3	Drilled concrete shaft foundations .....	80
5.4	Direct embedment foundations .....	110
5.5	Precast-prestressed, hollow concrete shafts and steel casings .....	113
5.6	Design and construction considerations.....	113
6.	Design of pile foundations .....	115
6.1	Pile types and orientation.....	116
6.2	Pile stresses .....	121
6.3	Pile capacity .....	122
6.4	Pile deterioration .....	137
6.5	Construction considerations.....	139
7.	Design of anchors .....	139
7.1	Anchor types .....	139
7.2	Anchor application.....	142
7.3	Design analysis .....	144
7.4	Group effect .....	163
7.5	Grouts.....	163

7.6 Construction considerations .....	164
8. Load tests .....	167
8.1 Introduction.....	167
8.2 Instrumentation .....	169
8.3 Scope of test program .....	170
Annex A (informative) Bibliography .....	177

# IEEE Guide for Transmission Structure Foundation Design and Testing

## 1. Overview

### 1.1 Scope

The material presented in this design guide pertains to the design of foundations for conventional transmission line structures, which include lattice towers, single or multiple shaft poles, H-frame structures, and anchors for guyed structures. It discusses the mode of loads that those structures impose on their foundations and applicable foundation performance criteria. The design guide addresses subsurface investigations and the design of foundations, such as spread foundations (footings), drilled shafts, direct embedded poles, driven piles, and anchors. The full-scale load testing of the above-listed foundation types is also presented.

This design guide does not include the structural design of the foundations nor the design of the structure. Citations [B5]<sup>1</sup> and [B50] provide guidance for the design of lattice towers and tubular steel poles, respectively. The foundation engineer should have an understanding of the magnitudes and time-history of various loading conditions imposed on the foundations in order to provide a suitable foundation to support the transmission line structures under the actual loading conditions that may be reasonably expected in actual service.

### 1.2 System design considerations

A transmission line is a system of interconnected elements, each individually designed. The overall line must integrate all of these individual design elements into a coordinated structural system.

Every decision made for the system should consider total installed cost, of which foundations are a major consideration. For example, wire tensions are sometimes increased to minimize the number and/or height of the supporting structures. However, if a significant number of angles is in the line, total installed costs may be higher because of increased angle structure and foundation costs. Similarly, when developing structure configurations, a wider base structure could be considered to reduce foundation loads and thereby decrease the foundation cost. This must be evaluated against the added cost of widening the structure.

---

<sup>1</sup>The numbers in brackets correspond to those of the bibliography in Annex A.