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Development of Computer Modeling System for Analysis and Design of Electrical Transmission Lines

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Abstract

A computer modeling system was developed for the analysis and design of electrical transmission lines. The major functionalities of the system include: design of individual electrical transmission towers, design of electrical transmission lines, set-up of high-intensity-wind profiles based on wind-tunnel experiment data, Finite Element Analysis, design modification based on results of Finite Element Analysis.

Keywords: Electrical Transmission Tower, Electrical Transmission Line, High Intensity Wind, Finite Element Analysis, Database

1. INTRODUCTION

Electrical transmission lines is still the major means for transporting and distributing electrical power over the world, but they have been found vulnerable to high intensity wind (HIW) such as tornados and downbursts. One example is the windstorm struck in Manitoba on September 5 of 1996, which caused a cascade collapse of 19 towers and a power outage for 5 days. Other incidences were also frequently reported over the world, especially in North America. Finite Element analysis (FEA) has been widely used in engineering, and it is believed that FEA is an efficient and powerful tool to investigate failure mechanisms behind these incidences and to find out a more efficient way for designing or strengthening transmission line structures to more effectively withstand high intensity winds. Although a number of general-purpose commercial FEA software is available for engineering structural analysis, there are several drawbacks in using them to analyze an electrical transmission line affected by HIW: (1) the geometric structure of an electrical transmission line is very special. It is time-consuming to use general-purpose FEA software to construct and to modify a geometric model of such a structure; (2)

Specialized finite elements, e. g. a beam-column element that is able to incorporate local plastic hinges, a cable element that is able to efficiently capture the behavior of conductor under HIW, are crucial to investigate collapse mechanism of electrical transmission lines, but they are not available in commercial software; (3) The load pattern of a HIW, which need be defined by a profile and be able to describe both spatial and time-history variations, is not easy to be established by the loading templates provided in general-purpose FEA software; (4) The FEA results obtained from general-purpose software need be checked manually by users against design codes. That is not only time-consuming, but also requires the user has adequate knowledge on FEA and on design codes. It is because of the above reasons that specialized software such as PLS-TOWER and PLS-CADD are very popular in electrical transmission industry. Nevertheless, these software are only limited to linear Finite Element analysis, which is not sufficient to investigate collapse mechanism of electrical transmission lines affected by HIW, where both geometric and material non-linearity are obviously involved.

A R&D project was set up and funded by Manitoba Hydro. The project was implemented in two phases: (1) development of more efficient Finite Element formulations for investigating collapse mechanisms of electrical transmission lines; (2) development of a computer modeling system for analysis and design of electrical transmission lines. The research done in the first phase has been reported in [1,2]. In this report, the work done in the second phase is documented.

2. DESIGN STRATEGY FOR DATABASE IN COMPUTER MODELING SYSTEM

A database is the core of the computer modeling system, where design information of an electrical transmission line and profiles of HIW are stored. The information need be fetched out later for modification or for Finite Element analysis. The efficiency of the database is crucial for a computer modeling system. Basic design considerations on the database are:

- All data type must have a clean and clear definition, so that they will consume a minimum memory storage;
- There is an efficient searching mechanism, so that the needed data can be easily located and fetched out;
- There is an efficient interface for the database to interact with other computation modules.
- An electrical transmission line is a ‘repeated’ structure in the sense that the same type of tower is installed at many different locations. To save storage, only one copy of the tower is stored in the database. The same strategy is also adopted for conductors.

Relation between the database and other modules or device is shown in Fig. 1.

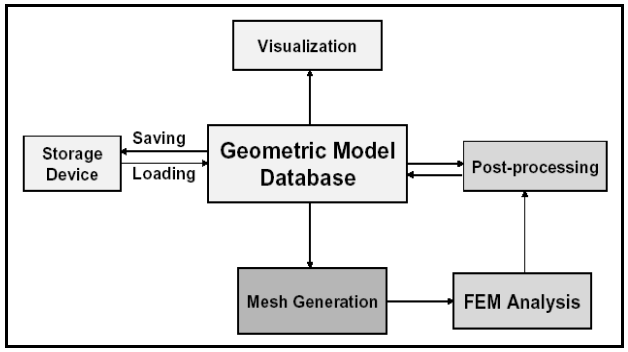

Figure 1 Relation between database and other modules

The database includes the following data types:

- Material
- Beam section (angle)
- Beam
- Tower
- Conductor (guy, cable)
- Insulator
- Downburst
- Transmission line

Each data type is implemented as a C++ class. Most of the data types are not independent. The definition of one data type is based on one or more other data types. Relations between the data types are shown in Fig. 2 in a bottom-up way. First, material data types are created. They are then used in definition of beam sections (angles), guys and conductors. Beam sections are used to create tower members (beams and braces). A tower consists of beam members, braces and/or guys. Towers and conductors are then used to create a section of transmission line.

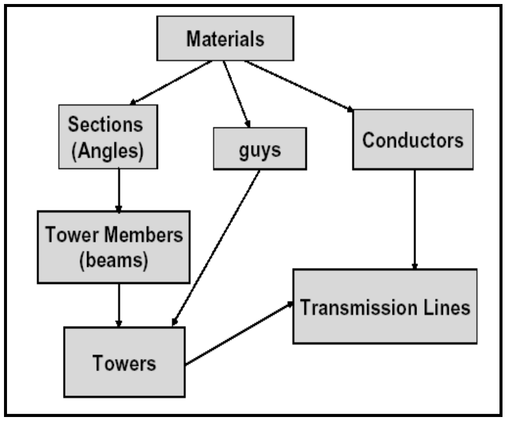

Figure 2 Relation between data types

3. DEFINITION OF DATA TYPES

Clean and clear definitions of data types are the base for designing C++ classes. Especially the definition of equity between two objects of the same class is important for saving computer memory; only one copy of the same objects is to be stored in the database. In the following, the attributes used in the definition of each data type are briefly described.

a. Material

A material is defined by a label, elasticity modulus, Poisson's ratio, thermal expansion coefficient, expansion rate, yielding strength, ultimate strength, ultimate strain, and mass density.

b. Section (Angle)

Attributes of a Section (or Angle) include: label, height, width, thickness, member shape (I-form, L-form, O-form, etc.), drag coefficient, and material.

c. Beam

Beam data type is dependent on Section and used in construction of Tower. Attributes of Beam include: label, member group (to distinguish if it is a primary member, e.g. the four legs of a tower or it is a secondary member, e.g. braces in a tower, or it is a guy), first-node, second-node, and section.

d. Tower

Tower is a complicated structure, Fig. 3. Tower contributes include: label, an array of nodes, an array of beams, and an array of attachment points where insulators are installed.

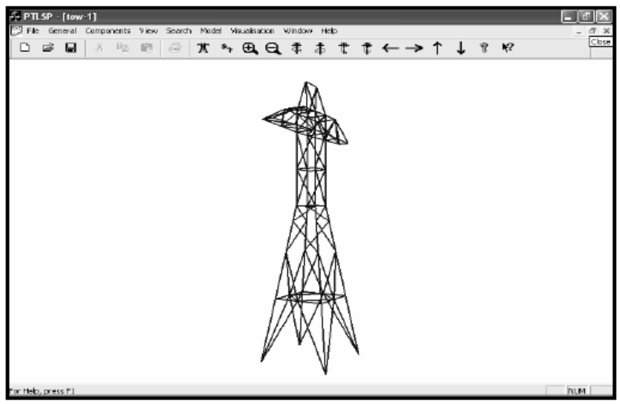

Figure 3 An Electrical Transmission Tower

e. Conductor

Conductor is defined by a label, cross-section area, outside diameter, drag coefficient, unit weight, ultimate tension, average elasticity modulus, average thermal expansion coefficient, and average creep strain.

f. Insulator

An insulator is defined by a label, length, diameter, weight, ultimate strength, and drag coefficient.

g. Transmission Line

A section of electrical transmission line consists of a number of towers and conductors spanned over these towers, Fig. 4. Therefore the definition of a transmission line is mainly concerned with the locations where towers are installed and the type of conductors used.

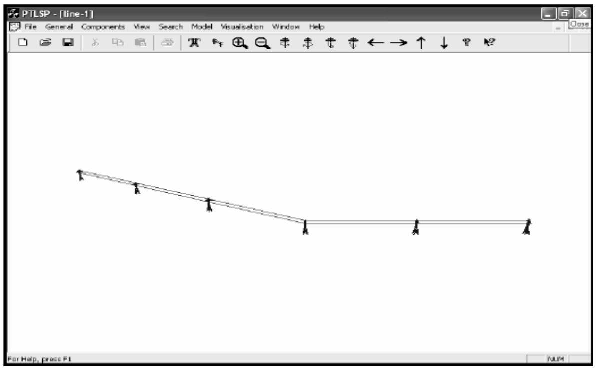

Figure 4 A section of transmission line

Two coordinate systems are needed to define an electrical transmission line, Fig. 5, one is a global system, and the other is a local system for each tower. The global coordinates of its base center define the location of a tower. The orientation of the tower is defined by the direction angle of its local coordinate system in the global system.

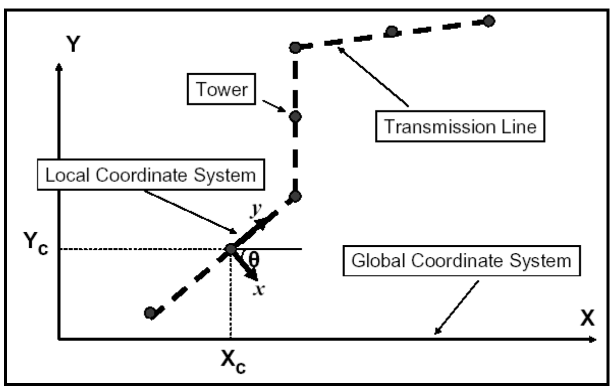

Figure 5 Coordinate Systems used in defining a transmission line

The process of creating a transmission line is shown in Fig. 6. First the number of conductors is specified; then the type of a tower to be installed is selected and global coordinates for that tower are provided; the orientation of a tower in the global system is given. A transmission line is described by a label, the number of conductors, an array of towers and their installation locations, an array of conductors.

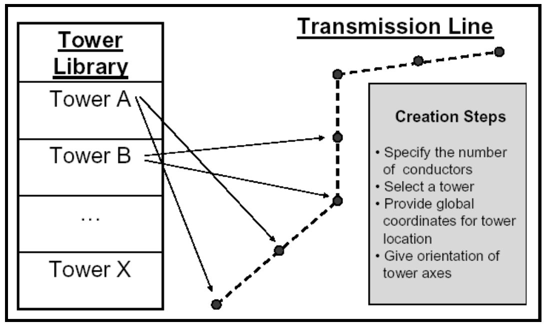

Figure 6 Construction of a transmission line section

h. Downburst

Wind load is another complicated data type for the variety of wind profiles. In this project, as a first step, a simple downburst model, the Oseguera-Bowles-Vicroy (OBV) model [3] was adopted. The profile of the model can be defined in a local coordinate system, Fig. 7. It has the following features:

- It is an analytical model;
- It has a non-turbulent profile;
- It has the following velocity components:
  - Radial velocity: **Ur**(r,z),
  - Vertical velocity: Uz(r,z),
  - Translation velocities of downburst center: Vx, Vy

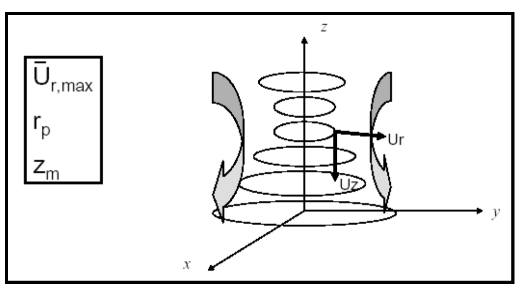

Figure 7 OBV downburst profile in a local coordinate system

For more information about this downburst model, one can refer to Reference [3]. When a downburst is applied to an engineering structure, e.g. an electrical transmission line, the velocity field in the global coordinate system is obtained by supposing the local velocity field with the translation velocity at the downburst center, Fig. 8.

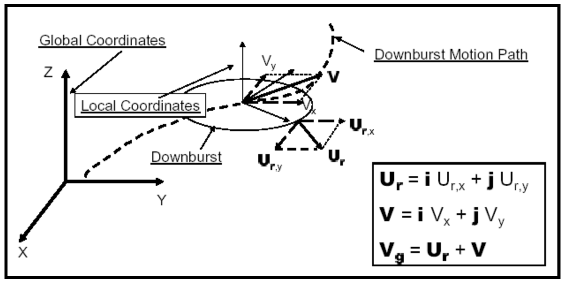

Figure 8 Velocity field in global coordinate system

Aerodynamic forces acting on a tower member are calculated in the following steps:

- Global wind velocity is decomposed into two components, one is in earth horizontal plane, the other is downward and normal to the horizontal plane;
- All tower members are projected into the two planes that are perpendicular to the two velocity components, and their equivalent lengths are obtained;
- Aerodynamic forces from the two velocity components are calculated separately and their attack angle are assumed zero;
- At any time point, only the tower that is the closest to the downburst center is considered.

Drag and lift force acting on a tower member with an arbitrary cross-section and a profile shown in Fig. 9 is obtained by [4,5]

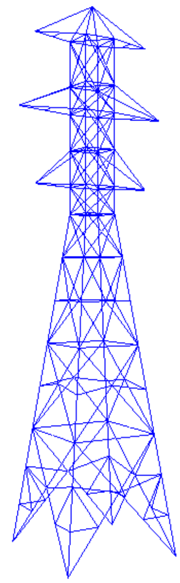

Figure 10 Design of Tower Model

$$D(\alpha) = \frac{1}{2}\rho U_r^2 h C_D(\alpha)$$

$$L(\alpha) = \frac{1}{2}\rho U_r^2 h D_L(\alpha)$$

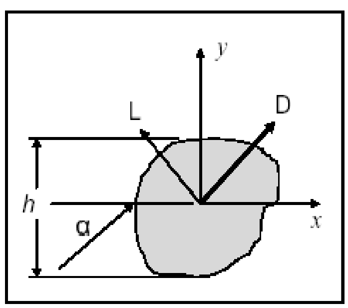

Figure 9 Aerodynamic forces acting on a member with arbitrary cross-section

4. IMPLEMENTATION OF COMPUTER MODELING SYSTEM

Standard C++ is a far more powerful and polished language than that was first introduced by Stroustrup [6]. New language features such as namespaces, exceptions, templates, and run-time type identification have been introduced recently. These features allow many techniques to be applied more directly than was possible before, and the standard library allows the programmer to start from a much higher level than the bare language. Based on those reasons, Standard C++ and Standard Template Libraries (STL) were selected for the implementation of the computer modeling system.

As an option, the computer modeling system can output FE data that can be fed into a third party FE software, e.g. ANSYS, for FE analysis. To generate ANSYS input file from the database, two things need be done: First, the structure of a typical ANSYS input file need be dissected for automatic generation; then, all the elements that are useful for analyzing transmission tower/line and available in ANSYS need be listed out for selection.

5. DESIGN OF TRANSMISSION TOWER MODEL

The computer modeling system was tested by using it in the design of a tower model. The major geometric dimensions and material parameters are provided in the following:

- Tower height: 27.51 (m)
- Tower base width: 6.096 (m)
- Elasticity Modulus: 200 (MPa)

An initial design was first input into the computer modeling system. The design was then modified by the modeling system based on FEA results and checking against the design codes. In Finite Element Analysis, aerodynamic loads acting on the conductors and on the tower itself were converted into static loads. Three typical loading patterns, longitudinal bending, lateral bending and horizontal twisting, and their most critical combinations were considered in the design. The final design of the tower is displayed in Figure 10.

6. CONCLUDING REMARKS

A computer modeling system was developed for the analysis and design of electrical transmission towers and electrical transmission lines under high-intensity-wind. The computer modeling system is much more efficient than general-purpose FE software in constructing and modifying the design model of a transmission tower or a transmission line. In the current implementation, the computer modeling system can only check the design against the design codes. The obtained design is not necessarily optimal. Therefore, one further work need be done is to implement an automatic optimization procedure.

ACKNOWLEDGMENT

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