Application Note

Mechanical Reliability of Prysmian Group Optical Fibre

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EXECUTIVE SUMMARY:

- This document provides guidelines on the mechanical reliability of optical fiber cable manufactured by Prysmian Group. We describe how this reliability relates with the various processing steps before the cable is eventually put into service - e.g., manufacturing of the optical fibre, cabling, storage, installation (deployment and splicing) as well as other extrinsic factors.
- The main conditions affecting the mechanical reliability optical fibers - owing to strength degradation, are reviewed together with allowable limits vs. stress levels considering optical fibres proof-tested to 1% equivalent strain.
- Provided that these recommendations are followed, service lifetime projection ranging from 25 up to 40 years can be soundly expected. Several studies carried out on cables installed more than a couple of decades ago showed no evidence of any detrimental degradation in fibre performance.

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Background

The mechanical integrity of optical fibre must be guaranteed for the expected life of a communication link in order to prevent loss of service. An accurate knowledge of the fibre strength distribution is of utmost importance to predict long-term reliability.
In any large population of commercial optical fibre in today’s market the vast majority of the fibre exhibits a high strength in tension or bending, at a level termed the intrinsic strength of the glass. Typically, this is a strength of around 4.8 Gpa (700 kpsi) when measured at a tensile strain rate of 5 percent per minute for 125 µm glass diameter optical fibres.
The population also exhibits points, or flaws along the fibre, with lower strength. These flaws constitute another region, termed the extrinsic strength region. Both the intrinsic strength distribution and the extrinsic distribution are linear when plotted on a Weibull distribution coordinate system (characterizing brittle fracture) but with very different slopes as illustrated in Figure 1:

- The slope of the intrinsic strength region is high indicating a very high concentration of fibre exhibiting this strength.
- The slope of the extrinsic strength is much lower indicating a far lower concentration of fibre length with the larger flaws.

Also, the linearity on the Weibull plot means a probability of finding a flaw that decreases with decreasing strength. It is good news for the deployment of optical fibre, since the larger/weaker the flaws the smaller the chance of there being one.
Still, it is necessary to remove as much of the lowest portion of the extrinsic strength region as practical. There are enough flaws in this region to result in fibre breaks during installation and in service even when the strain on the fibres is kept low. The industry standard method is to proof test 100 percent of the fibres with a short duration strain of 1 percent, about 0.69 Gpa (or 100 kpsi), to remove all the flaws at the low end of the extrinsic distribution. Most of the commercial fibre population today will exhibit 5 breaks or less per 100 km during proof testing, and for production processes like Prysmian’s that have been developed and carefully maintained for highest quality, pristine glass conditions, the break rate is much lower. The very low proof test break rate is also a qualitative indicator of a very low concentration of flaws throughout the extrinsic region, that is, surviving proof test but still on the lower end of the scale.

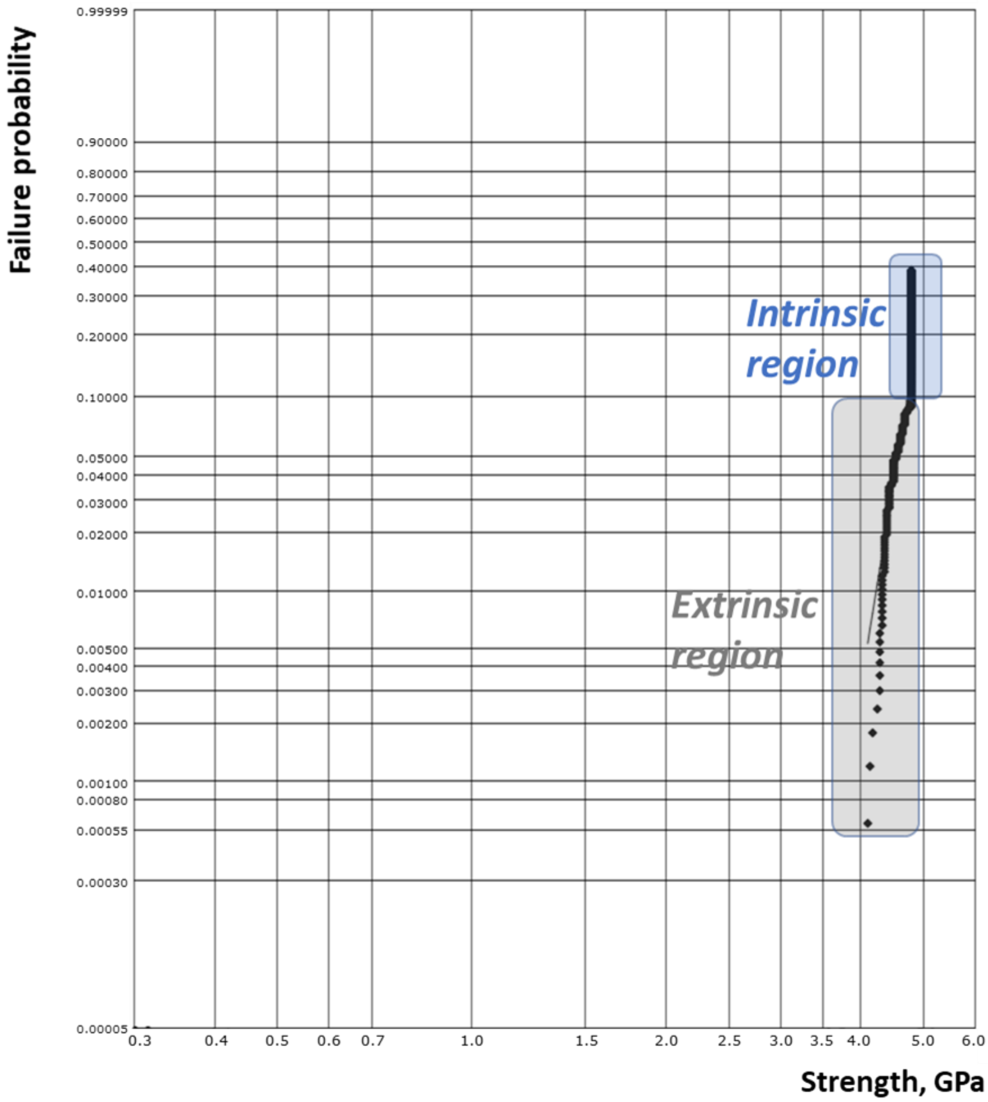

Figure 1 –Weibull plot for 1% strain proof-tested 125/250µm G.652 fibre population (20 m-long gauge length).

Study of Post-Processing

The guarantee of in-service strength of the optical fibre also assumes no further damage is inflicted on the optical fibre by post-production processes such as fibre re-spooling, transport, payoff of fibre during manufacture of buffer tubes, etc. To this end Prysmian Group has undertaken major studies of causes of fibre breaks to identify and correct possible threats to the mechanical integrity of the fibre in service, and today continues to monitor all aspects of the production processes closely.

One such study was to proof test 20,000 fibre kilometres a second time, and analyze the root cause of every fibre break that occurred by scanning electron microscope (SEM). In most cases it is possible to identify the cause of the break by SEM inspection. A second proof test will always result in a small number of breaks of flaws that just survived the first proof test, around a level of 10 percent or less of the original break rate. These breaks will always exhibit a failure strength at about the 0.69 GPa (100 kpsi)level. Other breaks that show a failure at lower strength can provide evidence of damage occurring after the original proof test strain of the fibre. Then these root causes can be corrected. Prysmian remains scrupulous in examining breaks and maintains a zero tolerance for post-proof test damage.

Another method is to examine every break that occurs during cabling, though these breaks were very rare. In the same way, SEM analysis allows break the causes in the cabling process to be identified and corrected. With careful attention to maintaining top quality processing in Prysmian, such breaks in cabling today are almost unknown.

Deployment

Optical fibre encounters many types of mechanical strain in commercial deployment with very low up to very high strain levels. We may list some of them in the following table:

Strain description	Strain level
Bending strain due to stranding of buffer tubes in cable	very low
Tensile strain in cable during installation	moderately high
Tensile strain in aerial cable deployment	low
Bending strain in coils of fibre in closures	low to moderate, but for relatively short lengths
Bending strain as deployed in MDUs	can be high (approaching or exceeding proof test level), but for very small sections of fibre
Bending strain in electronics	can be high but for very small sections of fibre
Bending strain during splicing	quite high (significantly exceeding proof test level), but for small lengths of fibre and very short duration, e.g. local injection/detection to measure splice loss.

Cable designs minimize strain the fibre through provision of additional strength members, so even in aerial applications the actual tensile strain in fibre is kept low, typically well below 0.2%. Thus even in very large volumes in cable, fibre breakage can be kept to virtually zero failure rate over 40 years.
For higher strain, usually small radius bends introduced in premise applications, we can consider the two regions of fibre strength. First, the vast majority of fibre that is characterized by the intrinsic strength region can tolerate very small bend radii, even to 3 mm, without danger of breaking over a lifetime. As an example, Prysmian maintains several collections of fibres wrapped around mandrels with a range of radii down to 3mm. In the 25 years life of the oldest of these there have been no fibre breaks, and none in more recent collections. Today, the fibre quality is even higher.
The danger to the fibre strength lies in the probability of an extrinsic strength flaw below a threshold strength falling in the stressed region of a small bend. As mentioned, this probability is extremely small, but not zero. Thus, for small bends in fibres we must consider the proof test level and the characteristic extrinsic strength distribution of the fibre population as well as the resistance of the flaw to grow that is defined partly by the stress corrosion factor. Then we can calculate the probability of finding a failure in the population of small bends.

Recommendations for Temporary and Permanent Maximum Strains

We may sort the strain conditions imposed on optical fibre into four classes:

Classes	Requirements
Installation	short duration, zero breaks tolerated,
Joining or splicing	short duration high stress, ppm breaks may be expected
Long lengths of installed cable	zero breaks tolerated
Short lengths of bending in deployment	ppm breaks to be expected in small bend radii, zero breaks tolerated in large bend radii

Using the Power Law Model [1] for lifetime projections and the measured parameters, conservatively estimated, characteristic of the Prysmian fibre population the probability of failure as a function of fibre strain can be determined and applied to each of the four classes of deployment conditions to establish maximum strain levels to provide for zero probability of failure or to hit a target of minimum parts per million (ppm) failure rate in service over a defined time period – either short duration or lifetime of the installation. For instance 1 ppm failure rate means it would need one million fibre kilometres to observe one break.

Looking first at strain in tension, as for long lengths of cable during installation, we can generate a family of curves as in Figures 2 and 3.

Figure 2 shows two strain situations:

- the first corresponds to what might be considered for long term deployment from 0.20% to 0.30% permanent strain,
- and the second is what might be considered for short duration strain as in installation from 0.35% to 0.50%.

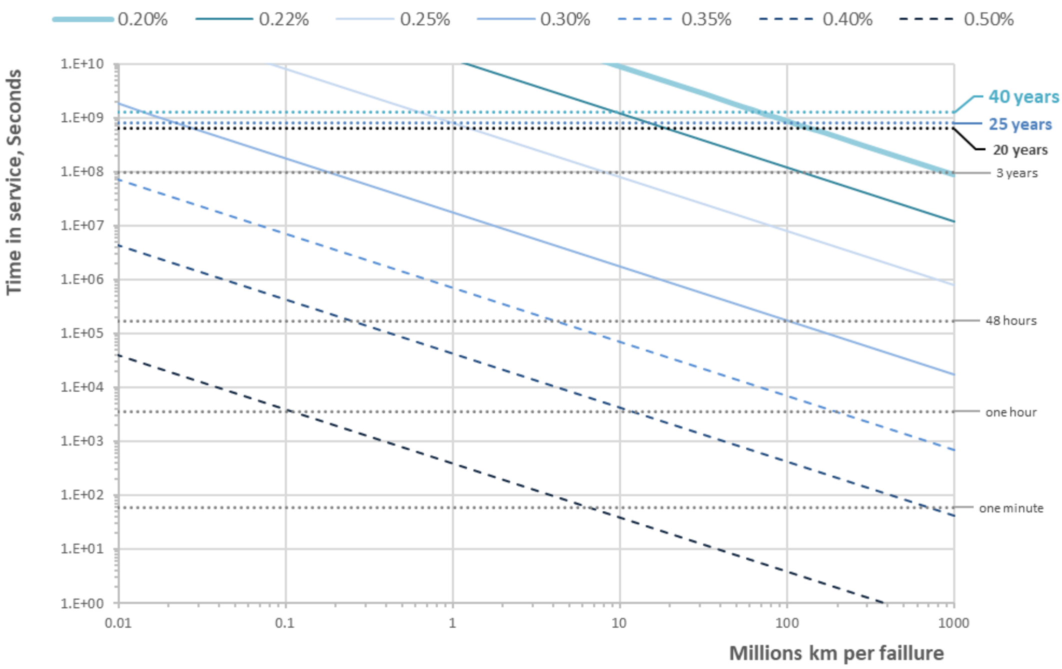

Figure 2 - Fibre Mechanical Reliability Under Tensile Strain.

Figure 3 is the family of curves generated for Prysmian fibre in bending, using the same conservative values for the parameters characteristic of the Prysmian fibre population. The same form of the Power Law Model is utilized for these curves, but the length of fibre under strain is adjusted, in accordance with the model, for the area of the fibre under maximum or near-maximum bending stress.

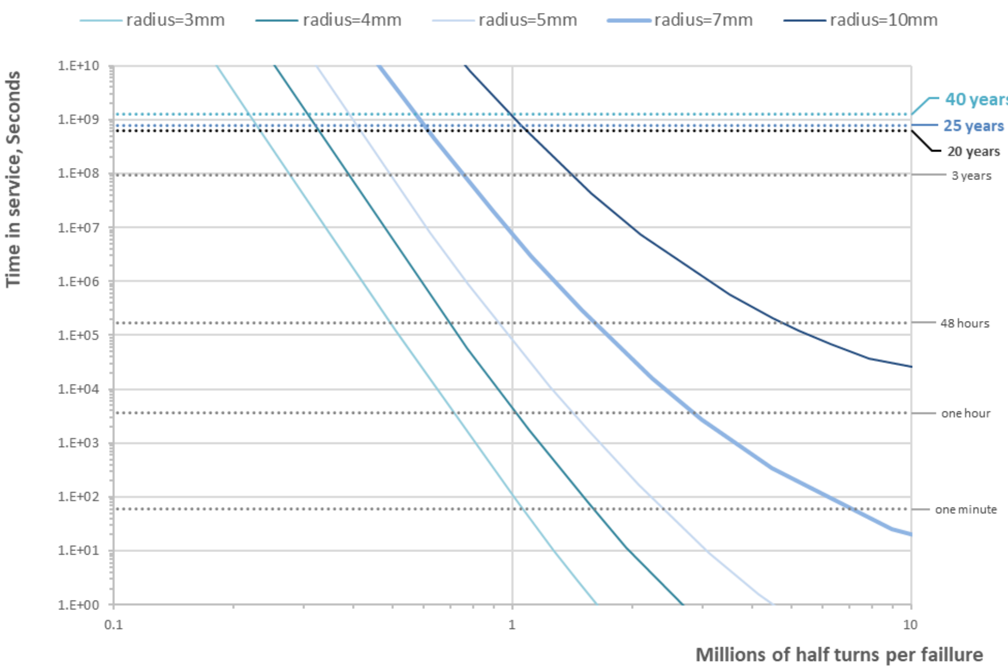

Figure 3 - Fibre Bend Mechanical Reliability.

It is seen at once that a different region of lifetime is encountered for these higher strains compared with the projections for long lengths at lower strain in Figure 2. The curve for the 10mm bending radius (2/3 of proof test strain) can be seen in transition to the lower-strain region. Under these high strains, there is much less difference in failure probability between 1 second and 40 years. This also implies that most of the failures in a very large number of such bends will occur early in the lifetime.
It is not recommended that optical fibre be in a bend radius significantly less than 3mm for any length of time, as such strain begins to approach the intrinsic region of the fibre strength.

Based on Figures 2 and 3, the following recommendations are given for maximum tension/strain in installation, joining, and long-term deployment of Prysmian optical fibre for fibre proof tested to 0.69 GPa (100 kpsi):

Duration	Maximum Safe Fibre Tension
5 hours	0.24 GPa (35 kpsi)
30 minutes	0.28 GPa (40 kpsi)
5 seconds	0.34 Gpa (50 kpsi)

Table 1 - Installation of cable, tubes or bare fibre - zero failure tolerance.

Duration	Minimum Bend Radius
10 minutes	3 mm

Table 2 - Splicing operations - <0.5 ppm failures.

Lifetime prediction	Maximum Safe Fibre Tension
40 years	0.14 GPa (20 kpsi)
25 years	0.14 GPa (20 kpsi)
3 years	0.15 GPa (22 kpsi)

Table 3 - Long-term deployment conditions - zero failure tolerance.

Lifetime prediction	Minimum Bend Radius
Up to 40 years	25 mm

Table 4 - Splice closure coil radius - zero failure tolerance.

The 25 mm bend radius over 40 years is just an example that gives a rather typical situation. That bend radius can be sustained for much more than 40 years for short lengths, a few meters at a time. The failure probability is not absolute zero, but is very small, like 0.01ppm or less. In practical terms, it is going to be impossible that so much fibre could be installed without a number of coiled lengths being damaged by operators, or without other dangers like wrong solvents or excess solvents used to clean the fibre, gasoline getting into the closure, water flooding, etc. There will be relatively large numbers of failures, on the order of ppm, but these will not be due to large flaws in the glass under high stress.

In practical terms it is possible to go with coils in closures down to 15mm bend radius with <0.1 ppm failures in 40 years.

Lifetime prediction	Minimum Bend Radius
40 years	~7 mm
25 years	~7 mm
3 years	5 mm
Short-term (48 hours)	4 mm

Table 5 - Small bend radius, < 0.5 ppm Failure.

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Conclusion

Maximum fibre strain recommendations have been projected from Prysmian optical fibre under various installation and deployment conditions. These recommendations are based on best characterization practices and the Power Law Model for optical fibre reliability.
The recommendations assume that the optical fibre is well-protected from extremes of heat and moisture, solvents, damage induced by installation, splicing or connectorizing, and other in-the-field factors over which Prysmian has no control, and which may impact the accuracy of the projections.
Based on this analysis and recommendations, there is no indication to suggest that optical fibre products manufactured by Prysmian Group would instrinsically fail over 25 to 40 years if processed, installed and used properly.

Additional remarks

Recently there has been interest in assessing how optical fibre cables have been ageing since their installation back in the early 80s or 90s. From these available studies despites limited, there was any evidence that cables and fibres have experienced any detrimental degradation during their service lifetime even after more than 30 years in operation.
The International Telecommunication Union (ITU) has published several documents gathering an up-to-date knowledge on this long-term performance of optical fibres and cables. Among them, the ITU-T Supplement G.59 [2] aims at providing an overview of the long-term behaviour of optical cables as well as guidelines to help minimizing the number of mechanical faillures during the expected lifetime of the fibre and cables.

References

1. IEC Technical Report TR 62048:2014: Optical fibres - Reliability - Power law theory
2. ITU-T G-series Recommendations – Supplement 59, Guidance on optical fibre and cable reliability (02/2018)