# The Mechanical Reliability of Corning Optical Fiber in Small Bend Scenarios

## White Paper

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The purpose of this paper is to provide guidance on the mechanical reliability of Corning's optical fiber for the particular case of very tight bends encountered in fiber-to-the-home (FTTH) and premises networks.

**Introduction**

As optical fiber is deployed deeper into access networks and ultimately within premises networks, it will be subject to increasingly tighter bends. Examples include distribution cabinets, small footprint modules, storage cassettes, and also in indoor installations such as MDUs (Multi-Dwelling Units) and in-home wiring. Consequently, Corning and others have commercialized new low-bend-loss fiber products with significantly lower optical bending loss in order to accommodate these deployment conditions. However, with this trend towards fiber with tight bends one must consider the implications on fiber mechanical reliability.

In response to the new fiber requirements for fiber-to-the-home and premises networks, a new ITU-T Recommendation (G.657) has been ratified. This standard is devoted to the specific requirements for optical fiber and cable used in the optical access networks to and within buildings and homes. Among other requirements, the recommendation addresses lifetime expectation in the case of small radius storage of single-mode fiber.

This paper will review fiber mechanical reliability in the context of tight bending scenarios and the new requirements of ITU-T G.657. We will also provide guidelines for safe fiber deployment in tight bending scenarios.

**Corning's Approach to Mechanical Reliability**
Corning Incorporated has been manufacturing optical fiber since the 1970's. For more than 30 years Corning has been a leader in the research of optical fiber strength and reliability. We've shown long-term commitment to developing the reliability science behind our models and tests. A sampling of this research can be found at:

http://www.corning.com/opticalfiber/technical_library/fiber_mechanical_reliability/basics.aspx

In the following paragraphs we will briefly review the key ingredients of our fiber mechanical reliability program.

**1. The Modeling of Mechanical Reliability**
Our modeling capability is well-known through publications, tutorials and direct customer interaction. We provide customers with state-of-the-art reliability modeling that incorporates a wide range of fiber tensile stresses, bends, lengths and stress durations. Corning has developed the tools and models to allow customers to take advantage of our proof test stress and fiber strength distribution. The cornerstone of our modeling effort is our unique ability to incorporate all these factors into a single model. The present discussion on fiber in tight bends fits well with this prior work in fiber mechanical reliability.

**2. Adapting to the Application**
Designing Around Proof Stress Level Flaws: For most fiber applications, long lengths of fiber are placed under some lower level of bend and/or tensile stress (see Figure 3). Here it is appropriate to design around the proof stress; and therefore, it is critical that the fiber manufacturer screen out flaws weaker than the proof test stress. Proof testing is conducted after the draw process where the entire fiber length is stressed to a predetermined stress level in order to eliminate the weakest flaws. The most common proof stress levels are 100 and 200 kpsi (700 and 1400 MPa). Corning has well-established guidelines on how much applied stress the fiber can withstand in service over time for a given proof stress.[1] For example, one can safely stress optical fiber to 1/5th of its proof stress for a 25 year in-service lifetime.

Failure Probability Design: There are applications where fiber users need to stress lengths of fiber in excess of what Corning would advise for proof stress level flaws. These applications typically involve short lengths of fiber placed in small bends and applications with longer lengths under high tensile or bending stress. Here one may exceed the applied stress guidelines for proof stress level flaws if the probability of encountering a flaw that will break during the in-service time is low enough (see Figure 3). This means that the manufacturer must have comprehensive knowledge of the post-proof test strength distribution. The length tested must be consistent with the application lengths under stress and the probability levels of interest.

**3. Fiber Strength Measurements and Understanding**
Most strength distributions reported in the published literature are obtained by testing 50 cm lengths of fiber in axial tension or by 2-point bending extremely short lengths of fiber. Such testing is necessary for Trade and Commerce, i.e., standards compliance, but is not sufficient for reliability predictions and design because the total sample size, i.e., characterized length, is too small. For decades Corning has been innovating methods for strength testing optical fiber that provide strength distributions relevant to the intended fiber applications.

In the early 1990s Corning developed a machine that automatically strength tests 20 meter lengths of fiber.[2] The sole purpose of this machine is to characterize the strength above the proof stress level on total sample lengths of fiber that are relevant to our customers. Since then we have strength tested tens of thousands of kilometers of fiber. Figure 1 shows all the flaws below 560 kpsi on nearly 4000 kilometers of fiber proof tested to 100 kpsi.[3] The probability of finding a flaw weaker than, say, 200 kpsi (1400 MPa) on a 20 meter length of this fiber is about 1 in 10,000. We can then scale this distribution to almost any length for engineering failure probability predictions.

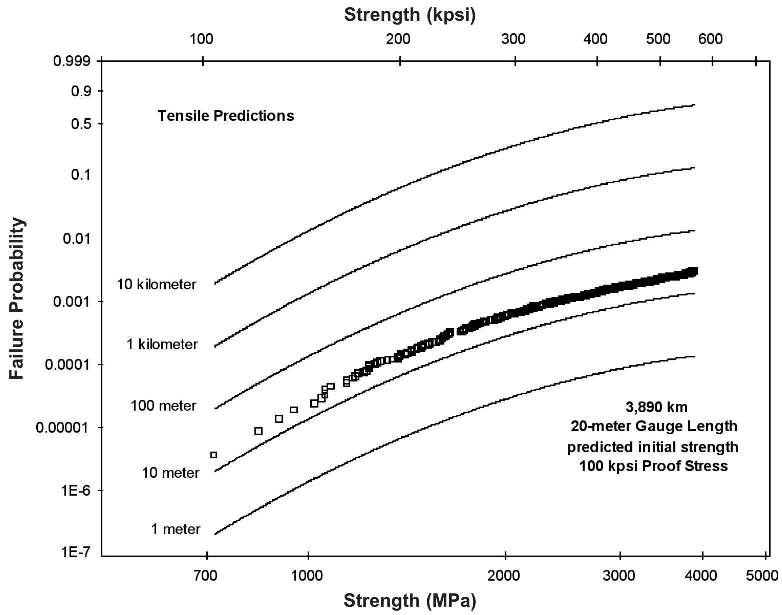


**Figure 1**. Strength of nearly 4000 km of standard single-mode optical fiber. The lines represent predicted distributions for lengths other than 20 meters. Note that fatigue during strength testing has been accounted for. This distribution is ready to be incorporated into reliability models.

## 4. Fiber Fatigue Behavior

The mechanical reliability of silica-based optical fiber is limited by the fatigue effect. Flaws in glass subjected to tensile stress in the presence of moisture grow subcritically prior to failure[1]. Michalske and Freiman[4] describe this fatigue mechanism as, "the slow extension of a crack due to a specific chemical reaction between strained silica bonds and water." Ritter describes fatigue in terms of strength degradation when he states that "time-dependent strength behavior (fatigue) of glass is generally believed to be the result of subcritical crack growth of a flaw to a dimension critical for spontaneous failure."[5] The crack growth rate and respective time-to-failure depend on the initial crack size, applied tensile stress, and environment (temperature, humidity, pH)[2-4].

The susceptibility of optical fiber glass to fatigue is reflected in the fatigue parameter "n". The higher the n value the more resistant the glass is to fatigue. The "n" value is most commonly obtained by measuring fiber strength, $\sigma_f$, for a range of stressing rates, $\dot{\sigma}$ (the rate of change of the stress during the test). At fast stressing rates there is less time for fatigue and the strength is relatively high. At slow stressing rates there is more time for fatigue and the strength is correspondingly lower. The "n" value is obtained from the slope of ln $\sigma_f$ versus ln $\dot{\sigma}$ by slope = 1/(n+1) and a typical value for silica in fiber form is about 20.

In mechanical reliability models a high n value leads to a higher allowable stress. However, since all optical fiber for telecommunication applications has a silica surface, the basic fatigue behavior for all optical fiber is expected to be equivalent. Certainly some lab-to-lab differences in measured n values exist due to test method and test environment differences. Within the standardized rates used for trade and commerce testing the n values should be the same for all optical fiber. Note also that there are claims of increasing n values with aging time. Any claim of higher reliability with aging time should be viewed with suspicion. While there is evidence that protective polymer coatings can affect the environment at the silica surface, it is unlikely that this effect is permanent over the intended service life of the fiber. Given the potential for variability and transience of any unexplained changes in the n-value one should consider taking a conservative view of the n-value in relation to fiber fatigue. Corning uses the widely recognized, reliable and experimentally endorsed n value of 20 for long-term reliability predictions. Moreover, we believe that fiber reliability behavior should be based on more than the n-value alone.

Corning has been at the forefront of research into the fatigue of optical fiber. The following list describes some of our investigations into fiber fatigue:

- Proof stress level flaws have an “n” value of about 20.
- Fatigue is relatively independent of flaw source and strength.
- Fatigue models must account for fatigue occurring during both high speed processing events and slower events.

In the next section we demonstrate how we use this knowledge of fiber mechanical reliability to establish practical guidelines for fiber use in a wide range of applications.

## 5. Design Diagrams

### Design Diagram based on Proof Stress Level Flaws (“Safe Stress” Design)

Figure 2 shows an allowable stress design diagram for optical fiber based on the proof stress level. This design method is commonly employed on fiber lengths longer than a few kilometers. The applied stress (bending and tensile) is based on the lowest possible strength, the proof stress. Note that the allowable applied stress depends on the duration of the stress event. For example, one can place more stress on the fiber for a relatively short installation event than for 20 year life.

### Design Diagram based on Failure Probability

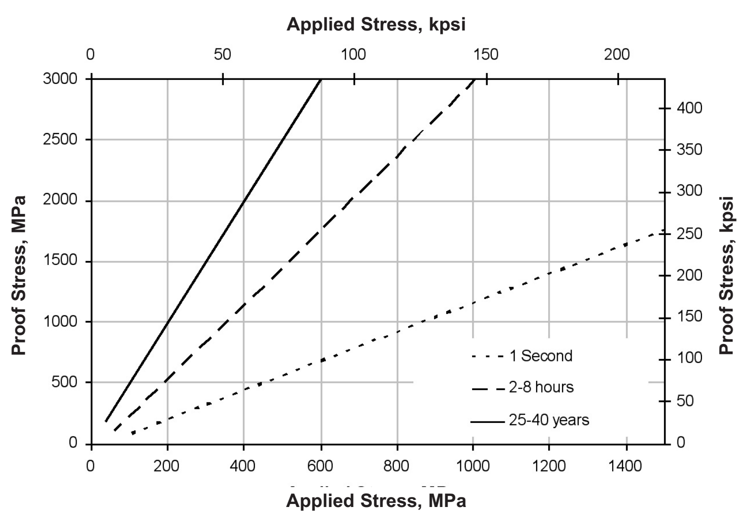


**Figure 2.** Design diagram showing proof stress vs applied stress for different durations.

Combining the strength distribution in Figure 1 with Corning’s fatigue understanding and reliability model, the following design diagram for standard optical fiber in bending can be created. In this diagram we have included a range of bend radii, load durations, and lengths in bending. Consider the case of a 1 meter length or 16 turns of fiber permanently wound to a bend radius of 10 mm with an associated stress of about 450 MPa. The failure probability would be approximately $10^{-5}$, or 1 in 100,000 for a 25 year period, which is low for most applications. The bending of fiber tightly for short time periods is also of interest. Consider the bending induced when handling for termination and installation. Again, one is counting on the fact that the probability of encountering a flaw is low, implying that large sample lengths are necessary to precisely determine that probability. Consider the case of threading 10 meters of fiber around a tight corner during installation. Using Figure 3 we estimate a failure probability of 1 in 10,000 for a 1 second exposure to a 4 mm bend radius. These examples demonstrate that Corning has the capacity to quantify the mechanical reliability for a wide range of applications.

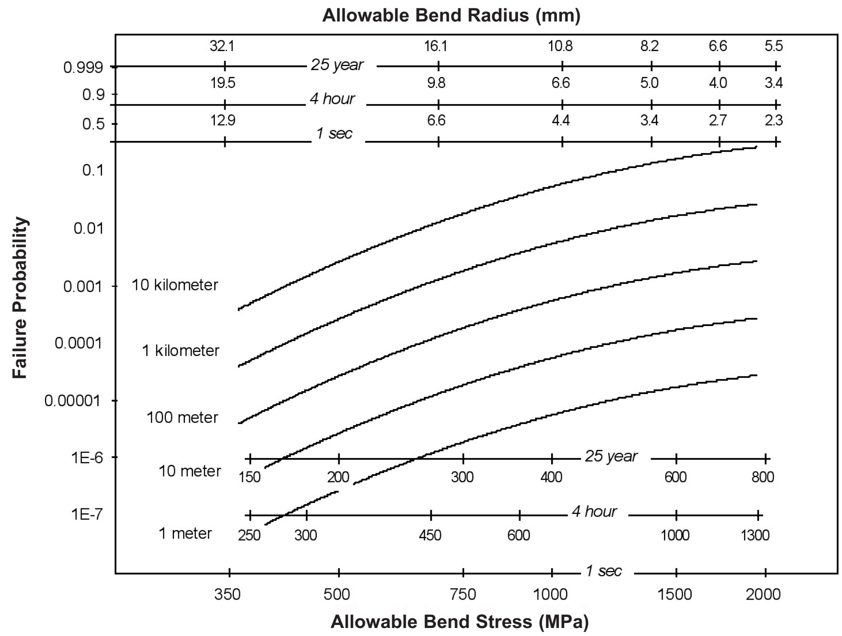


**Figure 3.** Design diagram for standard optical fiber in bending.

**FTTH and Premises Guidelines**

The results given in Figure 3 can be further interpreted to describe the probability of failure over 25 years on a "per turn" basis relevant to FTTH installations. Table 1 shows the probability of failure for a 360° turn for several bend radii. These values are based on Corning's fiber strength distribution and our reliability model, and are therefore applicable to Corning fibers and other fibers of an equivalent high quality.

**Table 1:** Failure probability/turn over a 25 year lifetime

| Radius (mm) | Probability of Failure/Turn |
|---|---|
| 7.5 | $1x10^{-6}$ |
| 10 | $5x10^{-7}$ |
| 15 | $1x10^{-7}$ |

For a bend radius of 7.5 mm, this analysis indicates one million full turns (360° degrees) are needed to generate a single fiber spontaneous break over a 25 year lifetime, a very low failure rate. Another way to interpret this result is considering an indoor installation where the fiber is severely deployed with 10 full turns (360 degrees or, say, forty 90-degree turns) at a very tight radius of 7.5 mm. From Table 1, the probability of failure at this radius is about 1 ppm ($1x10^{-6}$) per turn over a 25 year lifetime, leading to a failure rate of about 10 ppm for this single indoor installation. In a hypothetical FTTH network with one hundred thousand homes passed, the expected number of fatigue related breaks would be only one fiber failure ($10^5$ x 10 ppm) in the whole FTTH network in 25 years of operation.

The real case of a FTTH network is obviously more complex than this example. Fiber undergoes bending throughout the network, within the central office, in street cabinets, and within the end-user home. One has to consider not only bends within cabinets and storage units, but also in indoor installations and ultimately within optical cable due to fiber excess lengths. It is possible to build a bend spectrum for any specific network that captures the number of turns (or the length under bending) occurring at each bend radius. Armed with this information, Corning has the modeling capability and engineering experience to assess fiber reliability for any installation.

**Summary**

With the trend towards increasingly tighter bend radii in access and FTTH networks it has become increasingly important to understand the reliability performance of optical fiber under tight bend scenarios. Understanding the strength and fatigue behavior of optical fiber and developing the associated lifetime models has been a primary focus for Corning over the past 30 years. Also, supplying reliable fiber, utilizing our world-class manufacturing processes, continues to be Corning's highest priority. In this paper we argue that reliability assessments require more than just an n-value. Fiber reliability is established by combining knowledge of the fiber strength distribution, fatigue behavior, and the applied stress history into a reliability model. Corning has a proven track record in engineering reliability solutions for optical fiber.

## Reference

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