SYSTEM DESIGN CRITERIA FOR OVERHEAD TRANSMISSION LINES:

WITH EMPHASIS ON OPGW CABLE

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1. INTRODUCTION

Optical Ground Wire (OPGW) cable today forms an integral part of a Power Utility Company's transmission network and is utilised for mission-critical circuit control ensuring optimal operational efficiency and protection. OPGW cable, by definition, is a composite cable which serves both as a conventional overhead ground wire with the added benefit of providing optical fibre communications. The optical communication carrier can be completely separate from the power transmission line to form an additional revenue stream whilst the cable serves the traditional purpose of conducting bus bar fault currents down to ground and protecting the power conductors against lightning strikes. With proper design considerations, OPGW cable has proven its reliability in protecting the optical fibres from electrical, mechanical, and environmental stresses and with proper installation techniques, OPGW cable can have a design lifespan of up to 30 years [1].

In South Africa, when implementing an aerial transmission network the standard reference used by Power Utility Companies for the design of aerial transmission networks is the South African Standards Code of Practice: SANS 10280:2004 titled "Overhead power lines for conditions prevailing in South Africa". This standard essentially deals with the design and mandatory safety requirements of tower structures, insulators, conductors, and associated hardware. Therefore, when deploying OPGW cable on transmission tower structures, the cable has to be treated as a conductor and falls within the criteria of the aforementioned document. This document places very stringent requirements on the OPGW cable and associated line hardware to meet the mandatory safety requirements stipulated in the Occupational Health and Safety Act.

This paper will focus on SANS 10280:2004 and associated standard documents such as IEC 60826 and NRS 61-2:2004 that define the functional requirements of the OPGW cable and associated hardware in both test and field deployment conditions. It further illustrates how the correct interpretation of these standards has evolved to incorporate system type testing of aerial conductors and OPGW cable to ensure a minimum design life expectancy.

2. An overview of the Code of Practice and Standards for the Implementation of OPGW on Transmission Lines

Although SANS 10280 does not describe the functional design specification of overhead conductors, and OPGW cable in this case, it does place a specific requirement on the design and performance criteria for conductor supports and associated line hardware fittings detailed in section 6 entitled “Support & Fittings.”

Subsection 6.6.1 entitled “Mechanical strength requirements” states “*The mechanical strength of insulators and fittings used in strain structures should be such that they are at least as strong as the minimum breaking strength of the phase or earth conductor to which they are attached.*”

At first glance this requirement seems straightforward since it defines the minimum breaking load of the associated OPGW or conductor hardware, however in practice this is far from the case. The minimum breaking strength referred to in this paragraph is the Ultimate Tensile Strength (UTS) of the conductor or OPGW cable and is defined during the manufacturing and design of the cable by the overhead cable manufacturer. In the case of the associated hardware (strain assemblies in particular), the minimum breaking strength of the device cannot be defined in the same manner as that of the conductor or OPGW cable.

SANS 10280 invokes the international standard IEC 60826 “Loading and strength of overhead transmission lines” which provides guidelines on, inter alia, the failure sequence of the tower structure, tower foundation, conductors, hardware and insulators. It also refers to factors such as cost and time to repair or replace components that might fail. The IEC document defines the failure sequence for tangent, angle, or dead-end towers to be:

1 Tower Structure
2 Tower Foundation
3 Hardware (conductors and associated hardware)

Furthermore, the failure sequence of the conductors is specified as:

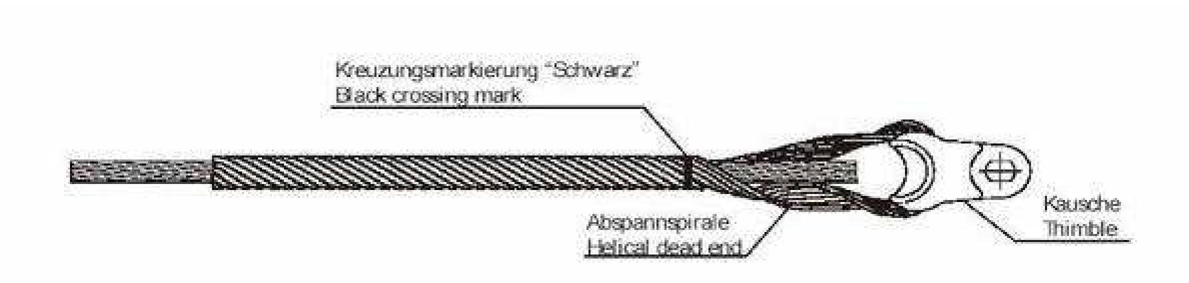
1 Conductors
2 Insulators
3 Hardware

Therefore counter intuitively from IEC 60826, it is apparent that the strain hardware is the component to fail last in the event of a catastrophic structural failure of an overhead transmission line. Trans-Africa Projects, transmission line consultants to Eskom, further verified this failure sequence.

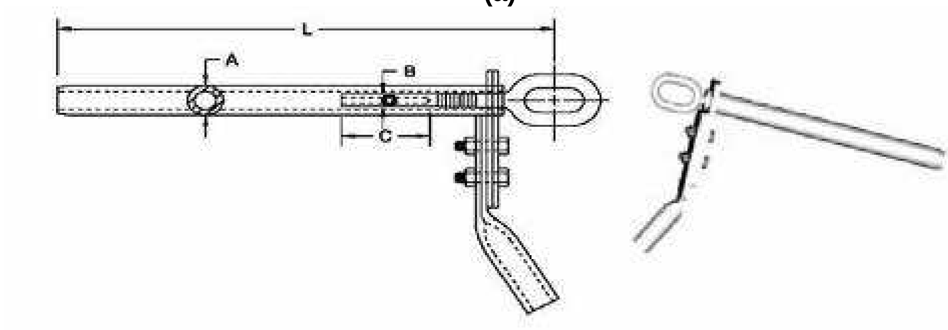
In the case of OPGW cable, the aforementioned requirements are stipulated in NRS 61-2:2004 titled “Specification for Overhead Ground Wire with Optical Fibre: Installation Guidelines”. Specifically section 4.4.1 states that all the hardware shall be approved by the OPGW manufacturer and customer (see CIGRÉ TF22.11.03). This requirement places the onus of the technical requirements of the associated hardware on the OPGW cable manufacturer and not on the manufacturer of the hardware. Furthermore, it addresses the ambiguity of component testing vs. systems testing of the conductor (OPGW cable) and associated hardware implied in SANS 10280 section 6.6.1 by stating further in section 4.4.1 that “Hardware assemblies, including down-lead clamps, for OPGW shall be compatible with the cable to ensure that the system so formed will survive the operating design life.”

When SANS 10280 is read in conjunction with NRS 61-2 it is clear that both the OPGW cable, and for that matter any aerial conductor, and the associated hardware have to be type tested together as a system to obtain a total system performance guideline. This is done by assembling the associated strain hardware and cable and then tensile testing the total system to cable UTS. For aerial conductors this is easily tested when using crimp type compression fittings. However, for OPGW cable a standard compression fitting cannot be used as such a fitting would damage and ultimately destroy the optical carrier and optical fibres.

From an economic point of view, for OPGW cables and smaller conductors, helically preformed spiral dead-ends are used in strain assemblies (Figure 1.). Since the compression force of these types of fittings is not as severe as the crimp type compression fittings, there is a chance at high applied tensions that the OPGW cable or conductor will slip out of the strain assembly or birdcage at the assembly.



(a)



(b)

Figure 1. (a) Conventional helically preformed spiral strain assembly (b) an example of a crimp type compression fitting.

When helically preformed spiral strain assemblies are used, it is not always possible to meet a system performance requirement of 100% of the conductor or OPGW cable UTS as outlined in SANS 10280 and NRS 61-2. In this case, IEC 61284 can be used as a guideline between the manufacturers and the end user for determining the specified minimum failure load (SMFL) of the OPGW cable (or conductor) and helically preformed spiral dead-end according to the formula:

$$SMFL = X \times 0.95 \times UTS$$

where X is defined by the customer. The international norm, as well as defined by Eskom Transmission, is to set X equal to 1, thus the specified minimum failure load is 95% of the conductor (or OPGW cable) UTS when using helically preformed spiral strain assemblies.

This 95% of UTS becomes the norm when Aberdare Telecom Networks tests OPGW and ACSR cable and associated hardware fittings.

2. System Type Testing of Aerial Conductors and Associated Hardware

The importance of system testing OPGW cable and its associated hardware in South Africa was illustrated when an OPGW field failure was reported in the Western Cape region in 2004. The OPGW cable in question was of aluminium conductor steel re-inforced (ACSR) construction, illustrated in figure 2. ACSR conductors have been used extensively in power transmission networks and is a standard cable construction internationally. The inner steel layer provides the mechanical strength of the conductor whilst the outer layer of EC grade aluminium increases the

conductivity of the cable.
Two types of field failures were reported for the OPGW, namely:

1. Failure of the outer aluminium wire layer (wire breaks).
2. Slippage of the strain unit (helically preformed spiral dead-end) resulting in the outer aluminium layer bird caging.

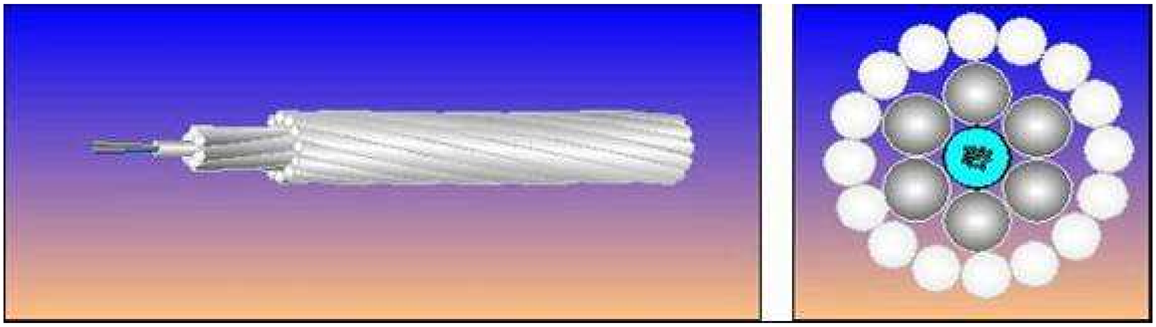


Figure 2. A typical ACSR (A1/S1A) equivalent construction central tube OPGW cable.

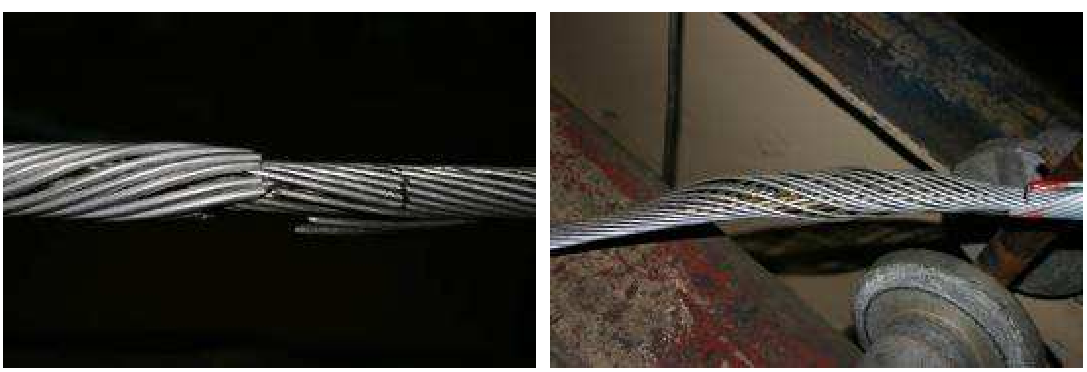
It was assumed that the OPGW cable was defective, and following the field failure incident the OPGW cable was tested by the hardware manufacturer to determine the cause of failure (refer to figure 3.). Without any involvement from the OPGW cable manufacturer it was concluded that:

1. The EC grade aluminium outer wire layer of the OPGW cable are unable to reach the holding strength above the modulus of elasticity of the aluminium wire.

2. Adding a steel reinforcement under the EC Grade aluminium layer yields a minor improvement

3. No slippage of the helically preformed spiral dead-end was observed.

4. The minimum failure load (where the EC Grade aluminium wires break) of the ACSR equivalent OPGW cable is 53% of the UTS.



(a) **(b)**

Figure 3. (a) Failure of the outer aluminium layer, and (b) bird caging of the aluminium layer under tensile load.

It should be noted that the design principles of the ACSR equivalent OPGW cable were not well understood by the hardware manufacturer at the time of test. Similar reports of field failures have been raised previously for all dielectric self supporting (ADSS) optical fibre where it was observed that long span ADSS cable (for span lengths ≥ 300 m) has a tendency to slip in the helically preformed spiral dead-ends. As in the case of ADSS cables, the helically preformed spiral dead-end has to actively engage the strength element of the cable. In the case of long span ADSS cables; this was achieved by changing the material composition of the helically preformed spiral dead-end fitting from aluminium alloy to high strain steel.

Similarly for ACSR conductors and equivalent OPGW cables, the helically preformed spiral dead-end fitting needs to actively engage the steel core of the cable, as the cable is not designed for the aluminium layer to be the main load bearing element. Typically, the aluminium layer only contributes 35 – 40% to the cables UTS. It is clear that in order to reach a SMFL of 95%, the design of the helically preformed dead-end needs to be carefully considered.

When considering a helically preformed spiral dead-end for an aerial conductor or an OPGW cable, the proper design criteria need to be considered:

1. Material composition
2. Length of the dead-end
3. Cable diameter
4. Open helix (spiral depth)

As a rule of thumb, the material composition of the dead-end must mirror that of the aerial conductor it will be used with. The length of the dead-end fitting is also important as it determines the distribution of the compression force along the cable length. Furthermore, the cable diameter and spiral depth is important as they will determine how much compressive force will be transferred from the dead-end to the OPGW cable.

In order to protect the OPGW cable from excessive compressive forces, a protection rod layer is used under the helically preformed spiral dead-end fitting as shown in figure 4.

Figure 4. A typical helically formed spiral dead-end and protection rod configuration used in the type test.

The OPGW manufacturer conducted a further investigation into the design of helically preformed spiral dead-end fittings to determine the SMFL that can be achieved on the ACSR equivalent OPGW cable. As recommended by two independent international hardware suppliers, four sets of aluminium clad steel (ACS) helically preformed spiral dead-ends were tested. The tests were conducted at the OPGW cable manufacturer’s premises and witnessed by the end user. The test results are summarised in table A.

TABLE A **Minimum failure load of ACSR equivalent OPGW cable and helically preformed spiral dead-end from two international suppliers**.

OPGW CABLE TYPE	DEAD-END MANUFACTURER	DEAD-END DESIGNATION	DATE OF TEST	FAILURE LOAD (kN)
ACSR 48/12	Manufacturer A	EPAWFO16/1/2600 RAAWFO24.5D	19/05/2004	57%
ACSR 48/12	Manufacturer A	EPAWFO16/1/2600* RAAWFO24.5D*	19/05/2004	79%
ACSR 48/12	Manufacturer B	AW237152 RW165300	20/05/2004	92%
ACSR 48/12	Manufacturer B	AW237152 RW165300	20/05/2004	94%
ACSR 48/12	Manufacturer B	AW237152 RW165300	21/05/2004	94%
ACSR 48/12	Manufacturer B	AW237152 RW165300	24/05/2004	94%
* Dead-end and OPGW cable were torsion balanced. All other dead-ends were off-the-shelf products.				

The use of ACS (Aluminium Clad Steel) material for the helically spiral preformed dead-end resulted in a significant improvement in the minimum failure load of the OPGW cable and helically preformed spiral dead-end. For manufacturer A, it was necessary for the helically preformed spiral dead-end and OPGW cable to be torsion balanced to gain any appreciable improvement in the failure load of the system. The helically preformed spiral dead-end supplied by manufacturer B were a standard off-the-shelf set and yielded a SMFL of nearly 95%. The major differences in the design of the helically preformed spiral dead-ends between Manufacturer A and B were the length of the dead-end (and armour rods) and the rated tensile strength of the dead-end. Furthermore, the OPGW cable diameter vs. the dead-end range tolerance was smaller for manufacturer B compared to manufacturer A.

From table A it is clear that with the appropriate design of the helically preformed spiral dead-end, a minimum failure load of approximately 95% of the ACSR equivalent OPGW cable UTS can be achieved. Table A further supports the design principle of the ACSR equivalent OPGW cable with the outer aluminium layer not being a major component to the cable's UTS and that with the correct transfer of the lateral holding grip of the dead-end through the aluminium layer to the steel reinforcing layer, the design UTS of the cable can be achieved.

In order to support the results obtained in table A, a further set of tensile tests was performed on ACSR conductors, namely Hare, Mink, Fox, and Squirrel. These four ACSR design were chosen specifically since field failures have been reported in 2005 for Mink, Fox and Squirrel ACSR conductors. In these instances, slipping and bird caging of the conductor in a helically preformed spiral dead-end arrangement has been reported. The design of these conductors also poses a unique challenge in that only 40 – 45% of the calculated rated tensile strength (RTS) of the ACSR conductor is attributed to the aluminium layer. Therefore it is imperative for the helically preformed dead-end to actively engage the steel centre.

The test was initially conducted using a standard dead-end set consisting of ACS armour rods and ACS helically preformed dead-end spiral. The tensile test results for the various ACSR conductors is summarised in Table B. Of the four conductors tested, only the Hare ACSR conductor attained a minimum failure load of 95% of the cable UTS using the standard dead-end set. The minimum failure load of the ACSR conductor and dead-end set decreased as the size of the ACSR conductor decreases, which corresponds to an increase in the tensile strength contribution of the aluminium layer to the conductor UTS. It is also clear that as the ACSR conductor size decreases, the ability of the helically preformed spiral dead-end to actively engage the steel core decreases.

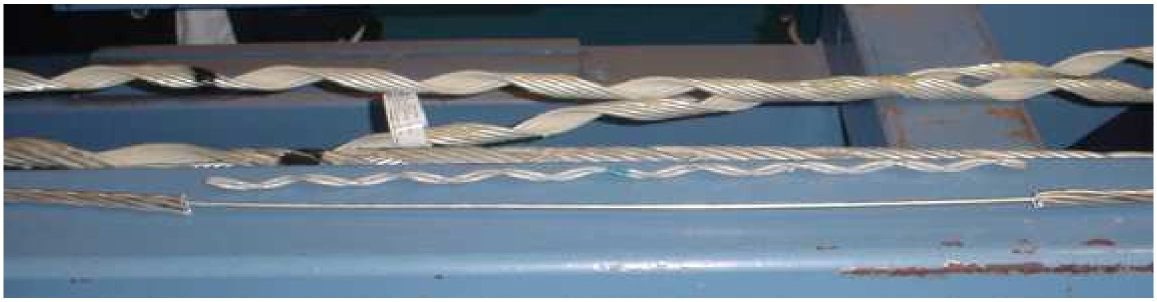
TABLE B Failure load of ACSR conductors for two different dead-end set designs tested to ≥ 95% of the ACSR's UTS

ACSR CABLE ID	*CABLE DESCRIPTION*	*UTS (N)**	*DEAD END CONFIGURATION*	*SYSTEM BREAKING LOAD (N)*	*% of CABLE UTS*
HARE	6/1/4.72	36,000	AlClad Steel DE + AR	34,335	95%
MINK	6/1/3.66	21,900	AlClad Steel DE + AR	20110**	92%
FOX	6/1/2.79	13,100	AlClad Steel DE + AR	10790**	82%
SQUIRREL	6/1/2.11	8,020	AlClad Steel DE + AR	5984**	75%
MINK	6/1/3.66	21,900	AlClad Steel DE / Al AR / Al CR / HSSW GR	25114**	115%
FOX	6/1/2.79	13,100	AlClad Steel DE / Al AR / HSSW GR	13,147	100%
SQUIRREL	6/1/2.11	8,020	AlClad Steel DE / Al AR / HSSW GR	8830**	110%

* Obtained from Aberdare Overhead Aluminium Conductors Handbook
** Tested to destruction (failure of Al armour wire / slipage of dead end / wire break)
DE - Dead End
AR - Armour Rod
CR - Conductive Rod
GR - Grip Rod
Al - Aluminium
HSSW - High Strain Steel Wire

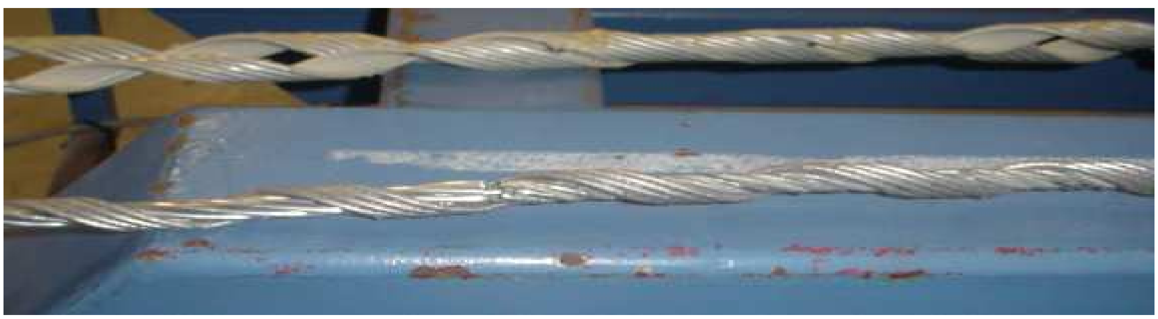
An alternative dead-end set design was considered in order to directly engage the steel core of the ACSR cable without having to rely on the helically preformed spiral dead-end to actively engage the steel core through the aluminium layer. In order to do this, a section of the aluminium layer was removed (see figure 6.) and a galvanised steel gripping rod set was attached to the steel core. In order to maintain electrical continuity, the gripping rod is built up with an aluminium conductive rod and an aluminium armour rod is used as an electrical bridge ensuring electrical continuity over the section where the aluminium layer was removed. To further enhance the electrical continuity of the bridge section, the lay direction of the aluminium armour rod is in the same direction as the aluminium layer of the ACSR conductor.

The minimum failure loads of the alternative dead-end sets with the corresponding ACSR conductor is tabulated in table 2. In the case of the Mink and Squirrel ACSR conductor, the conductor and dead-end set was tested to destruction, yielding a minimum breaking load of 115% and 110% of the conductor UTS respectively.



(a) Removal of the aluminium layer of a FOX ACSR conductor

(b) The steel grip rod is attached on the exposed steel core.



(c) Application of the aluminium conductive rods and armour rods to electrically bridge the section of aluminium layer removed. Note that the lay direction of the ACSR aluminium layer and the armour rod is in the same direction to maximise contact between the two layers.

(d) Completed alternative dead-end set.

Figure 5. Application of the alternative dead-end set.

3. Conclusion

The recent field failures of ACSR equivalent OPGW cables and conductors at strain assemblies highlight the need for migrating from a component type test approach to a system type test methodology. These field failures could have been prevented had there existed at the time of implementation, a concerted effort by both the manufacturers and the end-user to devise a process by which the system performance could be ascertained, and not relying on individual component performance guarantees.

Ironically, if SANS 10280, which is referenced in all aerial transmission line build tender documents, was adhered to by both the end-user and the manufacturers, these types of failures would not have occurred.

4. References

[1] Mark L. Lundergan *et al ´Field-Aging Study Shows Strength of Optical Ground Wire Cable”,* Lightwave Magazine October 1997, Pen Well Publishers