Panel Session: Structural Reliability-Based Design of Utility Poles and the National Electrical Safety Code

Nelson Bingel, Habib Dagher, Ronald Randle, Ronald Wolfe, Lawrence Slavin*,
Michael Voda, Jerry Wong

***Abstract*--The 2002 Edition of the National Electrical Safety Code provides basic safety rules for outdoor electric power and telecommunications lines and structures. The NESC specifies overload factors and strength factors in its Strength and Loading rules for transmission and distribution structures and poles. These factors have been selected based upon subjective criteria, including a combination of engineering judgment and experience. Although it is recognized that a long history of successful experience does provide a reasonable basis for the selection of these parameters, it is also understood that more objective criteria must be implemented to update and extend the NESC to reflect new materials, as well as to address the extended usage of structures to previously unforeseen applications. Thus, the American Society of Civil Engineers has developed the *Reliability-Based Design of Utility Pole Structures* manual to determine appropriate strength and loading factors based upon objective reliability criteria. Members of the NESC have worked closely with the ASCE in the development of this important document. The NESC is presently developing change proposals to incorporate the essential results of the SRBD Manual into the 2007 edition of the NESC.**

I. INTRODUCTION

THE 2002 Edition of the National Electrical Safety Code (NESC) utilizes Load and Resistance Factor Design (LRFD) in its Strength and Loading rules, comprising Sections 24 – 27, providing basic safety rules for electric power and communications utility lines and structures. As such, the NESC specifies Overload Factors and Strength Factors for transmission and distribution structures and poles. These factors have been selected based upon subjective criteria, including a combination of engineering judgment and experience. Although it is recognized that a long history of successful experience does provide a reasonable basis for the selection of these parameters, it is also understood that more objective criteria must be implemented to update and extend the NESC to reflect new materials, as well as to address the extended usage of structures to previously unforeseen applications -- e.g., joint-usage (power and communications) distribution poles with a proliferation of attachments. Thus, the RBD Committee of the American Society of Civil Engineers (ASCE) has developed the Manual of Engineering Practice, *R̲eliability-B̲ased D̲esign of Utility Pole S̲tructures* ("SRBD Manual") [1] to determine appropriate strength and loading factors based upon objective, statistically-based, reliability criteria. The SRBD Manual is expected to be published and available to the public in 2003. Due to the mutual interest, members of the NESC have worked closely with the ASCE in the development of this important document. Task Force 5.1.8 of the NESC is presently developing specific change proposals to attempt to incorporate the essential results of the SRBD Guide into the upcoming (2007) edition of the NESC.

N. G. Bingel is with Osmose, Inc., Buffalo, NY 14209 (e-mail: nbingel@osmose.com).

H. J. Dagher is with the Advanced Structures and Composites Laboratory, University of Maine, Bangor, ME 04469 (e-mail: hd@umit.maine.edu).

R. E. Randle is with EDM International, Inc., Fort Collins, CO 80525 (email: rrandle@edmlink.com).

R. W. Wolfe is with the Forest Products Laboratory, U.S. Department of Agriculture, Madison, WI 53705 (email: rwwolfe@facstaff.wisc.edu).

*L. M. Slavin, organizer of the Panel Session, is with Outside Plant Consulting Services, Inc., Rockaway, NJ 07866 (email: lslavin@ieee.org).

M. D. Voda is with Salt River Project, Phoenix, AZ 85072 (email: mdvoda@srpnet.com).

C. J. Wong is with Florida Power & Light, Juno Beach, FL 33408 (email: Jerry_Wong@FPL.com)

II. DESCRIPTION

The present Panel Session provides a basic review of the NESC Strength and Loading rules, followed by a description of the SRBD Manual and its development. There is also a description of present change proposals being developed for modification of the NESC to reflect the SRBD results and recommendations. The procedure for approving such changes to the NESC includes a public comment period (September 1, 2004 through May 1, 2005) following the availability of the NESC-2007 Preprint containing all proposed changes. All public comments are subsequently discussed and resolved within the NESC Subcommittees. The 2007 Edition of the NESC is published in August 2006.

A. NESC History (Strength and Loading)

As stated in the 2002 Edition of the NESC [2], the "purpose of these rules is the practical safeguarding of persons during the installation, operation, or maintenance of electric supply and communication lines and associated equipment. These rules contain the basic provisions that are considered necessary for the safety of employees and the public under the specified conditions. This code is not intended as a design specification or as an instruction manual." Thus, the utilities may typically provide their own detailed specifications and procedures that exceed the basic provisions of the NESC with regard to the physical design of their structures, including transmission structures and towers, and distribution poles. Nonetheless, in many cases the NESC does serve as a baseline and is often used as the design criteria -- particularly for distribution facilities

The NESC provides for the basic strength requirements using the recognized Load and Resistance Design (LRFD) format for which the following relationship must be maintained:

$$\text{load factor} \times \text{load} \leq \text{strength factor} \times \text{resistance} \qquad (1)$$

This relationship is used to ensure that the structure will withstand the effects of severe storm events. Section 25 of the NESC currently specifies two storm events: Combined Ice and Wind (Rule 250B), based upon the historical NESC Loading Districts map, and Extreme Wind (Rule 250C), based upon the three-second gust wind speed map of the ASCE 7-98 and ASCE 7-02 Standard [3]. In NESC-2002, and earlier editions, the latter loads are only applicable to structures exceeding 60 ft. height, thereby excluding most distribution poles. The "load" term in (1) is calculated from the weights of the conductors plus ice, as appropriate, as well as lateral wind forces on the structures and ice-covered conductors, cables, … Section 25 of the NESC also specifies a variety of "load factors" (or "overload factors") that are applied to these loads, which are a function of the type storm event (Rule 250B or Rule 250C), nature of the load (vertical, transverse, …), Grade of Construction, and (in some cases,) material. The purpose of the overload factor is to amplify the effects, as necessary, of the loads calculated from a particular storm map, which otherwise may not be sufficiently severe for the particular application.

The "resistance" term in (1) represents the strength of the structure or component, consistent with industry specifications for the particular structural material (wood, metal, concrete, …). Section 26 of the NESC designates "strength factors" to be applied to these industry-specified strength levels to account for the variable nature of the products and the nominal values specified by the industries. For example, the ANSI-O5.1 Standard [4] provides designated wood fiber strength and lateral load capability essentially corresponding to the average values of naturally-grown wood poles, characterized by a relatively wide variability that is also provided in the Standard. It is therefore necessary to apply a reduction factor, or "strength factor", that will yield a conservative value that is appropriate to meet basic safety requirements. For other materials, such as engineered products (metal or pre-stressed concrete), the variability is relatively small, and the industry-specified strength levels are already given at a "minimum" level or rating, corresponding to a strength factor of 1. In general, the strength factors in the present NESC are also a function of the Grade of Construction.

The Grade of Construction is a key parameter since it is used to designate the degree of importance of the utility line, and therefore the desired reliability level. Grade B construction is intended to be of higher reliability than Grade C, which is of higher reliability than Grade N (unspecified load and strength factors). In practice, Grade B level construction is often the objective for transmission lines and structures, while Grade C is applicable for most distribution facilities.

For a distribution line without significant route bends, the controlling NESC criteria is typically transverse wind load under Combined Ice and Wind. The corresponding Loading Districts map specifies radial ice thickness on the conductors of ½-in., ¼-in., or 0-in., corresponding to the Heavy, Medium, and Light Loading areas. The specified wind pressures correspond to a wind speed of 40 mph for the Heavy or Medium districts, and 60 mph for the Light district. For a Grade C distribution pole (wood, steel, or concrete), the corresponding overload factor to be applied to the calculated transverse wind load is 1.75 (most applications). The Grade C strength factor is 0.85 for wood and 1.0 for steel, reflecting the different material characteristics and industry standards for designating material strengths. For Grade B construction, where required, a greater overload factor (2.50) would apply, as well as a lower strength factor (0.65) for wood materials.

B. *SRBD Description and Methodology*[1]

The overload and strength factors in the NESC, as well as the applicability of its specific rules, have been selected based upon subjective criteria, including a combination of engineering judgment and experience. Although this procedure has generally been successful, it is desirable that more objective criteria be implemented in the NESC. For example, areas of discussion and disagreement within the utility industry have related to the use and quantitative specification of the various NESC overload and strength factors in (1), as well as the applicability of the various types of storm loadings to different applications. The SRBD Manual attempts to address these and other design-related issues beyond the scope of the NESC.

The objective of ASCE Manual of Engineering Practice, *Reliability-Based Design of Utility Pole Structures*, is to provide a design methodology for distribution and transmission pole structures that yields relatively consistent reliabilities across all materials. In future editions, it is planned to expand this document to cover SRBD for other types of utility structures, components and related load considerations. The SRBD Manual also addresses the following:

- Defines minimum reliability levels for both NESC grades B and C construction based on reliability analyses of existing NESC pole designs. Therefore, designers can still produce designs to NESC Grades B and C, with more consistent results.

[1] The present description is based upon the latest available draft of the SRBD Manual at the time of the writing of this paper.

- Provides a means for quantifiably increasing reliability whenever needed or justified. An essential line should be more reliable than a less important line.
- Achieves relatively uniform structural reliability across all pole materials, thereby allowing utilities to compare the cost of equivalent lines made of different materials.
- Opens the door for innovation by allowing the introduction of new materials into pole design.
- Encourages manufacturers to continually improve their products by providing design incentives for more reliable poles and better databases for strength. A manufacturer that develops better statistical data on pole strength is allowed to adjust the strength factors accordingly.
- Provides uniform procedures for defining the nominal strength of transmission and distribution structures to be used in conjunction with the available strength guides (e.g., ASCE Manual 72 [5], ANSI O5.1-2002). It also suggests that all future editions of strength guides provide nominal or characteristic strength values at, or near, the 5^{th} percentile of strength, i.e., the 5% Lower Exclusion Limit (LEL). A table (see Table I) is provided to be used with existing strength guides to adjust load and strength factors depending on the provided LEL of the nominal strength and the degree of strength variability.
- Complements ASCE Manual 74 [6]. The SRBD Manual does not provide new methods for calculating loads and load combinations, and refers to ASCE Manual 74's procedures for computing design loads and load factors that are independent of the materials of the supporting structures. It is consistent with ASCE Manual 74's approach that a loading agenda should reflect uncertainties in the loads and the accepted risk that these loads may be exceeded.
- Brings pole structural design in line with various other well-established Reliability-Based Design codes.

Fig. 1 illustrates the random (statistical) nature of the material strength as well as the storm loading. Whenever the severity of the storm loading exceeds the strength, the structure will fail. For example, the combination of a relatively rare storm at the upper tail of its statistical distribution with a weak structure or component at the lower tail of its strength distribution will result in failure. The frequency at which this will occur -- i.e., the failure rate of the utility line -- is related to the overlap region of the two random distributions. The greater the overlap region, the higher the failure rate and the lower the reliability of the utility line. Alternatively, the reliability may be measured by the degree of separation between the two distribution curves, β. As indicated in Fig. 1, the parameter B is defined as the ratio of the difference in the mean values of the statistical distributions to the combined standard deviation. Greater values of β correspond to higher reliability levels.

Although the curves illustrated in Fig. 1 are conveniently shown as symmetric, bell-shaped Normal distributions, more complicated, asymmetric distributions more realistically represent the storm loadings and structural strengths.

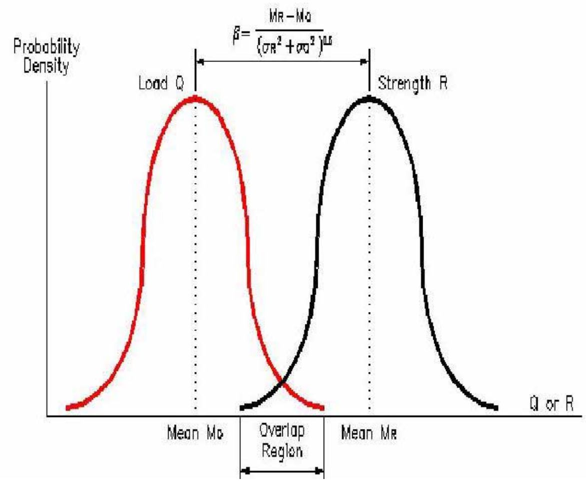

Fig. 1. Random nature of structural strength and variability of storm loadings.

In comparison to the somewhat subjectively-based overload and strength factors specified by the NESC for use in LRFD equation (1), more objectively-based values for these factors may be obtained by reliability-based techniques. It is assumed, therefore, that the storm loadings are properly characterized in a statistical manner, such as directly related to 50-year type storm events, in contrast to the historical Loading Districts map (Combined Ice and Wind) presently used in the NESC. Such statistically-based maps have been commonly used in the ASCE 7 building standard [3], including the Extreme Wind map recently incorporated into NESC-2002, as well as the recently introduced 50-year combined ice and wind map. Appropriate load factors may then be applied to loads derived from these maps, and solely used to effect the reliability of the structure or utility line, without regard to the selection of the strength factors.

In the SRBD implementation of LRFD, the strength factors are independent of the desired reliability level, and are solely dependent upon the basis by which the particular material or product strength is specified, in combination with the variability of the material. In general, it is recommended that the 5% LEL strength be specified by all product manufacturers, for which a strength factor of approximately 1.0 would be appropriate. Table I, however, provides a means of explicitly selecting equivalent strength factors as a function of the industry-provided nominal strength (% LEL) and has been developed to provide approximately equal reliability levels between different materials characterized by their variability. The latter is expressed as the Coefficient of Variation (COV_R), equal to the mean strength divided by the standard deviation. Based upon the results in Table I, a material with a specified mean strength (essentially 50% LEL), and COV_R of 0.2, would have a strength factor of 0.78 -- or, approximately 0.75 -- corresponding the three main wood species (Southern Pine, Douglas Fir, Western Re Cedar) as reported in ANSI-O5.1-2002.

C. Load Factors (Reliability Calibration to NESC)

Table II provides recommended load factors for the purposes of the NESC, resulting from an extensive reliability calibration effort of the SRBD Manual to historic NESC designs. As part of the effort, three types of tangent poles were designed at 40 US locations for both NESC Grade B and Grade C construction (240 poles). The reliabilities of these tangent poles designed according to the basic NESC rules were evaluated using best available probabilistic wind and wind-on-ice models at each of these 40 locations. It is important to note that the reliability of NESC designs varied with location and pole height, even within the same loading district. Since this calibration study was restricted to tangent structures, line tension effects were not considered at this time. Future editions of the SRBD Manual will consider angle and dead end structures.

TABLE I
RECOMMENDED STRENGTH FACTOR AS A FUNCTION OF NOMINAL STRENGTH (% LOWER EXCLUSION LIMIT) AND PRODUCT VARIABILITY

Nominal Strength, Lower Exclusion Limit, e(%)	Strength Factor[a] for COV_R =			
	0.05	0.1	0.2	0.3
0.1	1.01	1.16	1.44	1.71
1	0.97	1.07	1.23	1.37
2	0.96	1.04	1.17	1.26
5	0.94	1.00	1.08	1.12
10	0.92	0.96	1.00	1.01
20	0.90	0.92	0.92	0.89
50	0.87	0.85	0.78	0.69

[a]Assumes Log-normal Strength Variability

Using this information, SRBD load factors were selected that would require pole designs (e.g., wood pole class size) and reliability levels generally consistent with historic NESC rules and practices. Thus, the load factors indicated in Table II, as applied to the probabilistically-based ASCE 7 storm loads, and used in combination with the strength factors of Table I, provide "equivalence" to NESC construction, "on-the-average" across the majority of the United States. This calibration process was desired because it is widely recognized that the NESC has successfully provided for reliable, cost-effective utility lines in this country, over an extended period of time. Departures from traditional NESC designs will occur at locations where the ASCE 7 extreme wind map or combined ice and wind map reflect local conditions requiring significantly different (i.e., greater or lower) structural capability than that resulting from use of the NESC Loading Districts map (Light, Medium and Heavy). Departures from NESC designs will also occur for poles close to, but less than, 60 ft high that have not traditionally been designed for extreme wind.

The use of the SRBD recommended load and strength factors and procedures will allow proper consideration of new situations, such as the proliferation of attachments of various diameters on joint-usage distribution lines.

D. Development of Pole Resistance (Strength) Values

The strength factors are applied to the nominal specified strength or resistance values, where it is assumed that the designer has knowledge of its technical basis (e.g., average strength, 5% LEL, …) and the associated variability. It is the responsibility of the manufacturer or product supplier to provide this strength information to the user or utility designer. The manufacturer may develop this information using several methods, as described in the SRBD Manual:

- Empirical
- Theoretical (Monte Carlo Simulations)
- Default

The method selected will depend upon the particular product and the degree of understanding of the technology, which relate to product maturity and history. For example, the theoretical method may be applicable to well-understood, engineered products, such as steel poles for which accurate analytical structural models are available. Similarly, the default method may be appropriate for which an apriori estimate of the product variability may be conservatively assumed. However, for new technologies (e.g., fiber-reinforced polymer) or in non-engineered, non-uniform, highly variable products (e.g., naturally grown wood poles), the empirical method, based upon full-scale pole testing, may be most appropriate. Thus example, the ANSI-O5.1-2002 Standard provides fiber stress and pole strength values (mean and COV_R) as derived from a large data base of full-scale pole test results.

TABLE II
RECOMMENDED LOAD FACTOR AS A FUNCTION OF STORM LOADING AND NESC GRADE OF CONSTRUCTION

NESC Grade of Construction	Minimum Load Factors Applied to "50-Year" Events	
	Extreme Wind	Combined Ice and Wind
Grade B	Wind Force: 1.0	Wind Force: 1.0 Ice Thickness: 1.0
Grade C	Wind Force: 0.5[b]	Wind Force: 1.0 Ice Thickness: 0.5

[b]If any portion of the structure or its supported facilities exceeds 60 ft above ground or water level, a load factor of 1.0 should be used.

In general, the empirical method is applicable to all type pole products. Since it provides strength characteristics based upon full-scale tests, it eliminates the need to make assumptions about the pole properties and behavior. Nonetheless, to maintain validity in the empirical results, and to provide a common basis of comparison with other products, it is important that standard, consistent test procedures be applied. ASTM D1036 [7] provides such a standard procedure for wood poles, and other available standards provide similar procedures for non-wood poles [8]. In addition, consideration must be given to the number of data points in the test program. Depending upon the product variability, relatively few data points would imply a correspondingly low degree of confidence in the statistical results. An estimate of the 5% LEL (i.e. the 5% Lower Tolerance Limit, LTL), to a specified degree of confidence, may be obtained by the following equation:

$$5\%\ LTL = mean\ (1 - K \times COV_R) \quad (2)$$

where the K-factor is a function of the number of data points used as the basis for calculating the mean and COV_R values, and the type probability distribution. For a Normal strength distribution and a very large number of data points, K approaches 1.645. For smaller sample sizes, K increases, corresponding to a lower assumed estimate of the 5% LEL. For a Log-normal strength distribution (generally preferred), a modified procedure is used, for which the effective K-factor also depends upon the magnitude of the variability, COV_R.

All of the methods used to determine the 5% LEL strength assume sufficient quality control in the manufacturing process such that the method reasonably characterizes the deployed product. Although the present discussion and SRBD Manual primarily focus on single poles structures, considered to be under a cantilever load due to transverse wind loadings, and subject to a limiting pole bending moment capacity, the principles may be extended to more general implementations and failure modes.

E. Implementation (Design Examples)

In order to demonstrate the practicality of the design guidelines, and as an aid to the user of the SRBD Manual, an Appendix is included in the Manual that provides a number of examples in which the recommended procedures have been implemented. The examples comprise both transmission and distribution poles (e.g., see Fig. 2), in a tangent design situation, containing power supply and communications attachments, as subject to transverse wind loads. Both extreme wind and combined ice and wind loadings are considered, as appropriate. The effects of eccentric vertical loads are included, as well as the additional bending moments due to “P-delta” effects as the poles lean over to resist the loads. The latter may be very significant, depending upon the stiffness of the structure. Poles were designed using a variety of materials for each case (wood, steel, concrete, and fiber-reinforced polymer), based upon the strength and load factors as specified in Table I and Table II. The design criteria included verification of the pole strength at the ground-line as well as at other locations along the pole, when critical, consistent with ANSI-O5.1-2002 recommendations for wood poles.

F. Related NESC Change Proposals

Table III shows the schedule for the development and availability of the 2007 Edition of the National Electrical Safety Code. Although it is still several years prior to publication, change proposals had to be submitted by July 17, 2003. In particular, Subcommittee 5 (Overhead Lines -- Strength and Loading) of the NESC Committee has been considering change proposals that attempt to incorporate the results of the SRBD Manual, as described herein, into Sections 25-27 of the Code. Thus, Task Force 5.1.8 has been meeting to develop associated change proposal(s) generated from within the NESC. In addition, the ASCE RBD Committee has also submitted related change proposals. The NESC Committee will evaluate the various proposals and present their recommendations to the public in 2004, with all comments to be resolved before final publication in 2006.

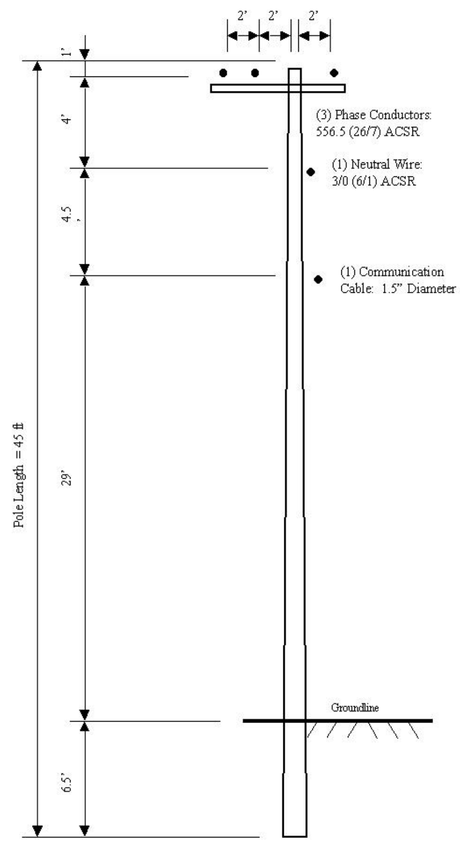

Fig. 2. Sample Distribution Pole Design Example.

The related SRBD change proposals currently put before the NESC propose the following changes:

- Replace the Loading Districts ice map with the latest available 50-year combined ice and ice map of ASCE 7.
- Adopt the strength factors of Table I (i.e., 0.75 for wood applied to the ANSI-O5.1 mean strength, and 1.00 for “engineered” products of typically low variability and a “minimum” specified 5% LEL strength).
- Adopt the load factors of Table II.
- Add reference to the SRBD Manual for proper determination of structural strengths (e.g. 5% LEL), to facilitate introduction of new structural materials.

TABLE III
SCHEDULE FOR DEVELOPMENT AND AVAILABILITY OF 2007 EDITION OF NATIONAL ELECTRICAL SAFETY CODE

Item	Due Date
Public Proposals Due	July 2003
NESC Subcommittee Recommendations	Oct. 2003
Preprint of Proposed Changes	Sept. 2004
Public Comments Due	May 2005
NESC Subcommittee Resolution	Oct. 2005
Submitted to NESC Committee and ANSI	Jan. 2006
Re-Submitted to ANSI (Final Recognition)	May 2006
NESC 2007 Published	Aug. 2006
NESC 2007 Effective	February 2007

G. Summary

The ASCE RBD Committee has produced a manual recommending guidelines for the design of utility pole structures, consistent with the LRFD format in the present NESC. The SRBD Manual provides a methodology for the proper determination of structural strength, preferably expressed as the 5% Lower Exclusion Limit, as well as appropriate strength factors to be applied to these values. In addition, through a calibration process, load factors have been determined to be applied to the ASCE 7 "50-year" extreme wind and combined ice and wind storms that will result in "equivalence" with the present NESC. Thus, the SRBD procedures will result in similar pole designs, on-the-average across the country, but with local variations, depending upon specific geographic location, number and type attachments, … The recommendations are reflected in change proposals under consideration by the NESC Committee for incorporation into the upcoming 2007 Edition of the NESC.

III. ACKNOWLEDGMENT

The authors gratefully acknowledge the support of the other members of the ASCE RBD Committee who helped develop the SRBD Manual, as well as other interested members within the NESC Committee.

IV. REFERENCES

Standards and Manuals:

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[2] *National Electrical Safety Code C2-2002*, American National Standards Institute, 2002 Edition.
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V. BIOGRAPHIES

Nelson G. Bingel is a graduate of Purdue University in Mechanical Engineering, and is presently Technical Manager at Osmose, Inc. of Buffalo, New York, responsible for evaluating wood pole strength and developing restoration methods for wood poles. He is an active member of IEEE and the Power Engineering Society, and is the American Wood Preservers Association (APWA) representative to the National Electrical Safety Code Committee. Nelson is the IEEE representative to the ASC Committee for the ANSI-O5 wood pole specification. He is chair of several working groups and task forces of the NESC dealing with issues related to strength and loading of overhead lines, and serves on the ASCE RBD committee.

Habib J. Dagher is Professor of Structural Engineering at the University of Maine, and serves as Director of its Advanced Wood Composites Center. Habib is an active member of the ASCE and is Chair of the ASCE RBD Committee.

Ronald (Ron) Randle is a graduate of the University of Wyoming in Civil Engineering. He is currently Vice President of Engineering for EDM International, Fort Collins, Colorado, responsible for technical analysis and testing programs on utility poles and components. Ron is a registered Professional Engineer in the State of Colorado. He is an active member of the IEEE and ASCE, and serves on the ASCE RBD Committee.

Lawrence (Larry) M. Slavin received his undergraduate training at the Cooper Union in New York City, followed by graduate work at New York University where he received his Masters and Doctoral degrees in Mechanical Engineering. Larry is Principal of Outside Plant Consulting Services, Inc., following a long career at Telcordia Technologies (formerly Bellcore) and Bell Telephone Laboratories. At Telcordia, Larry was Director of the Network Facilities, Components and Energy group. He represents the Alliance for Telecommunications Industry Solutions (ATIS) on the National Electrical Safety Code Committee, serving on various subcommittees dealing with overhead and underground lines, and also serves on the ASC Committee for ANSI-O5. Larry is a member of the IEEE.

Michael (Mike) D. Voda is a Principal Civil Engineer in the Electric System Engineering organization at Salt River Project, Phoenix. Mike is a registered Professional Engineer in the State of Arizona, an active member of the ASCE, and serves on the ASCE RBD Committee.

Ronald (Ron) W. Wolfe is Research Engineer at the Forest Products Laboratory, under the U.S. Department of Agriculture, at Madison Wisconsin. Ron is also currently on the staff of the University of Wisconsin where he teaches courses in wood pole technology. Ron serves as Chair of the ASC Committee for ANSI-O5 wood pole and products specifications, is an active member of the ASCE and ASTM, and serves on the ASCE RBD Committee.

C. Jerry Wong received the Bachelor of Science Degree from the Taipei Institute of Technology in 1971, the Master of Science and Doctor of Philosophy Degrees in Civil Engineering from the University of Cincinnati in 1978 and 1984, respectively. He is a principal engineer of Florida Power and Light Company, responsible for structural design. Jerry is a registered Professional Engineer in the State of Florida, and the EEI representative to the National Electrical Safety Code Committee. He is an active member of the ASCE, including the RBD Committee.