Pole Testing Ensures High Reliability and Long Life

Hydro-Québec pilot project verifies results of field-test methods.

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Electric utilities are placing increasing emphasis on cost-effectively extending the life of existing facilities while maintaining adequate levels of safety and reliability. In the case of overhead lines, utilities face the problem of aging wood poles (most will reach the end of their "design life" over the next 10 to 20 years) combined with tight capital and maintenance budgetary requirements.

Furthermore, since the mid-1990s, more telecommunications, cable television, internet and wireless carriers in the United States and Canada are seeking to expand their markets by attaching their equipment and cables to utility poles. Most in-service wood pole lines were not designed to carry this additional hardware and are overloaded beyond their original safety factors.

To compound the issue, extreme weather has increased liability concerns due to these additional loads. Overloading also can be an issue with newer poles if their fiber strength is lower then the accepted nominal value. Previous research on new poles and a sample test confirmed this is often the case with newer growth timber.

One solution to these concerns is to apply cost-effective, reliability-based inspection and pole management programs that provide quantifiable data on asset condition. With such data in hand, utilities can render appropriate judgments on preventative and corrective maintenance to maintain line availability at minimal cost and provide reliable life-extension.

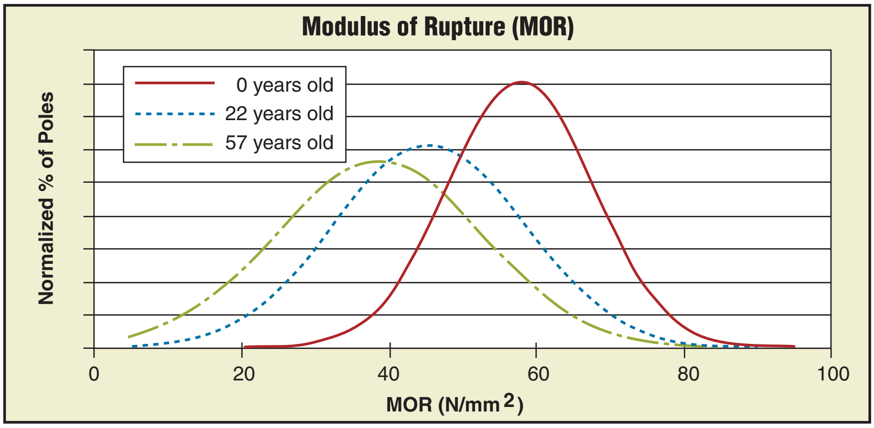

Fig. 1. Strength distribution for new and ex-service U.K. Scots pine poles.

A six-month pilot project carried out by Hydro-Québec (Montréal, Québec, Canada) between September 2001 and February 2002 incorporated new non-destructive testing (NDT) wood pole inspection tools with a reliability-based wood pole management program.

Hydro-Québec made a presentation on this project and this technique at the CEA Technologies conference "Workshop on Utility Pole Structures" held in Winnipeg, Canada, in June 2002. The concepts, inspection techniques and management methods described here are based on reliability-centered power line management, as pioneered in the United States in the 1980s and adapted to United Kingdom and Canadian practices. This approach to life-extension of overhead lines through reliability-based inspection and management is an alternative to rebuild approaches. It provides signifi-

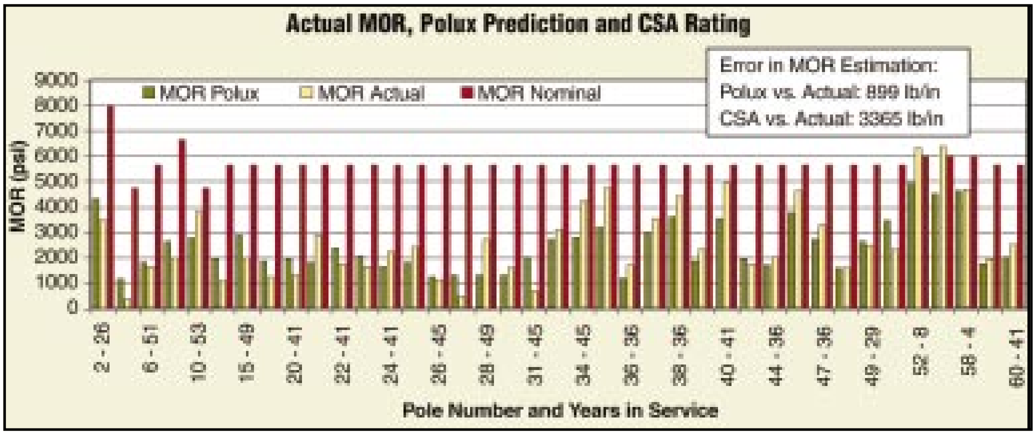

Fig. 2. NDE and destructive test data from Hydro-Québec test program.

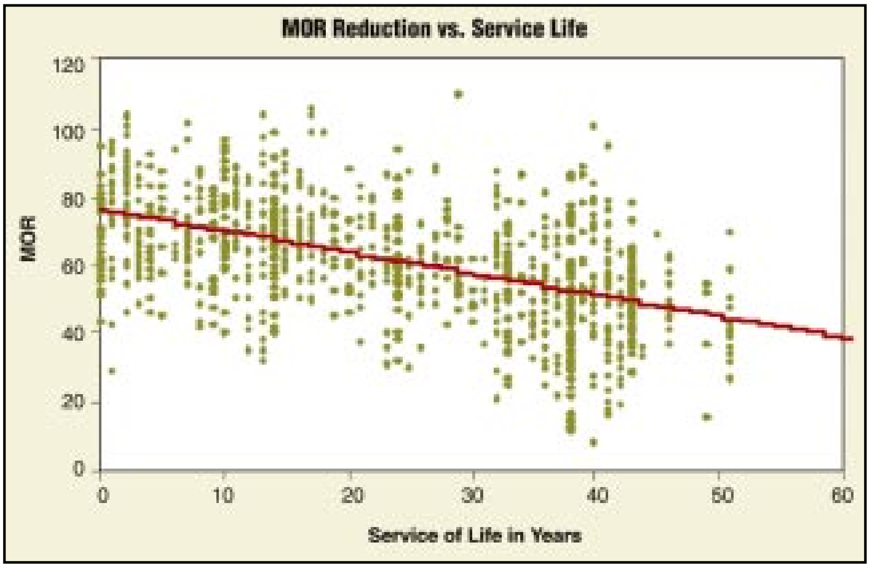

Fig. 3. Average strength reduction of in-service wood poles (Hydro-Québec).

cant cost-benefit ratios when applied in the United States, Canada and the United Kingdom.

An overhead line network consists of large numbers of relatively simple structures. The reliability of any one line segment is equal to that of the structure with the lowest reliability level (the structure that is the weakest link in the chain).

The pole structures can vary in strength because of the different fiber strengths of various wood species and the variations within the same species. Variations in strength around the mean value of any species have been measured at around 20% to 40% for new poles and up to 80% for in-service poles in the United Kingdom, United States and Canada. The strength variation follows a normal distribution about the mean, which is typical for natural products such as wood. The variation in strength of in-service wood poles has been assessed through several destructive test programs.

The results of the destructive testing of a sample of 150 U.K. Scots pine poles (Fig. 1) shows that while there is a wide variation in pole strength of a particular age, the average strength of wood poles decreases with time in service. Such results are typical of most species of wood used in transmission and distribution lines.

Project Background

Hydro-Québec conducted a comprehensive destructive testing program from 1996 to 2000 to evaluate all commercially available wood pole nondestructive evaluation (NDE) technologies and their capability to accurately measure pole strength. Close to 500 poles were measured for strength with the NDE instruments and then subjected to full-scale destructive tests. Hydro-Québec used the POLUX™ Strength Tester (distributed by Pole + Management Inc. of Montréal) to measure the remaining strength of its poles for this pilot project.

Figure 2 shows an example of the estimate to actual strength measured during the test program. Note that in almost all cases, the actual strength of the in-service poles tested was significantly lower than the mean strength rating given in the Canadian standard for wood poles for overhead lines (CSA 015 or ANSI 05.1). This result suggests that using the mean values available from the CSA or ANSI standards alone is inadequate for the purpose of assessing the strength of in-service wood poles.

The results of the destructive and non-destructive pole tests can be used to provide an average strength degradation rate for wood poles in a particular climatic region. Figure 3 illustrates the average strength degradation rate for wood poles in Hydro-Québec from both destructive tests and NDE assessments in the field. Applying this degradation rate to in-service poles is highly useful in asset management and maintenance planning.

Variation in wood pole strengths and the degradation of in-service poles have led to a review of safety margins in

Fig. 4. NDT wood pole test equipment includes the POLUX Strength Tester (left) and the Resistograph Constant Force Drill (above).

overhead line designs. Such margins are reduced if the pole does not continue to meet class requirement and if additional hardware is subsequently added. Safety margins for line designs must also be continually evaluated because of the increase in the range of applied loads (wind-on-ice loading and wind-only loading).

POLUX makes it possible to accurately measure the wood fiber strength of in-service poles. The instrument integrates visually rated wood pole parameters (knots, age, size) with its measurement of wood density and moisture content to compute the remaining strength of the pole.

The additional measurement of the Resistograph™ Constant Force Drill enables the user to identify decay cavities beyond the 2-inch (5-cm) reach of the POLUX probes but does not compute strength. Such voids are then factored into the calculation of the remaining section modulus. This integrated approach provides quantifiable strength data, which is characterized by a best strength estimate (mean value) along with a standard error of estimate (SEE), from which a normal distribution for the strength prediction can be generated.

Integrated vs. Conventional

Traditionally, the maintenance decision to repair, treat or replace a wood pole is made by the lineman in the field based primarily on visual sounding (with a 2-lb [0.9-kg] hammer) and boring/auger drilling inspection. These conventional line inspection schemes rely on the experience and knowledge of the linemen in the field and the line engineer in the office to provide a qualitative assessment of line condition.

The new integrated approach represents the combination of several tools, devices and methods, which provide repeatable, highly resolved and quantifiable data on material condition and remaining structural strength.

The new approach supplements standard inspection procedures with nondestructive pole strength evaluation and quantified component condition ratings. The results from the field inspection are combined with worst-case loading analysis (wind-on-ice loading) and detailed structural analysis to provide a factor of safety (FOS) value for any one structure. This assessment methodology is followed by a probabilistic approach enabling structures to be compared on a like-by-like basis. The approach also provides the utility asset manager with reliability, life expectancy, strength degradation and risk calculation data to assess the integrity and long-term performance of a line.

The pilot project objectives were to:

- Measure the remaining strength of the poles with the POLUX NDE instrument.
- Calculate the transverse and buckling loads on the pole due to wind and ice by taking inventory of the pole attachments and line hardware (including telecom and cable TV hardware).
- Use the Resistograph NDE instrument to look inside the pole for decay pockets to be factored into the calculation of the remaining section modulus of the pole.
- Determine the FOS by comparing

the remaining strength with measured strength.

- Calculate the probability of failure (POF) by using risk analysis techniques.

A risk assessment methodology was developed that accounted for wide variations in wood pole strength and applied loads, and the statistical distribution for load and strength on structures. The approach adopted in this project is illustrated in Fig. 5. The deterministic FOS value of the pole is calculated by dividing the mean estimated strength by the mean load while the POF factor for the structure is related to the overlap between the two distributions and represents the likelihood (risk) of component failure or reoccurrence of a failure event. The statistical load distribution is generated through analysis of past weather data (wind-on-ice loading), while the NDE predicted strength distribution is obtained from the SEE of the NDE equipment measurement.

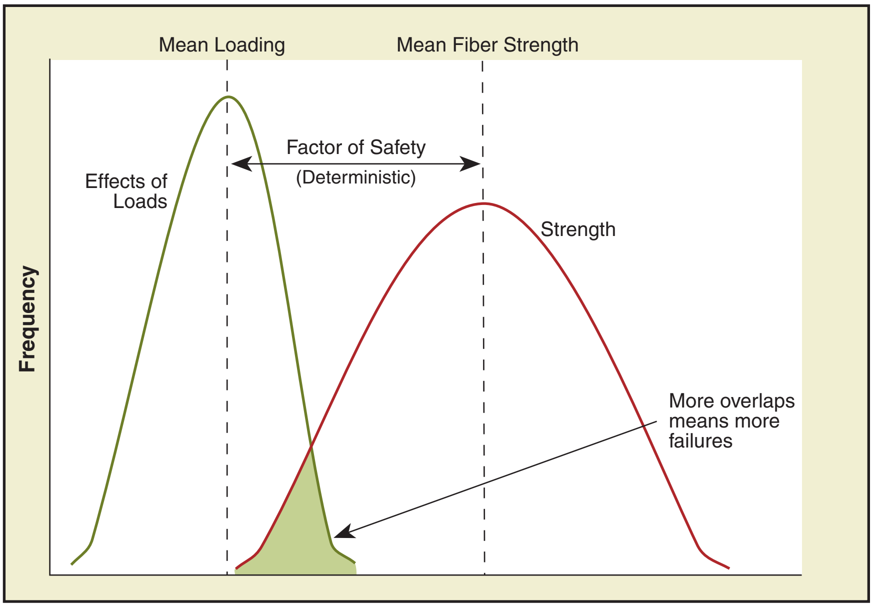

Fig. 5. Statistical distributions for load and strength of overhead line poles.

Effective Asset Management

With the basic theory and methodology in place, the next stage of the process is to see how the information is used to manage the overhead line asset. The first step is to carry out a systematic review of its present state, for example, the asset condition now at "year zero" of the life cycle. Although the life cycle of the asset can be set over any period of time, an arbitrary figure of 20 years was used for the purposes of the work reported here.

As most utilities have overhead lines that have undergone "piecemeal" replacement of individual structures and components throughout their service life, it is critical that all equipment is brought up to a common reliability level to compare against benchmark levels. Through the use of structural analysis tools and reliability-based methodologies, a FOS rating can represent the state of health of the asset.

To facilitate the decision-making process for the asset manager, the FOS rating must be placed in context. This is achieved by comparing the measured FOS against two benchmark levels: the "at-build" and "at-replacement" FOS. The at-build FOS is obtained from the Canadian Standards Association (CSA) 22.3 "Overhead Systems Construction Standards" or the equivalent U.S. National Electric Safety Code (NESC) standard for overhead lines. When inspecting in-service poles, one has to refer the structural strength rating of the pole to the at-replacement FOS. In asset management terms, this is the benchmark factor of safety (i.e., the FOS that should be designed into a structure when built). For example, in the United States, the NESC at-replacement criteria is a reliability index of two-thirds of the at-build index, which was developed as a result of U.S. experience and practice. In simple terms, it means that the structure needs to be replaced when its strength reaches two-thirds of its at-build strength.

In carrying out quantitative analysis to identify the present state of health of a structure, its FOS in the life cycle can be compared to the benchmark reliability levels. Knowing the rate of deterioration of the pole and component strength, the time remaining for a structure to fall below the at-replacement level can then be predicted. Using this integrated approach allows preventative maintenance planning. Figure 6 illustrates the decrease in mechanical strength of wood poles when identifying poles to be replaced. In this example, the minimum (at-replacement) FOS value is 1 for wood pole structures. Although FOS for all three structures is above the minimum FOS value at the zero-year inspection, only Structure 1 will remain above the at-replacement value at year 20. Structure 3 needs replacing now because its FOS will fall below 1 before its next inspection time. Structure 2 needs replacing at the next inspection cycle because its FOS will fall below 1 before the subsequent inspection cycle 3.

Pilot Project Results

The project was performed for Hydro-Québec by a team from IPEC Ltd. (Manchester, U.K.). A total of 887 in-service wood poles were inspected with the NDE equipment. The poles were assessed for a minimum 10-year life extension. Out of the 887 poles inspected, 243 had been classified as "old" (typically more than 30 years of age) and were scheduled for replacement based on conventional, time-based planning.

The rejection criteria established for the poles in the pilot project were:

- Reliability failure: Poles that were condemned because their strength measurement was less than load requirements.
- Condition failure: Poles that failed due to section modulus below 75%.

The table below summarizes the number of poles condemned using the

Results of Integrated Approach Inspections of "Old" Poles

	No. of "OLD" Poles Inspected	No. Rejected due to Reliability	No. Rejected due to Condition	Total Rejected Poles	Poles in Good Condition	Percentage Condemned
At Inspection	243	57	4	61	182	25.10%
Projected for 10 years	243	77	4	81	162	33.33%

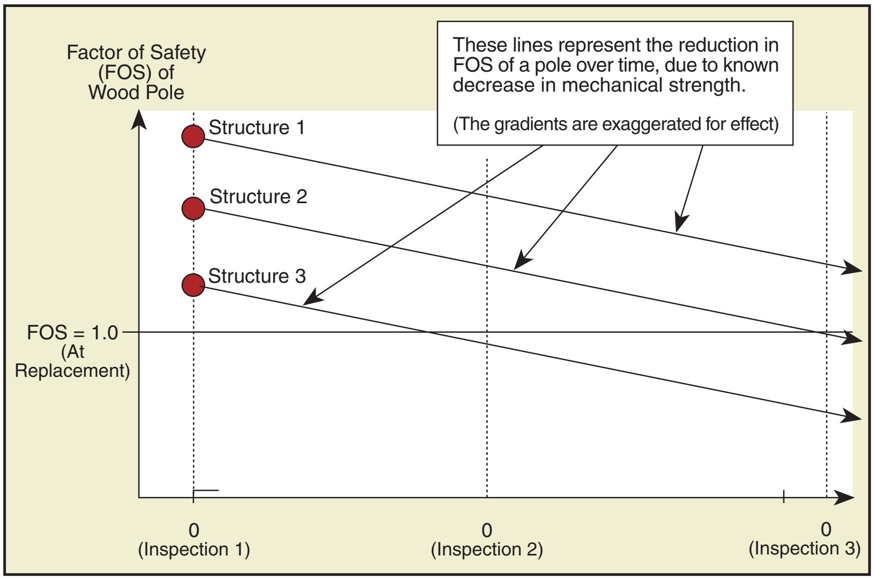

Fig. 6. Example of the application of RCM as a maintenance prediction tool.

above criteria and the reasons. Based on the measurement of actual pole strength, only 25% (61 poles) of the 243 old poles needed immediate replacement. A 10-year projection of the same poles indicated a further 8% (20 poles) were predicted to drop below the at-replacement criteria.

This result shows that two-thirds of the old poles were suitable for reliable life extension of a minimum of 10 years. Some of the remaining 644 (less than 30 years old) poles inspected were also rejected due to overloading by cable and communications lines or because the pole did not meet the class requirement.

Life-Cycle Cost Analysis

A realistic economic evaluation of the costs to upgrade a line to an acceptable level of reliability and then to maintain it must include the long-term costs of management and maintenance of the line. The use of Net Present Value (NPV) allows the life-cycle costs of the management options to be compared over a predetermined time period.

The economic evaluation provides the line manager with an effective tool to compare the management options available. The option chosen for any one line will be dependent on a number of factors including age of line, line condition (reliability, ground line decay and pole top condition), history of line failures, line criticality (importance of the line in the system) and the utility's internal maintenance strategy.

The life-cycle cost analysis of old poles given in the table on page 47 showed that the 10-year life-cycle cost of the integrated approach had a cost-benefit (cost reduction) of 67%, compared to the conventional, time-based approach. Significant cost benefits can be realized through the application of this new integrated approach. Asset managers receive the greatest benefit from this approach when they require life extension of wood poles with remaining service life.

Dr. Lee Renforth is managing director of Independent Power Engineering Consultants (IPEC) Ltd. He graduated with a Ph.D. from Manchester University, United Kingdom, in 1993. In 1995, he formed IPEC, which provides risk-based consultancy, inspection and databasing services to the worldwide electricity supply and telecoms industries. He has been developing tools and methodologies for the application of risk-based management of overhead lines in the United Kingdom in collaboration with electricity utilities in the United Kingdom. For more information on the above approach, contact Renforth at lee@ipec.co.uk.

André Taras graduated from the School of Engineering at McGill University, Montréal, Canada, and then pursued a master's degree in the field of strength and dynamics of structures. His professional experience includes working with the Canadian National Railways Research Centre from 1980 to 1991. Since 1991, he has worked for Hydro-Québec Research Institute (IREQ), involved in the evaluation of the strength and residual life of components of overhead distribution lines. He specializes in the testing, analysis and development of methods to determine the structural integrity and life expectancy of overhead line structures.