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SC B1 ISULATED CABLES
PS 1: Learning from Experiences

Increasing underground cable pulling lengths – a way to improve cost efficiency and reliability of projects

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SUMMARY

The standard method used in France for installation of underground links is to lay cables in ducts. One of the advantages of this type of solution is to have a reduced mobile working area, trenches being backfilled as soon as the ducts are installed.

In order to reduce costs and improve the reliability of underground cable systems, the French TSO has been working for several years to increase the pulling length of land cable sections between two joints. The average pulling length in France has increased by 40 % in the last decade. It has even reached, on a 38 km-long project, a mean laying length of 2984 m and a maximum of 3638 m.

This paper will present the solutions implemented by the French TSO and its suppliers to increase the mean delivery lengths and to control cable installation as close as possible.
One of the first steps was to work with cable manufacturers to increase the size of cable reels, and therefore the delivery lengths. Thus, in the latest cable supply framework contracts, cable pulling forces and deliverable lengths on reels were criteria considered for contract award.
The increase to 25 kV for screen interruption AC withstand level and the use of Sheath Voltage Limiters (SVL) of rated voltage of 12 kV at cross-bonded joints, allow to double the minor section lengths of the link.

Cable pulling is performed by qualified civil works companies and is considered as "core business" skills with high added value. Thus, the pulling is carried out by a small number of companies and skills management is improved.

It was also necessary to improve and facilitate calculations of the pulling forces induced by the cable route. For this purpose, a calculation tool has been developed internally, based on CIGRE TB 194 [1] formula, and included among the basic tools used both by the TSO and by contractors. With this tool, users may optimise their project and reduce the number of joints for instance.

In order to better understand and configure the tools for calculation of pulling forces, the TSO's R&D department has developed a cable pulling forces sensor in 2020. The purpose is to record the efforts directly on the pulling head of the cable, and not at the winch as this is usually done today. Indeed, the use of this sensor on some projects has already shown that the mathematic models could be optimised and hence, increase the pulling lengths even more.
A new sensor is currently under development: it will give the operator real time data of the pulling force on the head during the laying of the cable, for a more flexible pulling.

Being able to increase pulling lengths requires actions at various steps of a project. From the study phase, where the locations of the pulling pits need to be known to be included in the permit, to the pulling operation itself which needs to be controlled and mastered.

KEYWORDS
underground cable, pulling forces, calculation tool, installation, ducts.

1. INTRODUCTION

Over the past decade, the increase in the number of long underground cable links has led the French TSO to consider different ways of optimising their design. One of these actions is to increase the delivery length, in order to reduce the number of joints on the route (increase of reliability), to limit the space required for the work area and thus facilitate its acceptation by local authorities.

Increasing the length of the cable is also a way to reduce the installation costs of an underground cable. Indeed, it allows to reduce the number of joint bays and cable accessories. Calculations show that the global cost of a cable link with long length of cable sections is optimised by 4%.

The graphic below (Figure 1) illustrates the yearly evolution of mean delivery length between 2010 and 2020 and the corresponding amount of underground link commissioned by the French TSO, all voltage levels combined (HVAC and HVDC). From 1160 m in 2010, this mean delivery length increased up to 1670 m in 2020, allowing to save around 1 800 joints (and associated civil work) in 10 years. These statistics exclude circuits laid only inside substations (short lengths and often without joints).

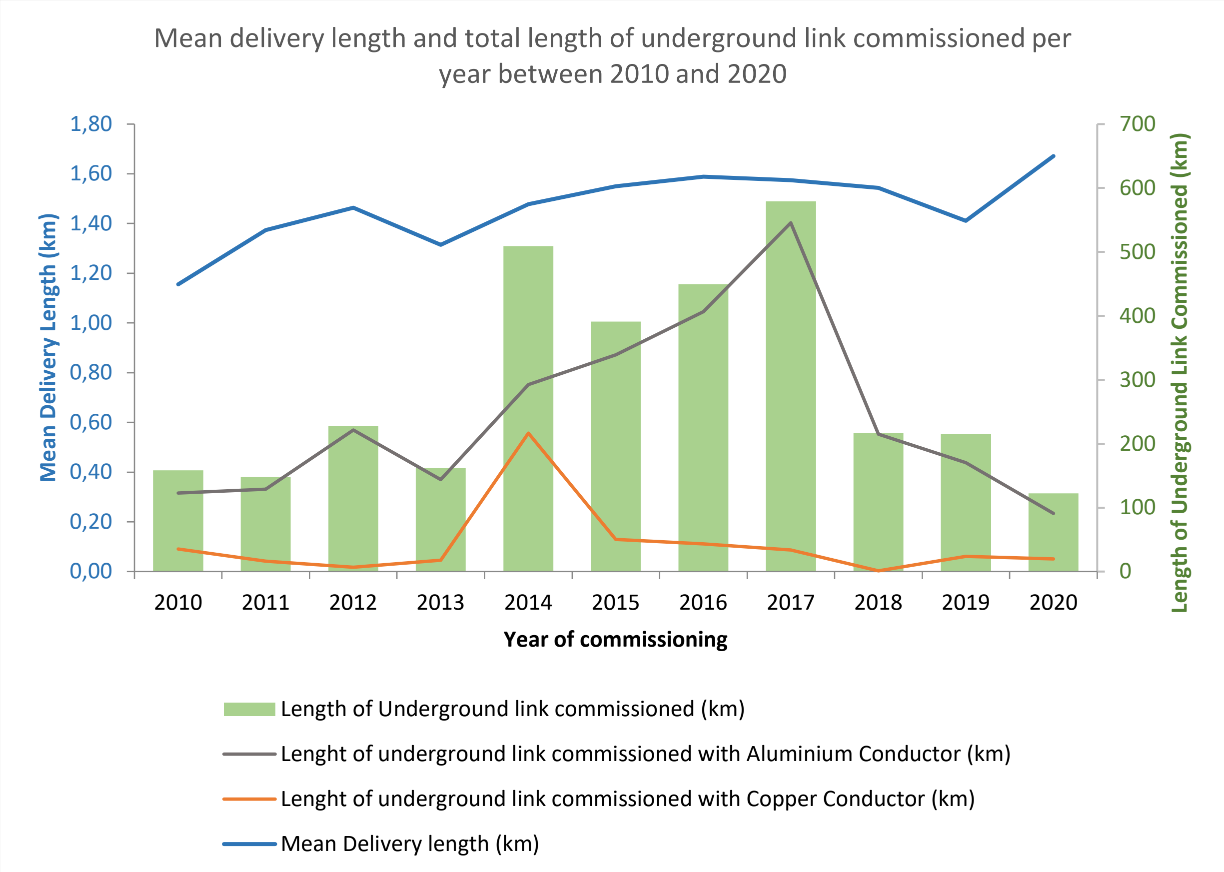

Figure 1: Mean delivery length and total length of cable commissioned per year between 2010 and 2020

The delivery length of copper conductor cable soared in 2014 due to two projects: Boutre-Trans (securing the supply in the south of France) and the link between France and Spain. Excluding the year 2014, aluminium conductor cables constitute an average of 90 % of the underground link commissioned.

The 3 projects described hereafter (Table 1) are particularly optimised regarding delivery length.

Table 1: Example of optimised projects regarding delivery length

Project (date of commissioning)	Total circuit length	Voltage level	Cable cross section	Mean delivery length	Max delivery length
Boutre Trans (2014)	65 km	225 kV	2 500 mm² Cu 2 000 mm² Cu	930 m	1 330 m
France Espagne (2014)	2 x 35 km	320 kV HVDC	2 500 mm² Cu	1 740 m	2 201 m
Fleac Villegats (2020)	38 km	90 kV	1200 mm² Alu	2 984 m	3 700 m

This is made possible particularly thanks to the laying configuration chosen by the TSO, the trefoil configuration in ducts:

- The installation of ducts (PVC or HDPE) allows refilling the trench as the installation progresses, which reduces the worksite's footprint, and thus its management and acceptability. Regarding this specific aspect, increasing the length of cables sections do not increase the construction management difficulties. On the other hand, pulling long sections of cables within duct implies managing the pulling efforts, both during studies and construction phases.
- The trefoil configuration rather than the flat configuration is beneficial with regard to induced currents, and therefore makes it possible to increase the length between two screen earthing points.

2. ACTIONS DONE ON THE CABLE SYSTEM WITH CABLE MANUFACTURERS

Several parameters related to delivery lengths are in the hands of the cable suppliers.

- First of all, the maximum tensile force that can be applied to a cable. The higher it is, the longer the pulling length can be through a duct. Moreover, it allows cable route with more bend.
- The factory capability to produce long lengths of cable and the size of the reels on which the cables are delivered and the associated handling equipment.
- Increase the screen interruption AC withstand level up to 25 kV to increase minor sections length for cross-bonded earthed cable system.

For the first two points, financial incentives have been included during the tender process. Thus, each candidate in the call for tenders must commit to a quantity of deliverable length on reels and a maximum pulling effort. A financial bonus is then considered according to the commitment made. The maximum delivery length for the most widely used type of cable in France (90 kV Aluminium sections) has almost doubled since 2010.

Until 2010, for cross-bonded earthing systems, the protection of screen interruptions against voltage surges was ensured by sheath voltage limiters (SVL) with a rated voltage of 6 kV. These SVL were suitable for a maximum induced voltage of 12 kV on the metallic screen (in short-circuit conditions).

In order to increase minor section maximum lengths, it was decided to increase the screen interruptions AC withstand level from 12 kV to 25 kV. But then, 6 kV SVL were not consistent any more for such a high induced voltage on the screens. So those SVLs have been switched

with new ones, of 12 kV rated voltage, in order to design a consistent new system as displayed in Figure 2.
With this upgraded design (validated by EMTP calculations), the maximum limit for minor section length have been doubled, and was not an obstacle any more for longer cable sections development.

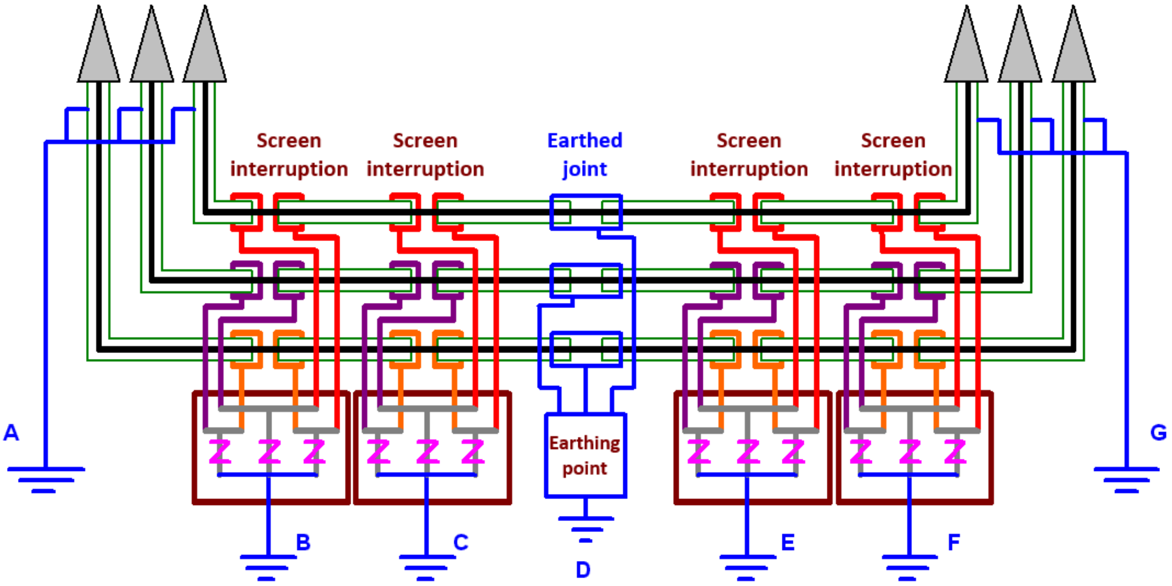

Figure 2: Typical cross-bonded system with 12 kV SVLs in B, C, E and F

3. CABLE PULLING AND CIVIL WORKS COMPANIES

The panel of companies working for the TSO is restricted: only qualified companies can work on the construction sites, provide studies or manufacture the cables.

For Civil Works companies, the work covers the ground excavation, the laying of the ducts, the backfilling of the trench and the pulling of the cables. The qualification process usually takes 2 to 3 years. Once qualified, the company is regularly audited on the construction site and the project team must report any discrepancies observed on site. Every three months, an internal evaluation is done by both technical and purchase teams in order to evaluate companies based on these audits. A contractor can be placed under reinforced observation and its qualification can be jeopardized if the work has deteriorated. The quality ratings also influences the market share of the companies.
Cable pulling is considered as a "core business" service, and companies are not allowed to subcontract it. Hence, they have to be proficient in this area to be and to stay qualified.
This approach enables the TSO to support the qualified companies in their improvements and to be confident in their capacities to pull longer cable section.

4. STUDY PHASE

When starting a new construction project, the TSO conducts internal studies to determine a preferred layout, picture the location of joint bays and evaluate the cable section lengths.
To calculate the tensile and compression forces on the cable, an Excel calculation tool based on CIGRE TB 194 “Laying & Installation Techniques” [1] was developed around 2010.
This tool is firstly used by the TSO for a pre-study, and then by qualified studies contractors.

Prescription							
Friction coef				Admitted forces			
Duct	Lubricant	Gaine extérieure du cable (PE)	Cablette (acier)	Angle (°)	Traction (daN)	Compression (daN/m)	
PVC	Non	0,20	0,30	Straight line	8 000	-	
	Oui	0,2		< 45°	Min [8000 ; 700*R]	700	
HDPE	Non	0,20	0,25	> 45°	4 000		
	Oui	0,15					
Different coef				Speed limit			
Other	-	0,00	0,00	12			

Project info.						
Pulling rope			Cable			
Etude RTE - CNEF 22			Etude - RTE 1 600 mm² Al 225 kV			
Linear mass	1,5	kg/ml	Linear mass		12,8	kg/ml
Max adm. Traction	33 000	daN	Max admitted forces	Traction	8 000	daN
				Compression	1 000	daN/m
			Delivery length		2 200	ml
			Max delivery length		2 200	ml

New installation	Installation	4	Sections	140

Installation	Start	End	Lubricant	Duct	Friction coef cable/duct	Friction coef pulling rope/duct	Sections
Installation 1	1	18	Oui	PVC	0,20	0,30	17
Installation 2	18	63	Oui	HDPE	0,15	0,25	45
Installation 3	63	138	Non	HDPE	0,20	0,25	75
Installation 4	138	141	Non	PVC	0,20	0,30	3

Figure 3: Calculation tool - cable and ducts data

Figure 3 is a screenshot of the first sheet of the calculation tool. The user has to describe the type of cable that will be pulled, the size of the pulling wire rope, the appropriate installation (HDPE, PVC, other…) and whether lubricant will be used to facilitate the cable pulling or not.

During the study phase, as the awarded cable manufacturer is not known yet, standard data for each type of cable (weight, length of cable that can be put on a reel, maximal forces supported by the cable) has been defined. Once the cable manufacturer is known, all these data are automatically filled with the exact value.

The friction coefficient in the calculation depends on the use of a lubricant. For the moment, there are only two possible values: 0.30 if there is no lubricant used, 0.20 otherwise.

The user describes in another sheet (Figure 4) the route of the cable: a line represents a homogeneous section in terms of curve and gradient. They can choose whether it is a horizontal or vertical type of curve. Lastly, it is possible to add some pushers to help the pulling task.

PS Start - PS End	PN Start - PN End	Friction coef pulling rope - ducts	Friction coef cable - ducts	Length (m)	Altitude natural ground		Depth of excavation		Horizontal bend		Vertical bend			Inclined bend						Pushers		Intermediate winch	Admitted traction force on the head of the cable	Admitted compression force on the head of the cable (daN/m)
					PN Start	PN End	PN Start	PN End	Bend radius (m)	Angle subtended by the bend (°)	Bend radius (m)		Angle subtended by the bend (°)	Bend radius (m) c1	c2	Angle subtended by the bend (°)	Angle of inclination (°)	Max. admitted traction force (daN)	Max. adm. Compression force	Normal way (daN)	Reverse way (daN)			
	START																							
101	1 - 2	0,30	0,20	3,98	34,44	34,44	1,21	1,38									2,45						8 000	1000
102-103	2 - 3	0,30	0,20	3,00	34,44	34,49	1,38	1,60						10,00		17,19	3,26	8 000	800				8 000	800
104	3 - 4	0,30	0,20	6,81	34,49	34,57	1,60	1,28									3,36						8 000	1000
105-106	4 - 5	0,30	0,20	3,00	34,57	34,58	1,28	0,93							10,00	17,19	6,87	8 000	800				8 000	800
107	5 - 6	0,30	0,20	10,00	34,58	34,59	0,93	1,00									0,34						8 000	1000
108	6 - 7	0,30	0,20	10,00	34,59	34,66	1,00	1,63									3,21						8 000	1000
109	7 - 8	0,30	0,20	9,68	34,66	34,73	1,63	1,37									1,95						8 000	1000
110	8 - 9	0,30	0,20	6,54	34,73	34,81	1,37	1,48									0,26						8 000	1000
111	9 - 10	0,30	0,20	2,75	34,81	34,87	1,48	1,51									0,63						8 000	1000
112-115	10 - 11	0,30	0,20	6,00	34,87	34,71	1,51	0,84							20,00	17,19	4,88	8 000	400				8 000	400
116	11 - 12	0,30	0,20	6,91	34,71	34,74	0,84	0,52							20,00	19,80	2,91	8 000	400				8 000	400
117-118	12 - 13	0,30	0,20	3,00	34,74	34,87	0,52	0,68									0,57						8 000	1000
119	13 - 14	0,30	0,20	5,78	34,87	35,27	0,68	0,84									2,38						8 000	1000
120	14 - 15	0,30	0,20	4,22	35,27	35,37	0,84	0,80									1,90						8 000	1000
121	15 - 16	0,30	0,20	10,00	35,37	35,60	0,80	0,70									1,89						8 000	1000
122	16 - 17	0,30	0,20	10,00	35,60	35,93	0,70	0,78									1,43						8 000	1000
123	17 - 18	0,30	0,20	10,00	35,93	36,04	0,78	0,91									0,11						8 000	1000
124	18 - 19	0,30	0,20	5,70	36,04	36,25	0,91	1,27									1,51						8 000	1000
125-129	19 - 20	0,30	0,20	7,50	36,25	36,49	1,27	1,70							17,00	25,28	1,46	8 000	471				8 000	471
130-132	20 - 21	0,30	0,20	4,50	36,49	36,45	1,70	0,95						14,00		18,42	9,00	8 000	571				8 000	571
133	21 - 22	0,30	0,20	10,00	36,45	36,74	0,95	1,04									1,15						8 000	1000
134	22 - 23	0,30	0,20	10,00	36,74	37,01	1,04	1,00									1,78						8 000	1000
135	23 - 24	0,30	0,20	10,00	37,01	37,28	1,00	0,83									2,52						8 000	1000
136	24 - 25	0,30	0,20	10,00	37,28	37,55	0,83	0,93									0,97						8 000	1000
137	25 - 26	0,30	0,20	10,00	37,55	37,81	0,93	1,17									0,11						8 000	1000
138	26 - 27	0,30	0,20	10,00	37,81	38,08	1,17	1,34									0,57						8 000	1000
139	27 - 28	0,30	0,20	10,00	38,08	38,44	1,34	1,40									1,72						8 000	1000
140	28 - 29	0,30	0,20	2,22	38,44	38,40	1,40	1,49									3,35						8 000	1000
141-142	29 - 30	0,30	0,20	3,00	38,40	38,55	1,49	1,64	7,00	24,56													7 000	1000
143-144	30 - 31	0,30	0,20	3,00	38,55	38,57	1,64	1,62						10,00		17,19	0,77	8 000	800				8 000	800
145	31 - 32	0,30	0,20	9,78	38,57	38,49	1,62	1,70									0,94						8 000	1000
146	32 - 33	0,30	0,20	1,50	38,49	38,49	1,70	1,67						5,00		17,19	1,15	5 000	1000				5 000	1000
147	33 - 34	0,30	0,20	1,50	38,49	38,49	1,67	1,63						5,00		17,19	1,53	5 000	1000				5 000	1000
148	34 - 35	0,30	0,20	1,50	38,49	38,49	1,63	1,53						3,50		24,56	3,84	3 500	1000				3 500	1000
149	35 - 36	0,30	0,20	1,50	38,49	38,49	1,53	1,43						3,50		24,56	3,84	3 500	1000				3 500	1000
150	36 - 37	0,30	0,20	1,50	38,49	38,47	1,43	1,44						3,50		24,56	1,15	3 500	1000				3 500	1000
151	37 - 38	0,30	0,20	1,50	38,47	38,44	1,44	1,45						3,50		24,56	1,54	3 500	1000				3 500	1000
152	38 - 39	0,30	0,20	1,50	38,44	38,42	1,45	1,48						3,50		24,56	1,92	3 500	1000				3 500	1000
153	39 - 40	0,30	0,20	1,50	38,42	38,37	1,48	1,48						3,50		24,56	1,92	3 500	1000				3 500	1000
154	40 - 41	0,30	0,20	4,53	38,37	38,21	1,48	1,55									2,91						8 000	1000
155	41 - 42	0,30	0,20	9,72	38,21	37,84	1,55	1,46									1,65						8 000	1000
156	42 - 43	0,30	0,20	10,00	37,84	37,45	1,46	1,36									1,66						8 000	1000
157	FIN	0,30	0,20		37,45		1,36	0,00																

Figure 4: Calculation tool - description of the route

When both sheets are filled, the user can start the calculation to analyse the results.
The tool calculates compression and tensile forces on every parts of the cable and on the pulling rope, three of them are critical for a proper cable laying:

- Compression forces on the pulling rope: it is limited at 700 daN/m, to avoid the slicing of the duct.
- Tensile effort on the head of the cable: its limit depends on the cable supplier. If there is too much tensile effort on the head of the cable, the latter may be ripped off.
- Tensile effort on the winch: these are the combination of the tensile forces on the head of the cable and on the pulling rope. For the time being, the limit is the same as the limit of the tensile effort on the head of the cable.

If these three variables remain under the limits, the pulling of the cable in this configuration is safe. If not, it is possible to reverse the direction of the pulling. When the challenging areas are located on the other side of the pulling site it is less difficult to manage them. If this is still not enough, the route should be reconsidered and maybe shortened.

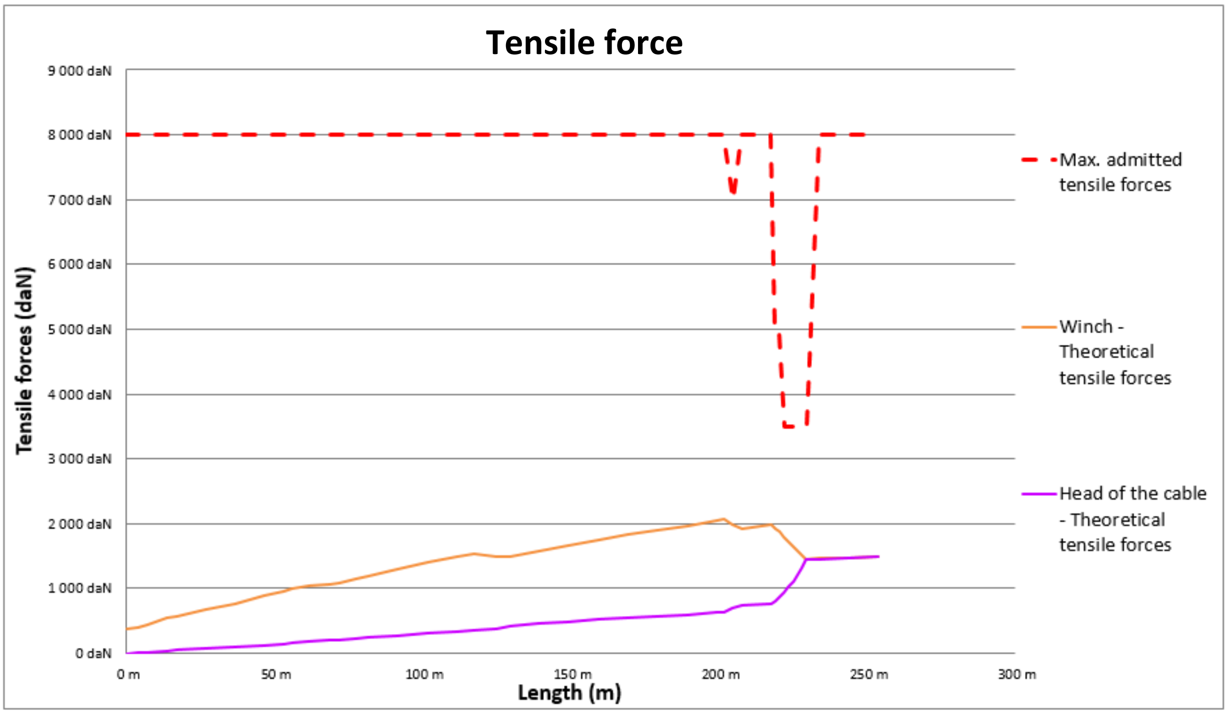

Figure 5: Calculation tool - Graph of the tensile forces

Thanks to the graph presented in Figure 5, the user can see if the pulling of the cable is possible. As long as the curves of the tensile forces on the winch (yellow) and on the head of the cable (purple) are under the dotted curve, the pulling is safe. The dotted line is the maximum admitted tensile force, which depends on the angle subtended by the bend of the portion. In this example, between 205 and 230 meters, the angle is less than 45 °, so the compression force is critical for the safety of the pulling. Therefore, the maximum admitted tensile force is the product of the compression force and the bend radius.

The graph in Figure 6 presents the expected compression forces on the head of the cable and on the pulling rope.

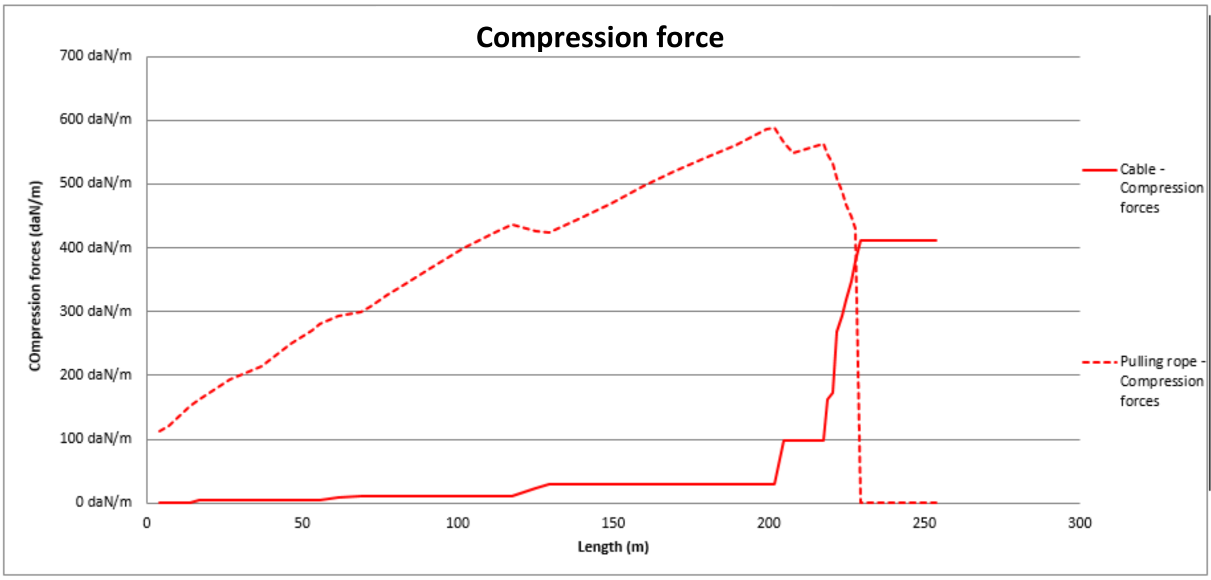

Figure 6: Calculation tool - Graph of the compression forces

At the end of the study phase, the qualified engineering consultancy company gives to the project team the projected cable route, with enough details for the Civil Works company to conduct the achievement of the works the easiest, safest and in the most productive way. One of the expected deliverables is the proof, with the calculation tool's results, that the laying of the cable is possible and will not damage it. All solutions to optimise, i.e. reduce, the forces on the cable have to be studied as well.
This tools is widely used in order to define for each project, the maximum length that can be pulled through ducts, and so the position of the joint bays. It is worth to note that a same project could have very tricky cable route which does not allow to pull more than few hundred meters, and also long straight line which allow to maximize the deliverable length.

Once the study phase is over, the construction phase takes place with another company.

5. CONSTRUCTION PHASE

When the Civil Works (CW) company takes charge of the project, it has to check the results and notify the TSO for mistakes or miscalculations. Once the civil works are over, and before the cable pulling phase, the CW firm must recalculate the forces (with the TSO's tool or its own) with the corrected route. The firm has to prove that the pulling operation is safe for the cable and, again, optimised for the cable.

During the pulling operation, it is impossible to have a live reading of the pulling effort on the head of the cable, because the only tensile effort measured is the one of the winch. As it is said earlier, it represents the tensile effort on the head of the cable combined with the tensile effort on the pulling rope but as it is the only value available during the pulling process, the TSO requires that it never exceeds the limits of the tensile effort given by the cable supplier for the head of the cable. On this side, the approach is conservative.

Stipulations for cable unwinding set up by the TSO are there to ensure that the cable is not damaged by the pulling operation. The winch must stop automatically if the maximum tensile force of the cable is reached. Moreover, if pushers are used to reduce the tensile forces, they have to be linked with the winch so that if one stops, the other stops at the same time. Finally, after each pulling, the Civil Works company has to provide the project team with both a paper and excel reports of the pulling forces, with warnings highlighted if the winch had to stop due to tensile forces.

6. ACTUAL AND FUTURE IMPROVEMENT OF CALCULATION TOOL

It is also possible to compare the theoretical forces with the real ones afterwards with the calculation tool. The laying of the cable shows that the tool might be conservative. Of course, this ensures a safe pulling, however the TSO wants to improve and optimise it. To do so, it first has to understand what margins are taken (friction coefficient for example), but also what really happens during a pulling, whether at the winch or at the head of the cable. The French TSO developed a cable pulling forces sensor to record the forces directly on the pulling head of the cable (Figure 7).

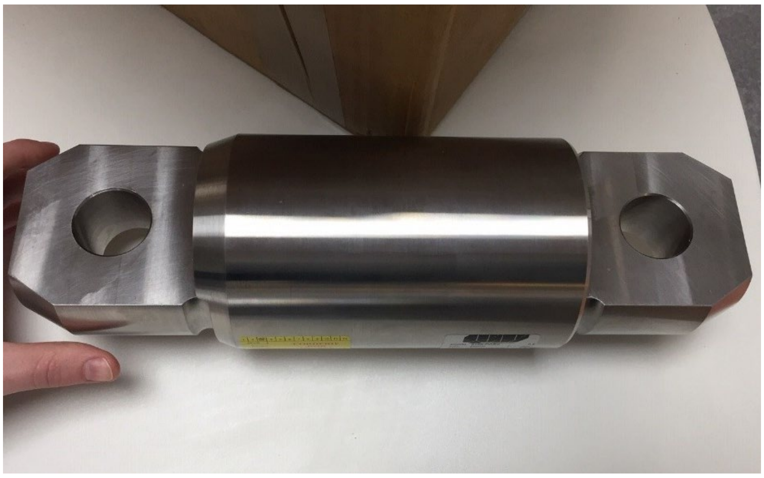

Figure 7 : Photograph of the pulling forces sensor

This waterproof sensor is put between the pulling rope and the head of the cable, and collects the data every second. Currently, the data is available after the pulling works, and it is used to improve the calculation tool. Since the signing of the new contract in 2019, the winch has to record the forces electronically.

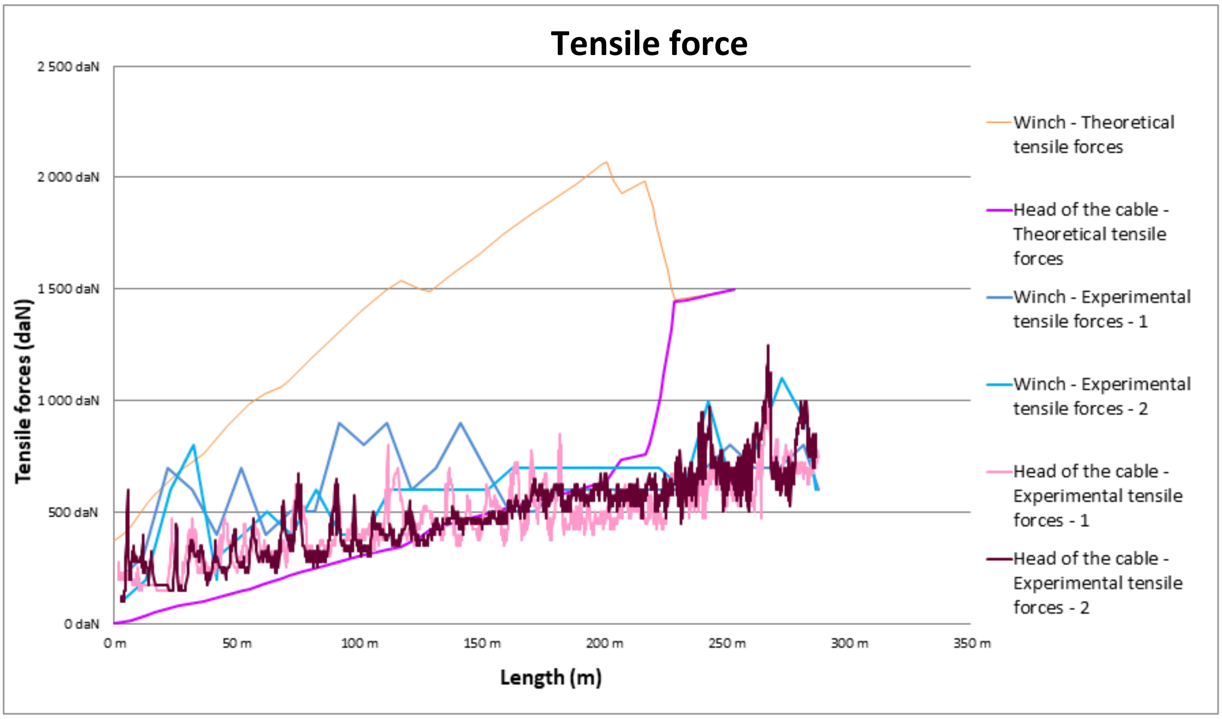

Figure 8: Calculation tool - Graph of the pulling forces (in theory and experimental) on the head of the cable and on the winch

Hence, both experimental forces (on the pulling head and on the winch) are available and once they are put in the calculation tool, it is possible to compare the theoretical and experimental curves to improve our knowledge on pulling cables (Figure 8). In this example, the experimental forces on the winch does not quite match the theoretical curve, and the theoretical forces on the head of the cable are undersized for the first part of the pulling and oversized for the second part. The pulling was still safe because the experimental data stay under the admitted limit but the graph shows that the TSO should reconsider its calculation tool model.

With a sufficient panel of results, it will be possible to approximate the experimental curves with the theoretical calculation, and therefore to enhance trust in the tool.

The last initiative of the TSO's R&D, and actually the main goal of the process, is the development of a cable pulling forces sensor that transmits the data in real time. In order to do so, the first step is to manage how to transmit data from under the ground. A prototype has been developed and is working. The next step is to combine an optimised version of the prototype with the existing sensor, and at last to set the terms and conditions of the use of the sensor by the Civil Works firms.

Another mean to upgrade the TSO's tool is to improve the knowledge of the friction coefficient. Nowadays, the coefficients available do not depend on the temperature, the civil work or the type of grease. This leads to a lot of approximations.
To avoid, or at least to understand the approximations, and to trust the calculation tool, the French TSO has studied further the friction coefficient evaluation depending on the temperature and the type of civil work, for the two kinds of grease used during the pulling operations in France. The TSO chose to focus on one cable cross section, the 630 mm² Aluminium (because it is the most deployed), with three types of ducts: 160 mm in PVC and HPDE and 140 mm in HPDE. The study has ended in February, and is showing that the friction coefficient in the tool is relevant but can be slightly optimised while keeping margins to ensure a safe pulling at any time. Among other things, the results also indicate that temperature does not influence the friction coefficient of the two greases.

7. CONCLUSION

In order to improve the reliability and to reduce installation costs of its underground cable, the French TSO has been working to increase the length of cable sections. It has chosen to lay is cables in ducts, in the trefoil configuration. It developed a calculation tool in 2010 to ensure safer pulling, and this tool is bound to be tweaked with experimental data and the tribology study. The TSO has also involved its suppliers: the cable manufacturers have been challenged on their capacity to produce and deliver longer lengths of cable, to improve the maximum tensile force that can be applied and to increase the screen interruptions AC; the Civil Work companies must be able to master the pulling of long length of cables to stay qualified. Finally, with the development of a cable pulling forces sensor that transmits the data in real time, the TSO will be able to monitor the pulling with the tensile force on the head of the cable.

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