American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Power Link Budget Analysis to Run Optic Fiber Cables for Connection Between Mabutsane and Motokwe Villages in Botswana

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Abstract

This paper presents design considerations and field implementation of low-cost optical fiber system to a small village approximately 87 Km to the north of Mabutsane, called Motokwe. The optical power link budget of two single mode Optical Fiber cables were considered and compared. The considerations to be made were the system margin, received power, and input power of either cables. Both cables were simulated using MATLAB and their respective results were obtained. The most suitable system was subsequently selected for the implementation. In this instance, the most suitable system was one that required the least amount of input power, least losses and had a considerably large system margin (at least 10dB).

Keywords: Attenuation; Macrobending; Microbending; Optical Fiber; Power Link Budget.

1. Introduction

A communication system transmits information from one place to another, whether separated by a few kilometers or by transoceanic distances[1]. An optical Fiber is a thin, flexible, transparent glass cylinder that acts as a waveguide or "light pipe", to transmit light between the two ends of the Fiber. The light may be used as a means of information transmission, making it an optical fiber communication medium [2].

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The need for connectivity has never been any higher than it is today and it is only expected to rise [3]. Optical fiber cable is a medium of choice because of its high transmission rates (up to 200 Gb/Second for Optical Fiber), large bandwidth, low attenuation over large distances as well as immunity to noise [4]. However, Botswana, like most developing countries has not yet connected optical fiber to most of the remote parts of the country, thus effectively leaving over 30% of the population without access to the internet. Figure 1 below is a Map of Botswana showing the areas of the country currently covered by optical fiber network (indicated in red). As can be seen on the map, the village of Motokwe, like many others does not yet have any Optical Fiber coverage. This paper is about the implementation of an affordable and practical optical fiber system from Mabutsane to Motokwe. This link will act as an optical fiber backbone. The most important aspects for a design engineer is determining which type of optical fiber is most appropriate for the distance to be covered, as well as taking into consideration all factors that might cause his optical signal to be distorted, or not received entirely and plan for them accordingly. The paper is structured as follows: section 2 is the materials and methods. Section 3 gives the results as well as the MATLAB code used for the simulation of the optic fiber system. Section 4 is the discussion and finally Section 5 is the conclusion.

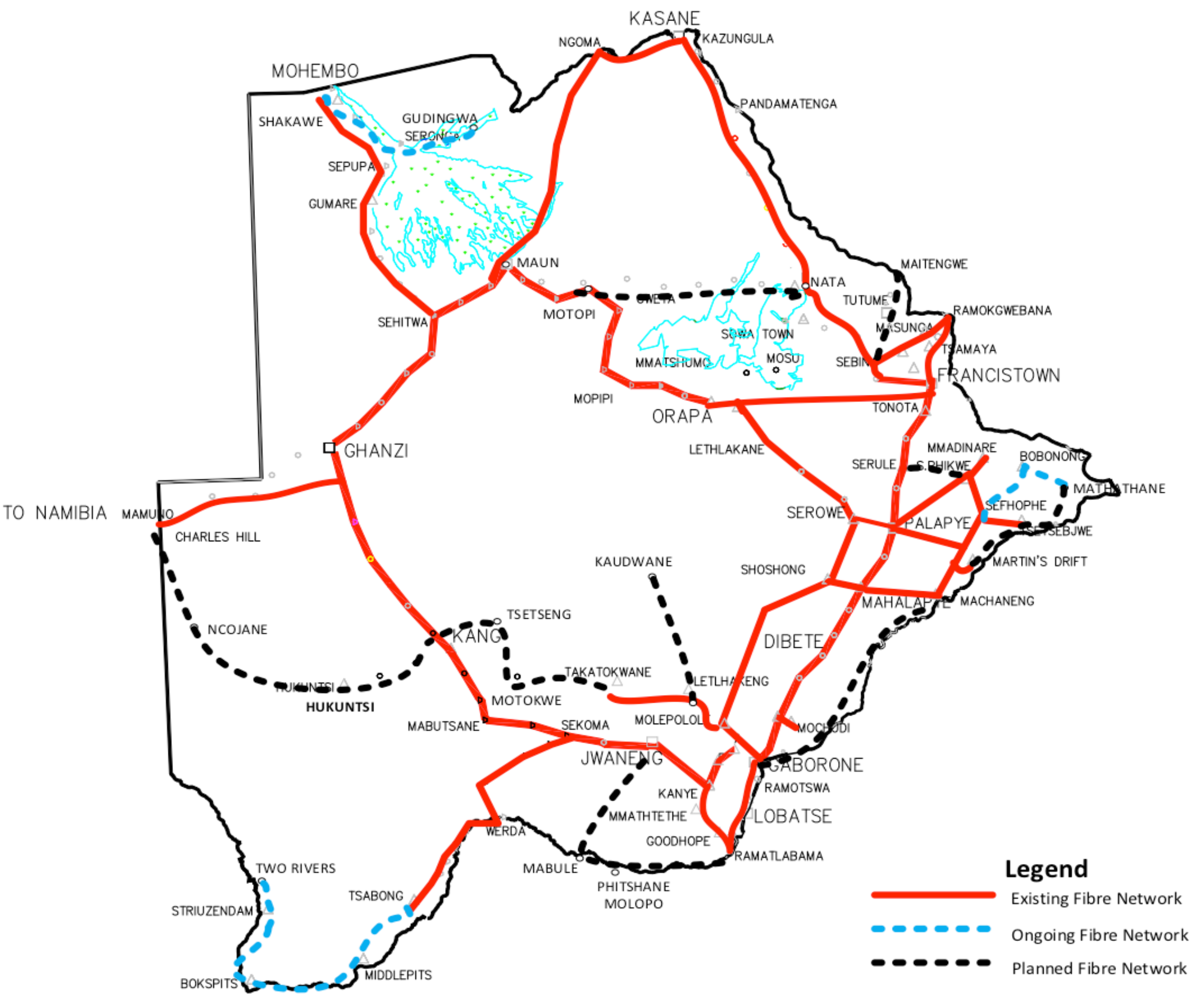


Figure 1: Optical fiber coverage in Botswana [5]

2. Materials and methods

In this study, google maps was used to measure the distance between the two villages as well as monitor the proposed route the cable lining was going to take. The cable is set to run just along the main highway that connects Mabutsane and Motokwe. This distance was ascertained to be 87.2Km, and for the entire length the line is generally 1 meter outside of the highway, right of the way line[6]. Along the stretch it was established there were 2 main changes in direction that could be characterized as macro bends. A Macro bend occurs when the curvature of the bend of an optic fiber is much larger than its diameter. This causes light waves to suffer sever loss due to radiation of the evanescent field in the cladding region. As the radius of the curvature decreases, the loss increases exponentially until it reaches at a certain critical radius [7]. For any radius a bit smaller than this point, the losses suddenly become extremely large as illustrated in figure 2 below.

Figure 2: Illustration that as the bend tightens, the optical loss increases [8]

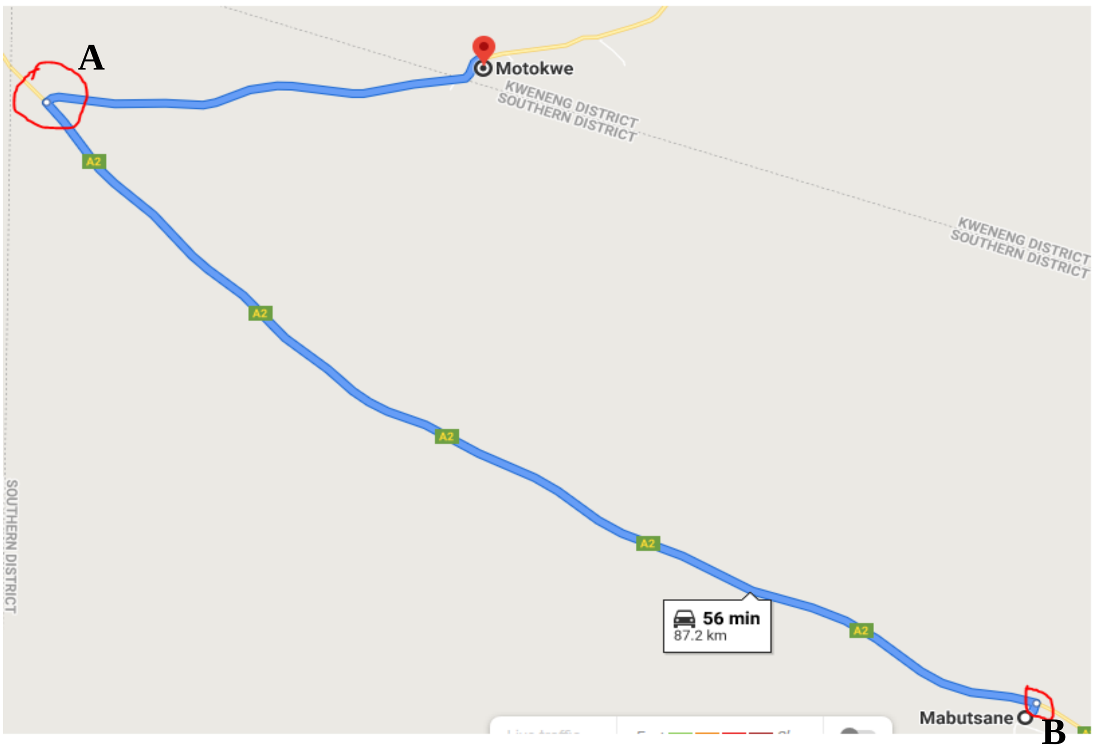


Figure 3: The proposed cable route [9]

However, opting not to bend the cable, some connectors were put at these turns in order to have a predictable loss from the optic fiber cable, which will be taken into account in the power link budget analysis for the network. These points are marked and labelled A and B in figure 3 below. Point A is about 64km from Mabutsane and point B is 1Km away from Mabutsane.

There are two Optical fiber cables that are used to make two distinct Optical systems which shall be subsequently simulated. The f the following properties, henceforth known as OF-1

Table 1: Optical Fiber 1 (OF_) Properties

Media Type	Single mode fiber
Min. Receiver Sensitivity (P_r)	-32 dB
Avg. Transmitting Power	0 dB
Source Power (P_s): Min/Max	0/5 dB
Max Transmitter distance (L)	120 Km
Typical Splice loss (l_{sp})	0.2 dB
Typical connector loss (l_c)	0.4 dB
Transmitter/Receiver Wavelength	1550 nm
Fiber attenuation (α_f)	0.2 dB/Km

The second Optical fiber cable to be simulated in our system is the single mode optical fiber cable with the proprietary name; " ***edge CWDM-1.25G-SFP-150-45*",** henceforth referred to as OF_2. It was connected to our system to give the following properties;

Table 2: Optical Fiber 2 (OF_2) Properties

Media Type	Single mode fiber
Min. Receiver Sensitivity (P_r)	-34 dB
Avg. Transmitting Power	-2 dB
Source Power (P_s): Min/Max	-2/7 dB
Max Transmitter distance (L)	150 Km
Typical Splice loss (l_{sp})	0.14 dB
Typical connector loss (l_c)	0.4 dB
Transmitter/Receiver Wavelength	1450 nm
Fiber attenuation (α_f)	0.3 dB/Km

Both the cables are spliced at every 10Km.

To find the number of splices, the expression below is used

$$n = \frac{L}{l_i} - 1 \qquad (5)$$

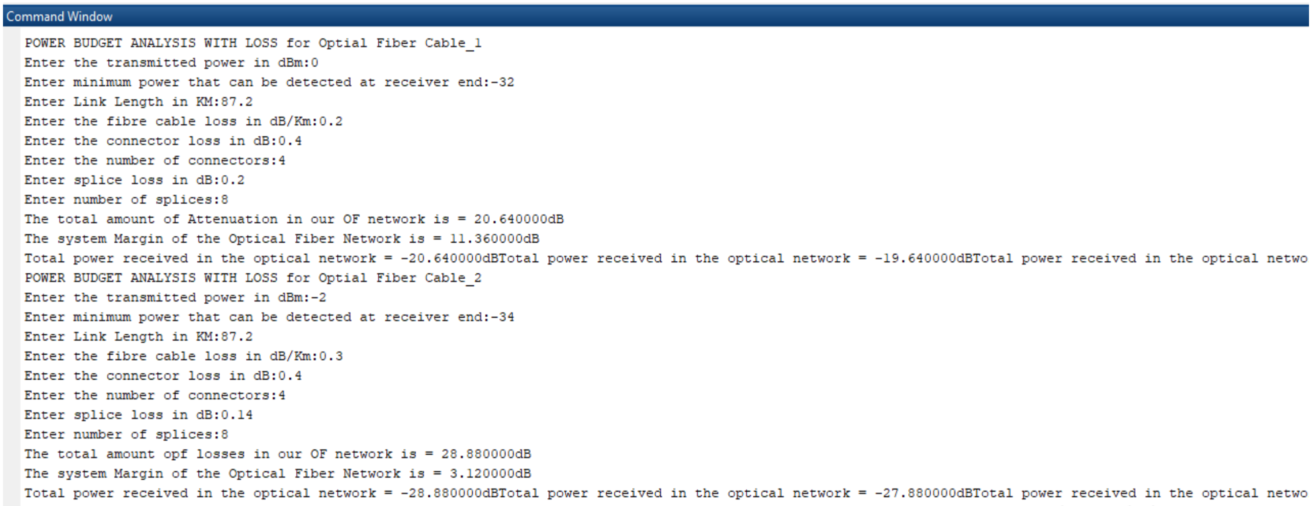
Where L is the total length of fiber and l_i is the length between splices. Using this expression, the number of splices, n, is found to be 8. The total number of connectors, m becomes 4, i.e one each on the transmitter and receiver side of the cable, and one each for the 2 bends. Using the optical fiber power budget in (4), the above values are used to simulate what the value of Transmission Power (P_t) is, as well as establish the System Margin of this system using *MATLAB.*

3. Results

Before simulating for the Mabutsane-Motokwe Optical fiber, the given 80Km Optical fiber cable was simulated first, using the same code. This cable's parameters, code and results are shown in appendix E.Both the "***edge 1.25G-SFP-120D"*** and the ***"1.25 G-SFP-150-45"*** were subsequently simulated. The code and simulated results are shown below.

```
clc;
close all;
clear all;

disp('POWER BUDGET ANALYSIS WITH LOSS for Optial Fiber Cable_1 ');

ps= (0:1:5);
ptr=input('Enter the transmitted power in dBm:');
pmin=input ('Enter minimum power that can be detected at receiver end:');
L=input('Enter Link Length in KM:');
af=input('Enter the fiber cable loss in dB/Km:');
cl=input('Enter the connector loss in dB:');
m= input('Enter the number of connectors:');
sl=input('Enter splice loss in dB:');
n=input ('Enter number of splices:');

%Total Attenuation
Lt= (m*cl+af*L+n*sl);
disp(sprintf('The total amount of Attenuation in our OF network is =
%fdB',Lt));

% To calculate the power received at the receiver of the optical system
prec=ps-ptr-Lt;

% To calculate the system margin of the optical system (dB)
ms=(ptr- pmin-Lt);

disp(sprintf('The system Margin of the Optical Fiber Network is =
%fdB',ms));
disp(sprintf('Total power received in the optical network = %fdB',prec));
plot(ps,prec, '--bs');
hold on;

%For Optical Fiber 2
disp('POWER BUDGET ANALYSIS WITH LOSS for Optial Fiber Cable_2 ');

ps2= (-2:1:7);
ptr2=input('Enter the transmitted power in dBm:');
pmin2=input ('Enter minimum power that can be detected at receiver end:');
L2=input('Enter Link Length in KM:');
af2=input('Enter the fiber cable loss in dB/Km:');
cl2=input('Enter the connector loss in dB:');
m2= input('Enter the number of connectors:');
sl2=input('Enter splice loss in dB:');
n2=input ('Enter number of splices:');

%Total Attenuation
Lt2= (m2*cl2+af2*L2+n2*sl2);
disp(sprintf('The total amount opf losses in our OF network is =
%fdB',Lt2));

%To calculate the power received at the receiver of the optical system (dB)
prec2=ps2-ptr2-Lt2;

% To calculate the system margin of the optical system (dB)
ms2=(ptr2- pmin2-Lt2);

disp(sprintf('The system Margin of the Optical Fiber Network is =
%fdB',ms2));
disp(sprintf('Total power received in the optical network = %fdB',prec2));
```

Figure 3: Matlab code used for the simulation



```
Command Window
POWER BUDGET ANALYSIS WITH LOSS for Optial Fiber Cable_1
Enter the transmitted power in dBm:0
Enter minimum power that can be detected at receiver end:-32
Enter Link Length in KM:87.2
Enter the fibre cable loss in dB/Km:0.2
Enter the connector loss in dB:0.4
Enter the number of connectors:4
Enter splice loss in dB:0.2
Enter number of splices:8
The total amount of Attenuation in our OF network is = 20.640000dB
The system Margin of the Optical Fiber Network is = 11.360000dB
Total power received in the optical network = -20.640000dBTotal power received in the optical network = -19.640000dBTotal power received in the optical netwo
POWER BUDGET ANALYSIS WITH LOSS for Optial Fiber Cable_2
Enter the transmitted power in dBm:-2
Enter minimum power that can be detected at receiver end:-34
Enter Link Length in KM:87.2
Enter the fibre cable loss in dB/Km:0.3
Enter the connector loss in dB:0.4
Enter the number of connectors:4
Enter splice loss in dB:0.14
Enter number of splices:8
The total amount opf losses in our OF network is = 28.880000dB
The system Margin of the Optical Fiber Network is = 3.120000dB
Total power received in the optical network = -28.880000dBTotal power received in the optical network = -27.880000dBTotal power received in the optical netwo
```

Figure 4: Results for the simulation of OF_1 & OF_2

The graph shown in Figure 5 was plotted using the above results.

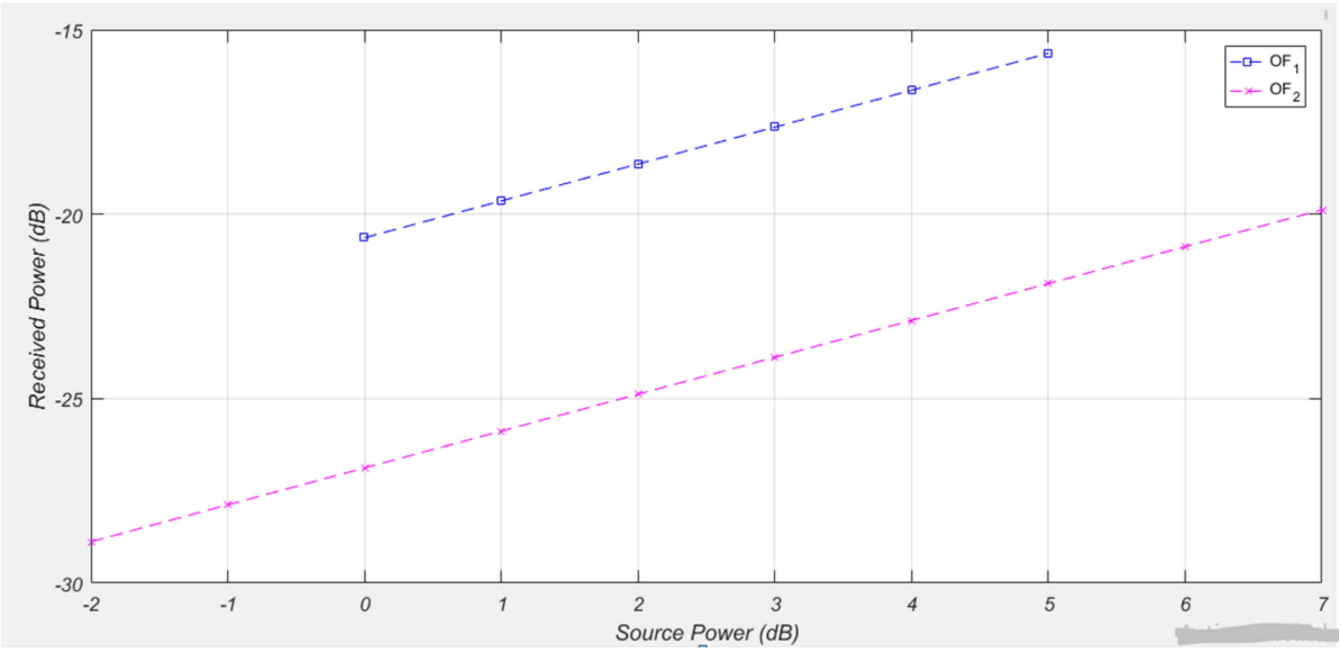


Figure 5: The received Power against the Source Power in dB

4. Discussion

For OF_1, the total losses amount to 20.64dB, giving a system margin of 11.36dB. The recommended minimum System margin is 10dB. This is a good indicator that the system's attenuation is not going to be a cause for the disruption in signal transmission for this system. The greater system margin is also ideal as it considers sources of signal losses otherwise not accounted for in the link power budget simulation. These losses are mainly because of a range of external factors, not factored into our "optic loss equation" that must none-the-less be taken into consideration in order to determine the cable construction that will continuously maintain the desired characteristics hence, predictable results. The external factors relating to the various environmental conditions can be divided into two categories:

i) natural external factors (temperature, wind, water, earthquakes, etc.), which are comprehensively listed in Appendix A;
ii) man-made factors (smoke, air pollution, fire, etc.), which are listed in Appendix B.

For both categories of factors, the tables show the *effects on the optical cables* laid in different environments. The cable to be laid down from Mabutsane to Motokwe, however, is going to be for the most part, a buried cable. Both Mabutsane and Motokwe are found in the Kalahari Desert, and like any typical desert, the area is characterized by extremes of temperatures, sporadic rainfall as well as some limited biodiversity [10]. The extremes of temperatures Increase optical loss due to high and low temperature, whilst the little moisture present, typically in the form of salt water may lead to corrosion of the cable amour which may reduce the lifetime of the optical fiber [11]. Possible “biological attacks” from insects, rodents and birds could damage the sheath, further limiting the lifespan of the cable[12]. Any system, therefore, that meets a minimum of the above-mentioned system margin along with the range of its received powers being at least equal to the minimum receiver sensitivity will be considered a viable system The results for OF_1 shown in table 1 show that the received powers range from -20.64dB to -15.64dB, with a system margin of 11.36dB. This is above our system’s minimum receiver sensitivity of -32dB, meaning this system is viable.

Table 3: Results for OF_1

Source Power (dB)	**Received Power (dB)**
0	-20.64
1	-19.64
2	-18.64
3	-17.64
4	-16.64
5	-15.64
System Margin (dB)	
11.36	

The results for OF_2 shown in table 2 show that the received powers range from -28.88dB to -19.88dB, with a system margin of 3.12dB. Now, although all the received values are above our system’s minimum receiver sensitivity of -34dB, the system margin is way below the recommended minimum of 3.12dB. This lack of adequate “margin of error” makes this second system not viable. The Power at the source can always be increased in an attempt to increase the system margin, however increasing the input power will directly increase the overall cost of implementing the system.

Table 4: Results for OF_2

Source Power (dB)	Received Power (dB)
-2	-28.88
-1	-27.88
0	-26.88
1	-25.88
2	-24.88
3	-23.88
4	-22.88
5	-21.88
6	-20.88
7	-19.88
System Margin (dB)	
3.12	

5. Conclusions

A low budget optical fiber system to be introduced to link Mabutsane and Motokwe with a single mode optical fiber with properties similar to that of OF_1 is a technically feasible project. The costs can further be minimized by transmitting the signal using the minimum input power of 0dB. The transmitter part of this system, which is laser, will be in Mabutsane, whilst the receiver (photodiode) part of the system will be in Motokwe. Both the transmission and receiving wavelength will be at 1550nm, with a maximum data rate of 1.25Gbps.

6. Appendices

Appendix A: Showing some of the natural external factors that could affect optical fiber cables.

Natural external factors		External cables					Internal cables	
		Trunk, junction and distribution					Customer premises	Central office
		Aerial	Buried	Duct	Tunnel	Underwater	Building	
Temperature change	B	Cable sheath contraction with core thrusting out					–	–
	A	Increase of optical loss due to high and low temperature						
Very low temperature	B	Embrittlement of cable sheath under low temperature			–	–	–	–
	A	Crushing due to ice formation						
Wind	A	Excess strain due to wind pressure	–	–	–	–	–	–
	B	Periodical excess strain due to cable dancing	–	–	–	–	–	–
Salt water	B	Corrosion of metal catenary	Corrosion of armour	–	–	Corrosion of armour	–	–
Rain and hot spring	B	Corrosion of metal catenary	Corrosion due to hot springs		–	–	–	–
Snow and ice	A	Sheath degradation, crushing and excess strain due to snow and ice	–	–	–	Sheath degradation and crushing due to ice	–	–
Water and moisture	A	Increase in optical loss due to water penetration. Decrease of strength of fibre					–	–
Sunshine	B	Degradation of sheath by UV rays	–	–	–	–	–	–
Lightning	B	Crushing damage due to lightning and hazards to personnel			–	–	–	–
Earthquakes and slip, ground subsidence and falling stones	B	Sheath degradation and impulsive excess strain due to falling stones	Cutting of cables due to ground movements		–	–	–	–
Condition of soil	B	–	Corrosion of armour	–	–	–	–	–
Rodents, birds and insects	B	Sheath damage due to birds, rodents and insects		–	–	–	–	–
Hydrogen	A	Increase in optical loss due to hydrogen					–	–
Water flow	B	–	–	–	–	Cable damage	–	–
Mould growth	B	–	–	Sheath damage	–	–	Sheath damage	–

A. Particular consideration for optical fibre cables.
B. Intrinsic consideration for outside plant.

Figure 6: Showing natural external factors affecting optical fiber cables [11]

Appendix B: showing the man-made external factors that could affect optical fiber cables

Man-made factors		External cables					Internal cables	
		Trunk, junction and distribution					Customer premises	Central office
		Aerial	Buried	Duct	Tunnel	Underwater	Building	
Factory smoke and air pollution	B	Corrosion of metal	–	–	–	–	–	–
	B	Chemical attack on sheath	–	–	–	–	–	–
Traffic (cars, trucks)	B	–	Damage to cable sheath and joints due to creep. Transient optical loss due to vibration of fibres		–	–	–	–
Induced voltage (AC traction systems, power lines)	B	Damage to cable and hazards to personnel			–	–	–	–
DC current	B	–	Electrolytic corrosion	–	–	–	–	–
Petroleum gas leakage	B	–	Sheath degradation due to chemical attack	–	–	–	–	–
Fire	B	Sheath (and cable core) burning	–	–	Sheath (and cable core) burning	–	Sheath (and cable core) burning	
Nuclear radiation	B	Under consideration					–	–
Hydrogen	A	Increase in optical loss due to hydrogen					–	–
Installation practices	B	Cutting or breaking of the cables						
	A/B	B – Strain due pulling-in for installation			A - Strain due pulling-in for installation		–	–
	A/B	B – Bending at pulley for installation	B – Bending and squeezing due to burying machine		A – Bending at pulley for installation			
					A – Bending at curve in duct	–	–	–

A. Particular consideration for optical fibre cables.
B. Intrinsic consideration for outside plant.

Figure 7: Showing the man-made external factors that affect optical fiber cables [11]

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