Finite Element Analysis of Ribbon Stack Coupling in Dry Single Tube Fiber Optic Cables

Allen M. Miller
Corning Cable Systems LLC, Hickory, NC
David A. Seddon
Corning Cable Systems LLC, Hickory, NC

Abstract

The recent trend in the fiber optic cable industry from grease filled cables to dry (grease-free) cables led to research indicating that sufficient levels of coupling between the ribbon stack and the remainder of the cable are necessary to control excess ribbon length (ERL) or slack in the cable. Under certain loading conditions, inadequate levels of coupling can lead to local accumulation of ERL and excessive signal attenuation. Water blocking greases used in the industry provided a high level of coupling; however, the cable industry desires to move toward the dry cable technology.

This paper describes an application of finite element analysis (FEA) used to evaluate the structural interaction between cable ribbon and cable jacket for duct and aerial installation during multiple load cycles. The nonlinear behavior of the friction interfaces and the significant stiffness difference of the ribbons in tension and compression are considered in the evaluation.

Finite element results compare closely with the measured ribbon displacements achieved in practical ribbon coupling tests for a variety of cables.

Introduction

The construction of a typical dry ribbon cable consists of a fiber ribbon stack surrounded by a dry coupling/ water blocking medium, a buffer tube and jacket as shown in Figure 1. Prior to recent dry cable technology, water blocking grease filled the interstitial space in the buffer tube and coupled the ribbon stack to the jacket side of the cable (remainder of the cable structure). The current industry trend to dry cables has led to new design issues to ensure sufficient coupling of the ribbon to the jacket for various load scenarios. Since the jacket side is the portion of the structure which is loaded during a duct installation or restrained in an aerial installation, control of the relative displacement between the jacket and ribbon is critical for proper signal transmission. Certain levels of excess ribbon length (ERL) are necessary for proper cable operation; however, accumulation of high levels of ERL can lead to excessive signal attenuation. Therefore, adequate levels of coupling are vital in cable design to ensure ERL remains within acceptable limits especially during cyclical loading.

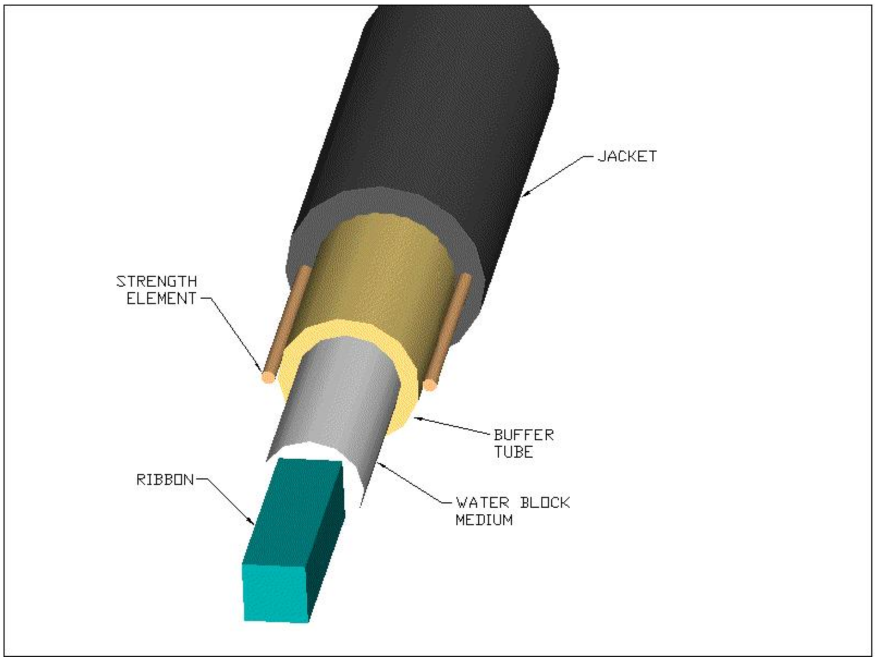

Figure 1. Dry Single Tube Cable Construction

Finite Element Model Descriptions

The finite element (FE) models used in this analysis are comprised of two dimensional elements representing the stiffness of the ribbon (which varies in tension and compression), the stiffness of the remainder of the cable, the coupling interaction between the components and the duct friction. Since ANSYS does not support different elastic tension and compression, Link 10 tension elements are overlaid with Link 10 compression elements to represent the bidirectional ribbon stiffness. Beam 3 elements are used for the remainder of the cable and Contact 178 elements represent the coupling between the ribbon and the cable as well as the duct to cable friction.

The duct installation model shown in Figure 2 has normal forces applied to the contact elements to produce the desired coupling interaction between the ribbon and jacket as well as duct friction. As longitudinal force is applied to the jacket, ERL (slack) is removed from the ribbon and tensile strain builds in the ribbon from zero at the applied load to a maximum at the coupling point, the first location at which the ribbon displacement equals the jacket displacement. This coupling point is initially at the applied load end and moves toward the symmetry plane as the installation force is increased. The distance from the applied load to the coupling point is defined as the coupling length. It is inherent in the finite element model and can be calculated for the first load cycle using equation (1). A modified version of equation (1) is necessary to account for any excess ribbon length which the cable may contain.

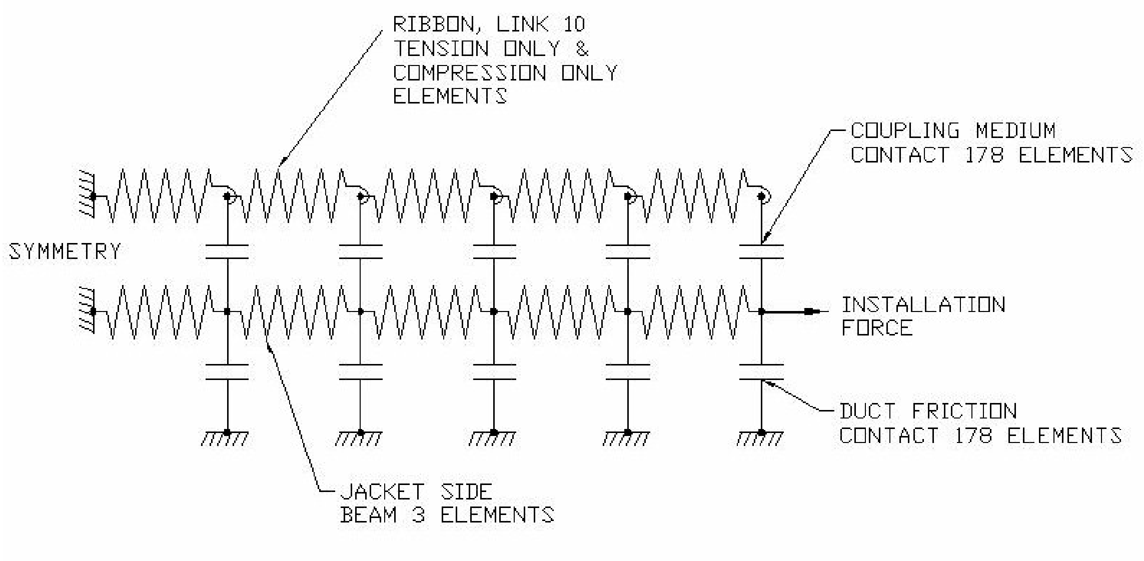

Figure 2. Duct Installation Finite Element Model Schematic

$$L = \frac{F\left(1 - \frac{K_t}{K_r + K_t}\right)}{\mu_r + \mu_d\left(1 - \frac{K_t}{K_r + K_t}\right)} \qquad (1)$$

Where:

L	is the coupling length
F	is the applied force
K_r	is a constant dependent on the design of the cable ribbon stack
K_t	is a constant dependent on the design of the cable jacket side
μ_r	is the ribbon to cable coupling force per unit length
μ_d	is the cable to duct friction force per unit length

As in the duct model, the aerial model shown in Figure 3 has normal forces applied to the contact elements to produce the desired coupling interaction between the ribbon and jacket. To represent environmental conditions such as wind and ice load, strain is applied to the jacket elements in the span (from the symmetry plane to the pole restraint). As ERL is removed from the cable, two coupling points form initially at the pole restraint, one which moves into the span and the other into the free end. As the applied strain continues to build, the coupling point in the free end eventually exceeds the available cable length and the ribbon moves into the jacket leading to potential problems in closures.

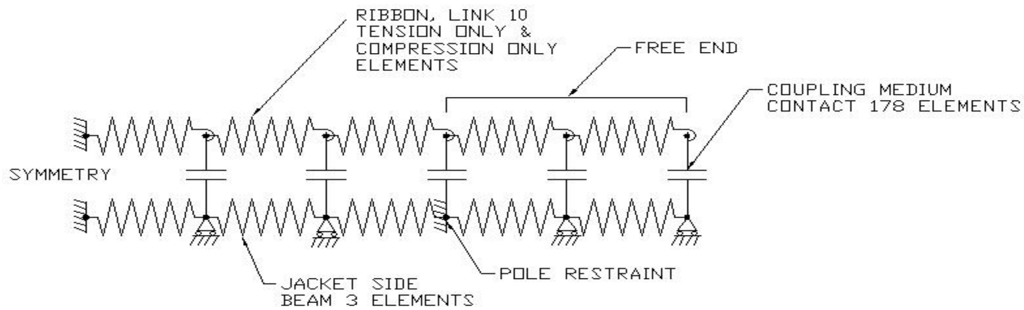

Figure 3. Aerial Cable Finite Element Model Schematic

Convergence Controls

Convergence is highly dependent on the class of problem, relative stiffnesses involved, and the type of loading as well as many other factors.

The FE models used in this analysis are very sensitive to the contact algorithm choice and the size of the load substep. Use of the default contact algorithm (the Lagrange Multipliers Method) produces memory read error on PCs. Of all four of the contact algorithms, the Pure Penalty Method provides the quickest convergence and is used throughout the analyses.

The minimum substep size required for the initial loading of 600 lbs for the duct installation Reference [1] and the imposed strain for the aerial wind and ice load case Reference [2] is typically 1e-5. The unloading and subsequent loading load steps typically require substep sizes as small as 1e-14 to obtain convergence.

ANSYS Results Comparison with Experimental Values

Duct Cable Results

The cable load deflection testing is conducted by coiling the cable to couple the ribbon to the jacket, anchoring the coiled end of the cable, applying a force to the jacket and measuring the differential displacement between the ribbon stack and the jacket at the loaded end. The duct installation finite element results are compared with experimental values for three different cable designs as shown in Figures 4 – 6. Test results are compared with the ANSYS results as shown in Figure 7 to validate the modeling. The ANSYS models predicted differential displacements that are within 10% of the measured experimental values.

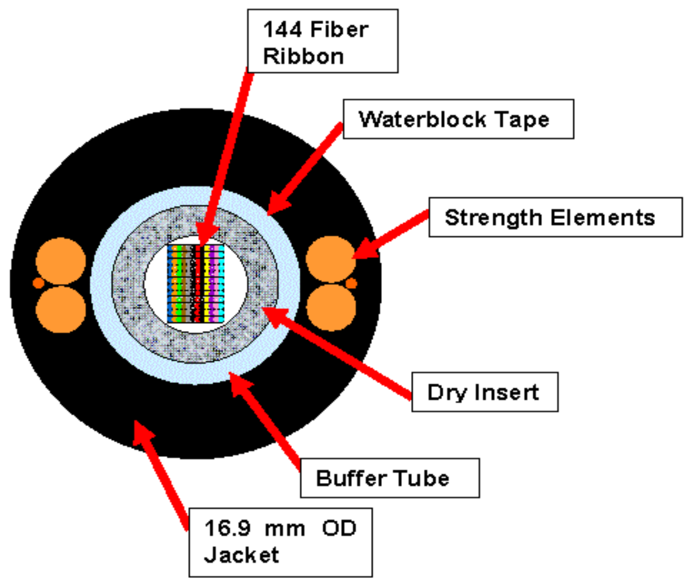

Figure 4. Test 1 Cable Design

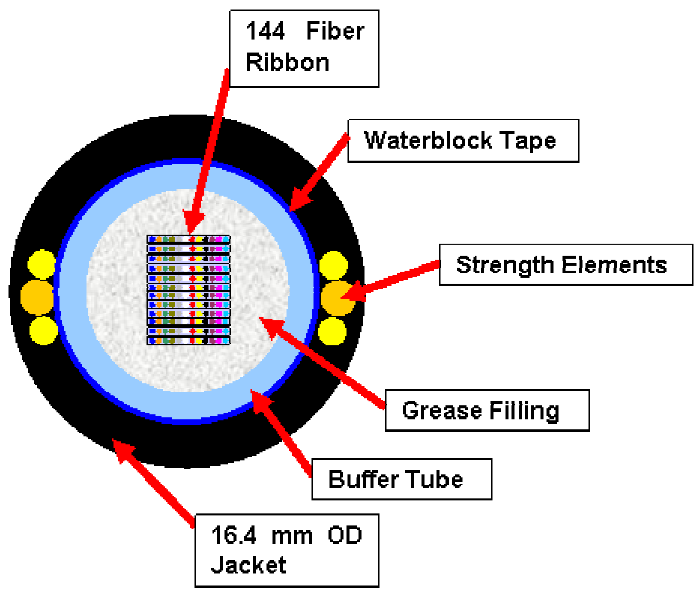

Figure 5. Test 2 Cable Design

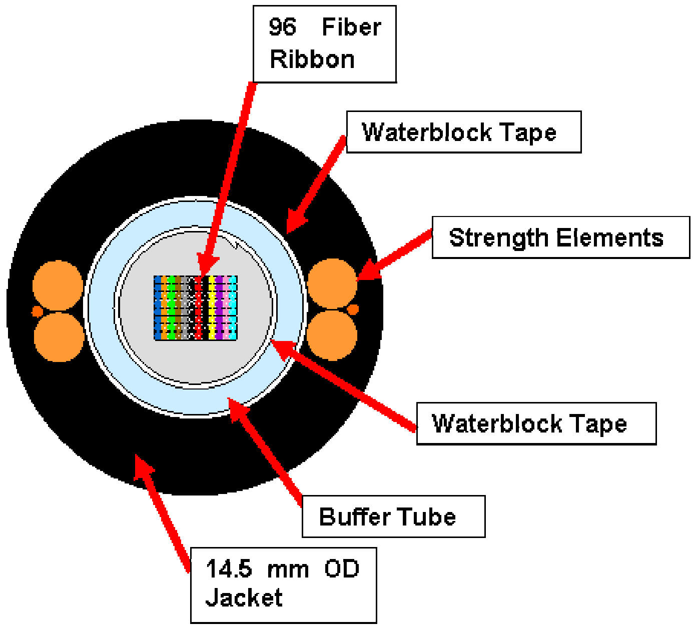

Figure 6. Test 3 Cable Design

Figure 7. ANSYS Results Comparison with Test

Aerial Cable ANSYS Results

The aerial cable model shown in Figure 8 is used to examine the effects of coupling, ribbon compressive stiffness and initial ERL on the resulting maximum local ERL after load cycling. The results plots, Figure 9 through Figure 10, show distinct discontinuities where the maximum ERL occurs in the span at lower initial ERLs and then shifts to the free end at greater initial ERLs.

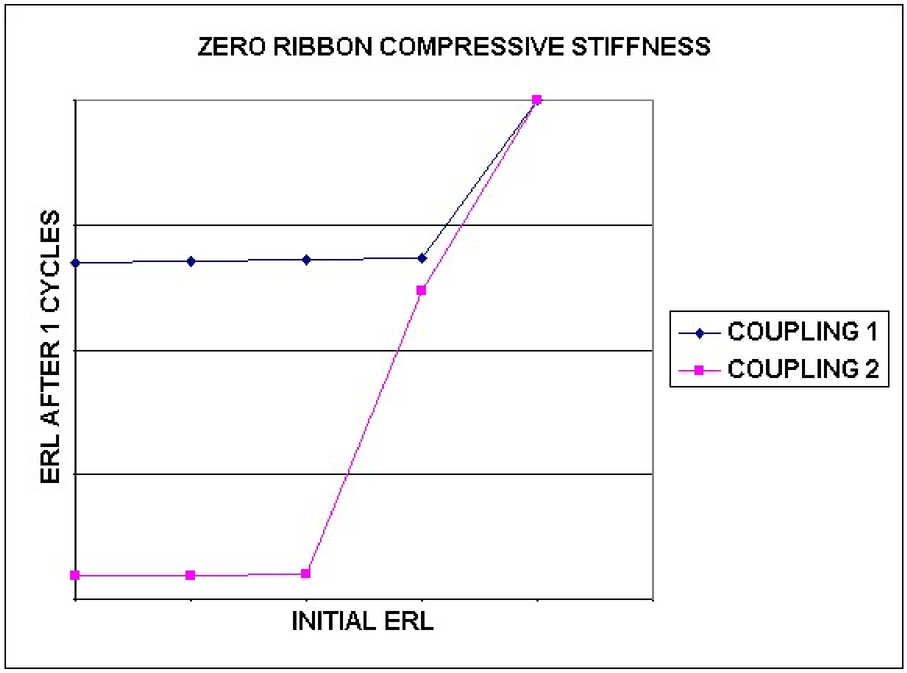

Figure 8. Maximum ERL after Loading Versus Initial ERL, Zero Ribbon Compressive Stiffness

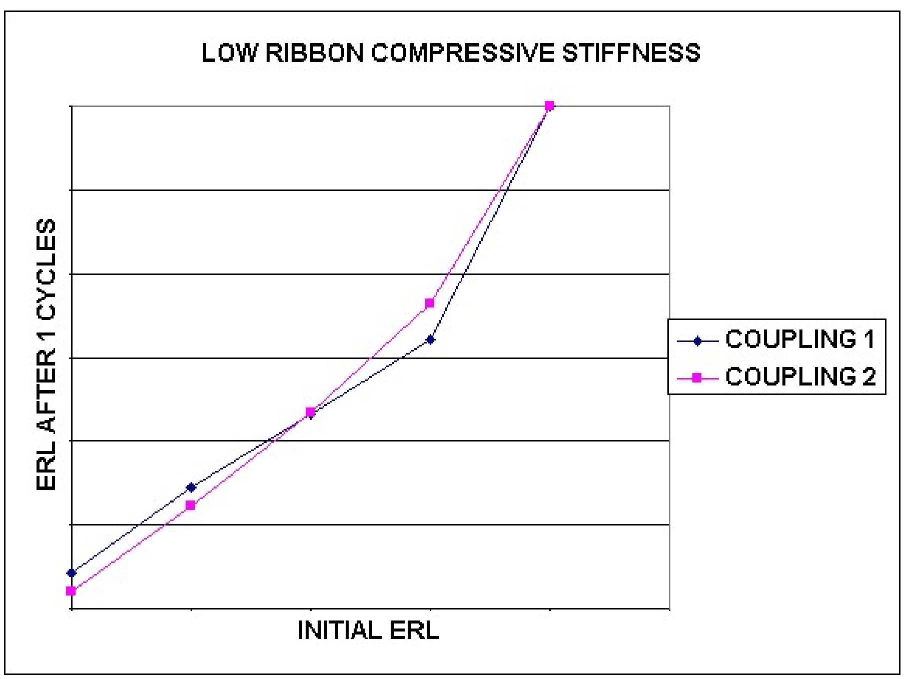

Figure 9. Maximum ERL after Loading Versus Initial ERL, Low Ribbon Compressive Stiffness

At low initial ERLs, the initial ERL has insignificant effect on final ERL for the zero ribbon compressive stiffness case. Ribbon to jacket coupling, however, has a significant effect on the final ERL as shown in Figure 8. As ribbon compressive stiffness increases, the initial ERL has significant effects on the final ERL while coupling has little effect as shown in Figure 9.

For constant coupling cases, greater ERL is present after load cycling as the ribbon compressive stiffness diminishes as shown in Figure 10 and Figure 11. This effect is more pronounced at lower coupling levels.

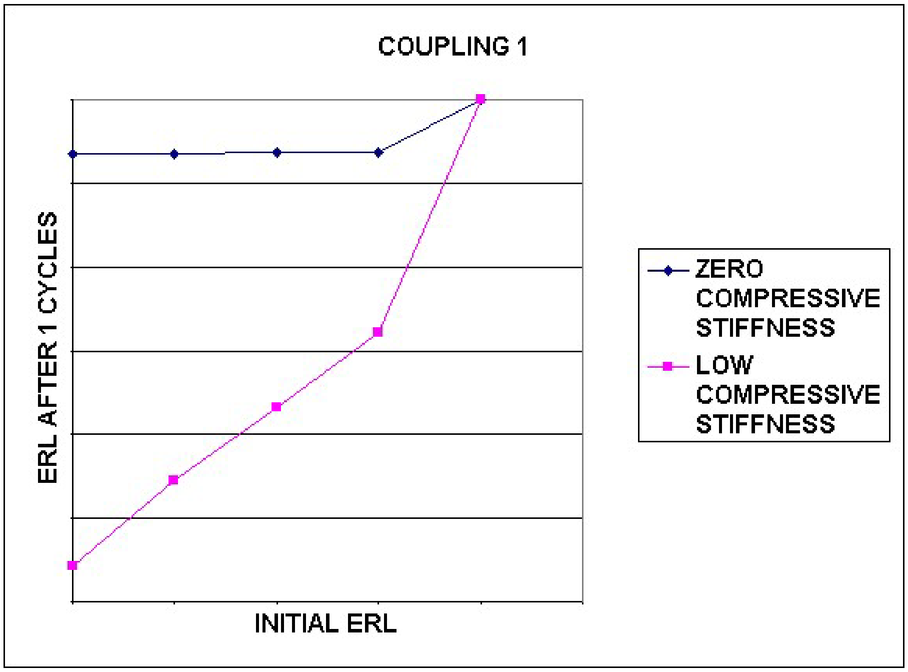

Figure 10. Maximum ERL after Loading Versus Initial ERL, Low Ribbon/Jacket Coupling

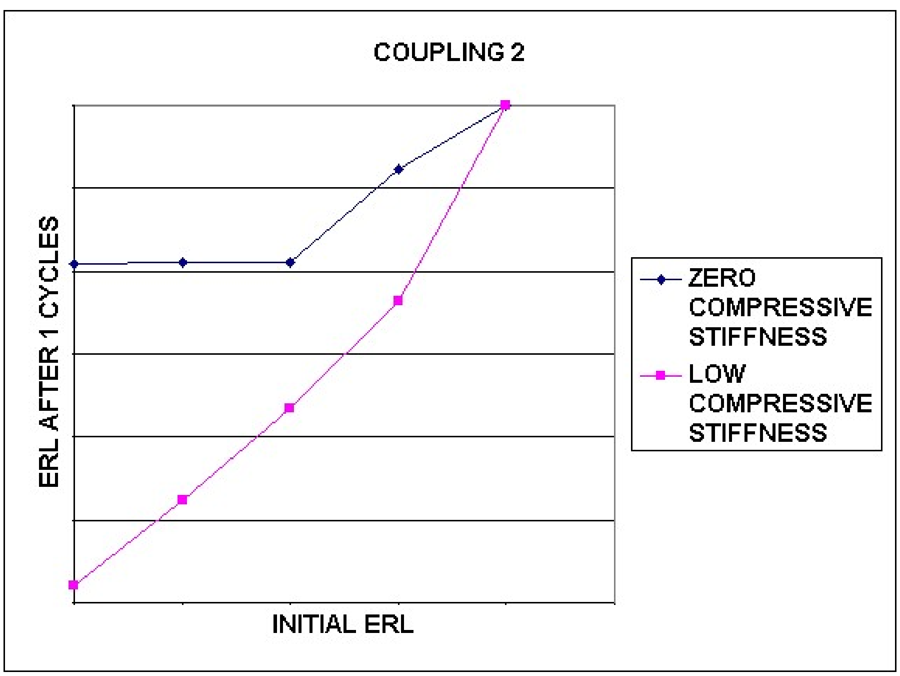

Figure 11. Maximum ERL after Loading versus Initial ERL, High Ribbon/Jacket Coupling

Conclusion

The finite element ribbon to jacket displacements compare within 10% of measured experimental values.

Coupling, ribbon compressive stiffness and initial ERL affect local accumulation of ribbon after load cycling. The initial ERL has a significant effect on the maximum local ERL after load cycling, especially as ribbon compressive stiffness increases. Low coupling levels result in greater accumulation of local ERL as ribbon compressive stiffness diminishes.

References

[1] "Generic Requirements for Optical Fiber Optics and Optical Fiber Cable," Telcordia GR-20-CORE Issue 2, 7/98.

[2] "National Electric Safety Code", 1997, IEEE, New York.