Computer-aided Design of Cables For Optimal Performance

Geometric Modeling and Finite Element Software for Structural Design of Cables

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Today, numerous cable applications require sophisticated designs that satisfy various strength, communication and power transmission functions. These cables often have highly complex constructions that require structural analysis beyond simple, idealized mathematical models. Other manufacturing industries have realized tremendous productivity and product quality gains through the successful implementation of general purpose, computer-aided design (CAD) tools into their development process over the past 30 years. The cable industry has not benefitted from these tools to the same extent, however, because it is difficult to model the helical wire geometries found in cables.

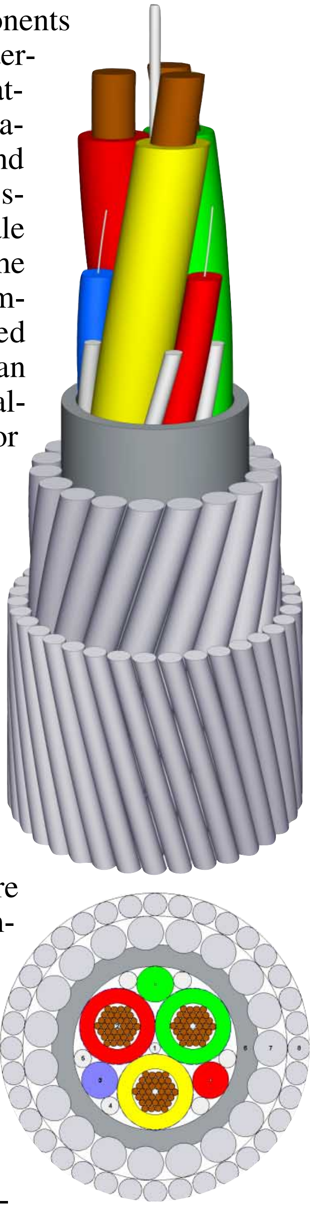
What is needed is a CAD tool developed specifically to model cable geometries. Such a tool should simplify model creation to facilitate rapid parametric design studies, and it should take advantage of known geometrical properties of the cable so that creation of finite element models is transparent to the cable designer.

In this paper, the CableCAD® software code for geometric and finite element modeling of cables is described. The program makes it easy to generate cable models such as for the ROV tether cable model depicted. For instance, meshed (same lay length) helical core components and contrahelically-laid external armor wires can be located by drag and drop operations that are intuitive and easily performed. The cross-section plot is drawn to scale and all components have the correct shape to verify component fit. An exploded three-dimensional plot can be produced for better visualization of the design and for documentation purposes.

A finite element mesh of all components is generated automatically by the code, and element nodes are created at all component contact points. Upon solving, plots of cable strain, torque or rotation, deformations and stress contours are generated to assess cable performance.

This cable design software is able to model both symmetrical and asymmetrical, axial and compound helical geometries. Nonlinear material behavior, layer locking (circumferential wire contact) and wire indentation into adjacent soft layers also can be modeled.

Construction variables such as lay length and num-



ROV tether cable model.

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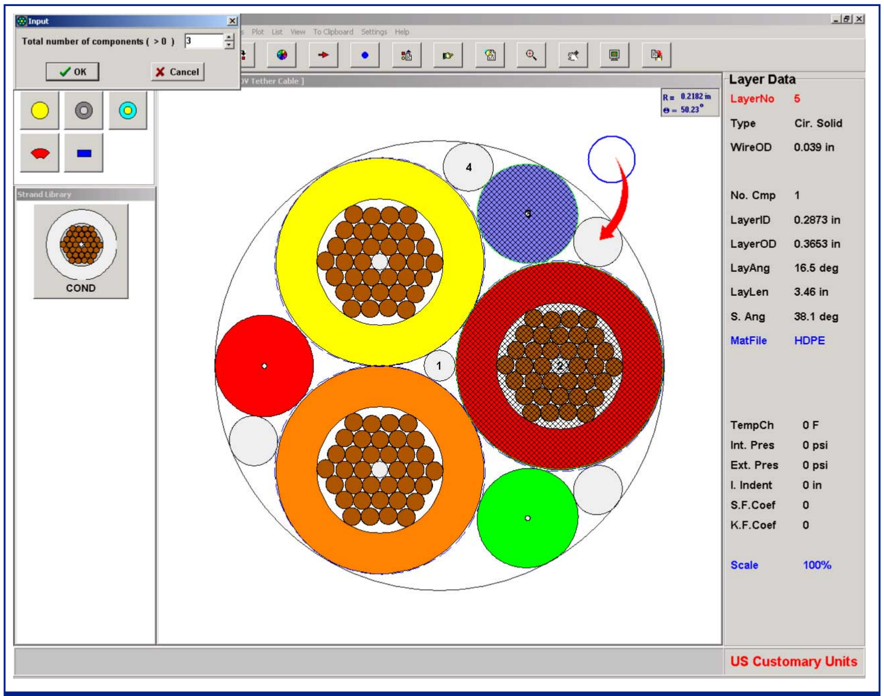
ber and diameter of tubes or wires can be modified easily, thereby permitting multiple design iterations to be completed in minutes.

Loads that can be applied simultaneously to the model include tension, twist, bending (including internal friction), cable external pressure or partial pressure (cable pinching), helical hose internal or external pressures, clamping and thermal loads (internal flux and external convection). Metallic, polymer and synthetic fiber components can be handled by the code.

Straight and bent cable analysis options provide cable deformations and internal component stresses. Axial, torsional and flexural rigidities can be found in terms of elongation, twist and bending curvature.



Total number of components (> 0) 3

R = 0.2182 in
θ = 50.23°

Layer Data
LayerNo 5
Type Cir. Solid
WireOD 0.039 in
No. Cmp 1
LayerID 0.2873 in
LayerOD 0.3653 in
LayAng 16.5 deg
LayLen 3.46 in
S. Ang 38.1 deg
MatFile HDPE
TempCh 0 F
Int. Pres 0 psi
Ext. Pres 0 psi
I. Indent 0 in
S.F.Coef 0
K.F.Coef 0
Scale 100%
US Customary Units

Drag and drop helical component.

Comparisons with actual cable test data and other general purpose finite element software show that the CableCAD code provides reasonable estimates of cable behavior. Also, modeling and run times are significantly less than that required for general purpose finite element programs.

CableCAD allows the cable designer to quickly evaluate many design concepts prior to expensive prototyping and testing.

The geometric and finite element modelers, and several verification examples, are described in the following.

Geometric Modeler

An accurate geometric description of a cable is needed to define the exact locations where components make contact. Since the shape of a circular component in the cable cross-section is not circular, and varies with radial location from the cable axis and the wire lay length, an automated geometric modeler is employed.

For contra-helical adjacent layers, contact occurs on a circle between the layers. For meshed layers (same lay length), the program automatically finds the radial and circumferential locations to fit wires or strands into the interstices of subjacent components using a drag and drop operation. A new component is dragged to the approximate location where the wire is desired and then dropped into the space between components. Its final location is computed by the program and this is confirmed visually in the cross-section plot. This operation is valid for any helical lay angle, where large lay angles produce non-circular bean shapes.

The geometric modeler allows rapid creation of complex cable geometries with the following capabilities:

- create, modify or delete any cable component or layer;
- drag and drop placement of helical wires and strands;
- dynamic layer data table;
- solid and jacketed circular, tubular, keystone and rectangular wire shapes;
- single, double and triple helical structures in cables and wire rope;
- user-defined strand library;
- user-defined material library (linear, nonlinear and color properties);
- color-coding of jacketed conductors;
- optimized compaction of cable cores;
- automatic generation of finite element mesh and nodes;
- created element boundary and symmetry constraints;
- pan and zoom of cable cross-section;
- printed and graphical documentation.

Finite Element Modeler

Cable structures consist of components with complex helical geometries. General purpose finite element programs, though versatile, are not well-suited to analyzing such structures. A considerable amount of time must be invested in joining components, meshing and applying boundary conditions. Also, a thorough understanding of the finite element method is required to generate a valid solution.

The finite element method discretizes structures into multiple elements whose shapes are selected to best match the structural boundaries. In the case of circular components used in cables, ring elements are employed.

The large, center component is meshed with a number of ring elements shown by concentric dashed circular rings. Contact points (A-F) with inner and outer adjacent components maintain connectivity in the radial (u) and circumferential (v) directions.

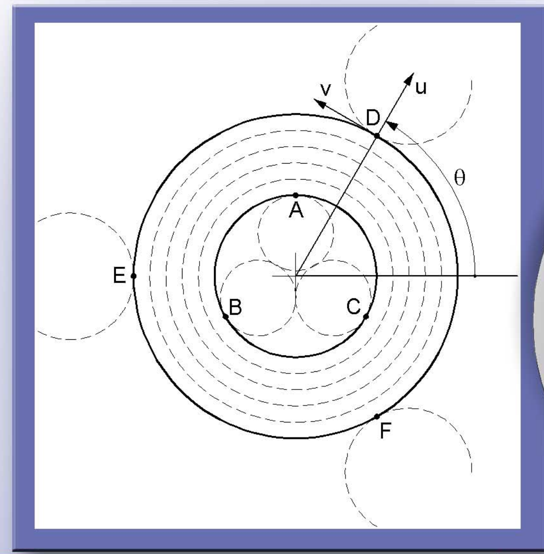
Each ring element is an axisymmetric solid element with internal degrees-of-freedom that are condensed to yield a macro-element stiffness matrix with radial and circumferential deformations acting only at the contact points. Due to the asymmetrical deformations expected for a typical ring element in a cable component, radial and circumferential displacement functions, u(r,θ) and v(r,θ), respectively, are expressed in terms of Fourier series shape functions with quadratic variations in the radial direction.[1]

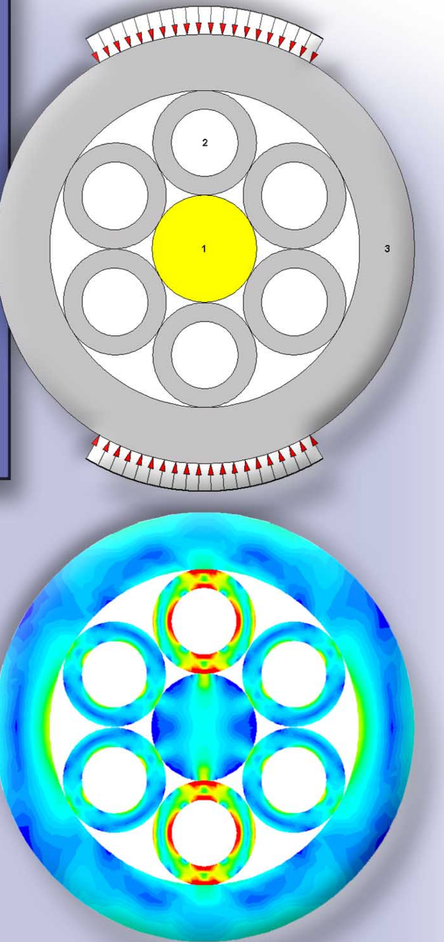
Element generation and other model parameters are controlled internally so that the details of the finite element method are transparent to the cable designer. This renders the program usable by a greater audience.

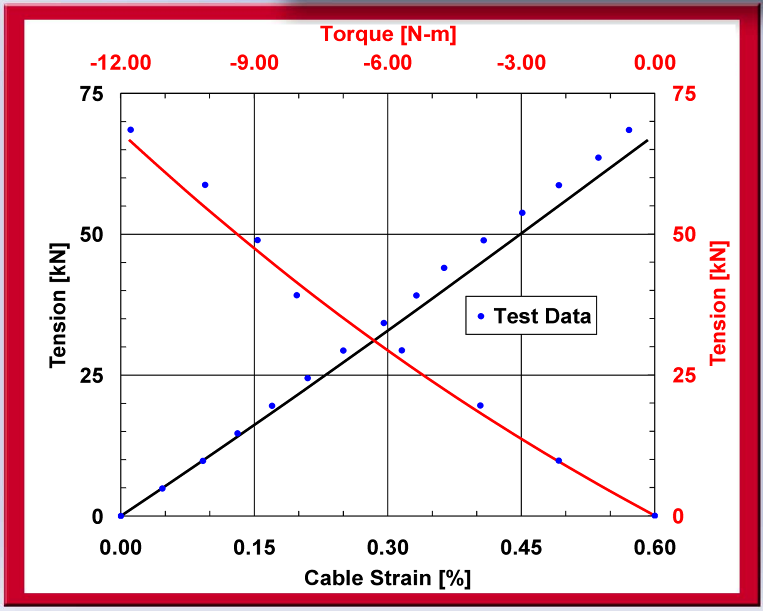
Examples

Many cable examples have been investigated to validate the CableCAD code, including simple seven-wire strands and complex electro-optical-mechanical cables. Validations are based on as-built cable test data or parallel modeling efforts using general purpose finite element codes.

ROV Tether Cable. The depicted ROV tether cable has a core consisting of three electrical conductors meshed with three optical fibers and six high density polyethylene (HDPE) filler rods. An HDPE core sheath and two contra-helically laid



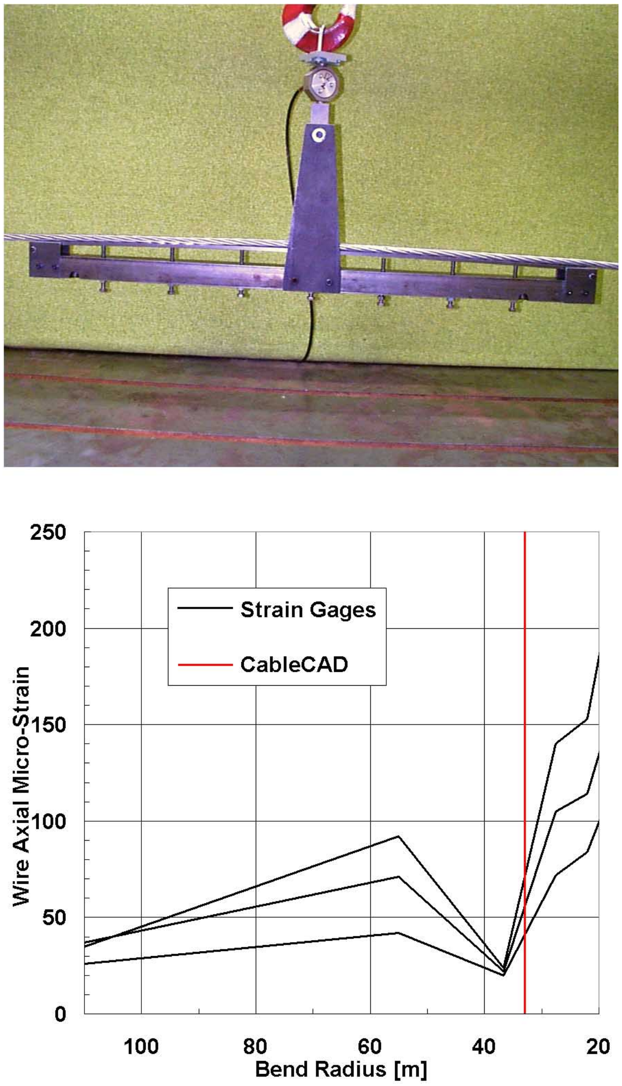




(top left) Ring element mesh.

(bottom left) ROV cable strain and torque plots.

(right) Pinched cable and CableCAD® stress contours.



Wire slip in bent cable.

steel armor layers protect the core components and provide tensile strength. In creating the model, color-coding of jacketed conductors have been specified. This cable was analyzed with CableCAD using nonlinear material properties for the HDPE core-sheath and for armor wire indentation into this sheath.[2] The slightly nonlinear curves of cable axial strain and reaction torque are in good agreement with test data.

Pinched Cable. In another example, a fiber optic tube cable is pinched with diametrically opposed pressure bands.[1] Both CableCAD and the general purpose ANSYS® software were used to model this cable.[3] The center component is a steel wire, the middle layer consists of six helical polypropylene tubes and the outer layer is an HDPE jacket.

A cable length corresponding to one lay length of the tubular layer is modeled with ANSYS solid elements. Whereas the time for a skilled analyst to create the ANSYS model was approximately one work day, CableCAD modeling was accomplished in minutes.

Pressure bands with an included angle of 60° are centered about the top and bottom of the cross-section to simulate a pinching load. Analysis results from both programs show that the effective stress contour plots differ by only one percent and deformation plots differ by about nine percent. The solution time for CableCAD was approximately five percent of that required for ANSYS.

Strand Bending with Wire Slip. A variable diameter sheave was used to test a simple ground cable for overhead electrical transmission lines. The cable consists of six steel wires laid helically around a single steel core wire. Outer layer wires were instrumented with electric resistance strain gages and the cable was loaded with a tension and then bent by forcing the sheave fully onto the cable. The bend radius was varied to detect wire slip.

Test results are shown in a plot of wire strain versus bend radius. As the bend radius is decreased (increased bending curvature), the strain increases. At about a 36-meter bend radius, the gages recorded a sudden relaxation of wire strain as wires slipped.

The 33-meter bend radius to initiate slip predicted by the CableCAD frictional bending model is within eight percent of the measured result. Wire slip is used in determining wire stresses and the flexural rigidity of bent cables.

Discussion

CableCAD analysis results have compared favorably with those of general purpose finite element codes and with actual cable test results. Both cable modeling and cable testing are important steps in developing a new cable design and should be regarded as complementary. For example, a computer model could be used in planning more focused cable tests, and certain cable behavior recorded in cable testing might better be understood by means of finite element analysis.

A finite element model can reveal stress distributions that are difficult, if not impossible, to measure directly, and physical testing could reveal cable behavior like "constructional stretch" that might not be apparent in a computer model.

Finite element analysis is the ubiquitous design tool of choice in most manufacturing industries today and is expected to become more commonplace in the cable manufacturing sector as well. CableCAD is a design tool that can be used to quickly evaluate many construction concepts for cables, wire rope and some types of flexible pipe. The program gives the designer the confidence to consider alternatives outside of historical design rules so that nontraditional cable constructions can be explored. This will help lead to innovative new cable constructions that meet the challenging operational requirements of today. As this type of design tool gains acceptance, improved and more powerful software ultimately will evolve as it has in other industries.

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