Return to Session

MEASUREMENTS OF THRUST LOAD IN CABLE SYSTEMS SEMI-RIGIDLY INSTALLED IN DUCT / MANHOLE STRUCTURES

Riccardo BODEGA, Prysmian Cables and Systems, The Netherlands, riccardo.bodega@prysmian.com
Henk GEENE, Prysmian Cables and Systems, The Netherlands, henk.geene@prysmian.com
Frank FRENTZAS, ComEd Chicago, USA, frank.frentzas@exeloncorp.com
Angelo DE ANGELIS, ComEd Chicago, USA, angelo.deangelis@exeloncorp.com
Jos VAN ROSSUM, Prysmian Cables and Systems, The Netherlands, jos.rossum@prysmian.com
Nathan KELLEY, Prysmian Power Cables and Systems, USA, nathan.kelley@prysmian.com

ABSTRACT

This paper describes an experimental approach for testing the suitability of racking systems to be used for the fixation of cables and joints in duct/manhole structures. To this purpose, thermo-mechanical forces that will occur in operation can be reproduced on a cable system of reduced length, which is fixed on a test installation composed of a full-size duct/manhole structure. Forces can be applied and measured at the cable while the racking system is monitored. This can be done for several test conditions, including asymmetric load.
Preliminary results indicate that this testing method can provide an effective picture of the suitability of the racking system, including the tracking of eventual weak spots.

KEYWORDS

Duct, manhole, cable joint, installation, semi-rigid installation, thrust forces, racking system.

INTRODUCTION

Duct/manhole structures are often used for the installation of cable systems, especially in North America. In such structures the cable system is considered semi-rigidly installed. In a manhole, the cable system is generally fixed on a racking system, to avoid uncontrolled cable bending, see figure 1. Inside the manhole the cable is then restrained from any movement due to thermal expansion. On the other hand, in a duct, the small clearance between outer surface of the cable and inner surface of the duct only allows the so-called snaking of the cable, see figure 2. Consequently, the cable may develop a thrust load when heated and its components may be subjected to compressive strain.

Thrust forces on HV cables can be as high as several tons, depending on the cable type, on the duct characteristics and on the temperature rise. Therefore, appropriate racking systems are required for a proper fixation of the cable and of the cable joints. A racking system can be considered appropriate if the reactions of the cable and joints are limited when thermo-mechanical forces that will occur in operation are applied to the cable. However, an estimation of the cable system reactions is rather difficult for cables installed in duct/manholes.
Firstly, the calculation of thrust forces for a ducted system requires a quite sophisticated modelling [1] and a number of input data that are not always known during the design phase.
Secondly, practical situations such as the presence of bends in the cable route and/or the positioning of the cable cleats have a strong effect the behaviour of the semi-rigid installation.

For these reasons, an experimental approach has been chosen for the characterization of racking systems. After estimating the maximal cable thrust assuming the installation fully rigid, a mechanical load can be applied on a sample of the semi-rigidly installed cable system. To that purpose, the test facility described in this paper has been constructed.

Figure 1: Rigid installation of Click-fit joints a manhole.

Figure 2: Snaking of a loaded HV cable inside a duct.

Return to Session

BACKGROUND

The thermo-mechanical behaviour of a cable system depends on many factors. Firstly, thermo-mechanical properties are affected by the characteristics of the cable itself (e.g. cable construction and materials). Secondly, the type of installation is crucial for the definition of the thermo-mechanical behaviour of the cable system. Another important aspect that has a key role in this context is the temperature. In particular the following parameters are essential: the maximal temperature at the cable conductor, the ambient temperature, the variation of ambient temperature and the temperature during cable installation.

All the features mentioned above are critical for the new 345kV XLPE 1600 mm^2 Cu (Milliken construction) cable circuit that will be installed in Chicago (ComEd, USA) [2]. The cable system will be installed in ducts with a nominal diameter of 6” (152.4 mm). This will allow a clearance of 28 mm between cable and inner wall of the duct. Consequently, limited cable snaking will be possible inside the ducts. The manhole size for this project will be 26 feet long (7.92 m).
The environment conditions in Chicago, where the ambient temperature may drastically vary between winter and summer, are also unfavourable. Moreover, the cable circuit is expected to experience the maximal current load during the hot season. This will produce heavy heating cycles that will mechanically stress the cable for a long-lasting period.
Therefore, the thermo-mechanical suitability of the cable system had to be proven. This has been successfully done in the framework of a type test. During the type test, the cable system was subjected to 20 daily heating cycles, with a maximum conductor temperature up to 110 °C in a critical ‘U’-shaped cable bend [3]. Figure 3 shows the 345 kV cable system during the type test.

On the other hand, for the study of the cable system reactions inside the manholes, a specific experimental test methodology needed to be defined, including the construction of a purposely-made test facility.

Figure 3: 345 kV XLPE 1x1600mm^2 Cu (Milliken construction) cable and accessories during type test.

TEST FACILITY FOR CHARACTERIZATION OF RACKING SYSTEMS

The test installation consists of the cable system fixed inside a full-size concrete manhole, which is connected by means of ducts to two manholes of reduced size. In each small manhole, a hydraulic cylinder can load the cable up to 100 kN compression force (pulling force is also possible, but up to 40 kN). The forces are transmitted from the hydraulic cylinders to the cable conductor via two pressure sensors (load cells). The load cells communicate with a laptop, where all the measured data are stored and displayed.
Any eventual movement of the racking system can be recorded by means of a camera, which is also connected to the data storage system. In Figure 4, a picture of a 345 kV cable systems fixed on the test racking system is shown.

The drawing of the whole test installation is represented in Figure 5. In Table 1, the main characteristics of the test set-up are described, whereas its schematic diagram is represented in Figure 6.
In addition to the characterization of the racking system, the test installation has been used to prove the feasibility of install the cable and the joint inside a manhole/duct structure of the size anticipated for the project.

Figure 4: 345 kV XLPE 1x1600mm^2 Cu (Milliken construction) cable system fixed on the test racking system.

Table 1: Main characteristics of the test set-up adopted in the present work.

Component	Main characteristics	
Cable	Length	≈25 m
	Voltage	345 kV
	Conductor	1x1600 mm^2 Cu, Mill
	Insulation	XLPE
	Outer diameter	≈ 130 mm
Joint	Type	Click-Fit CFJ(X)-420
	Voltage	400 kV
Duct	length	≈ 4 m at each side of the manhole
	Material	PVC
	Size	6.23’ (158 mm)
Manhole	Material	concrete
	Dimensions	8535 x 2745 x 2435 mm (lxwxh)
Racking system	Modular struts made of stainless steel. (Light version)	

Return to Session

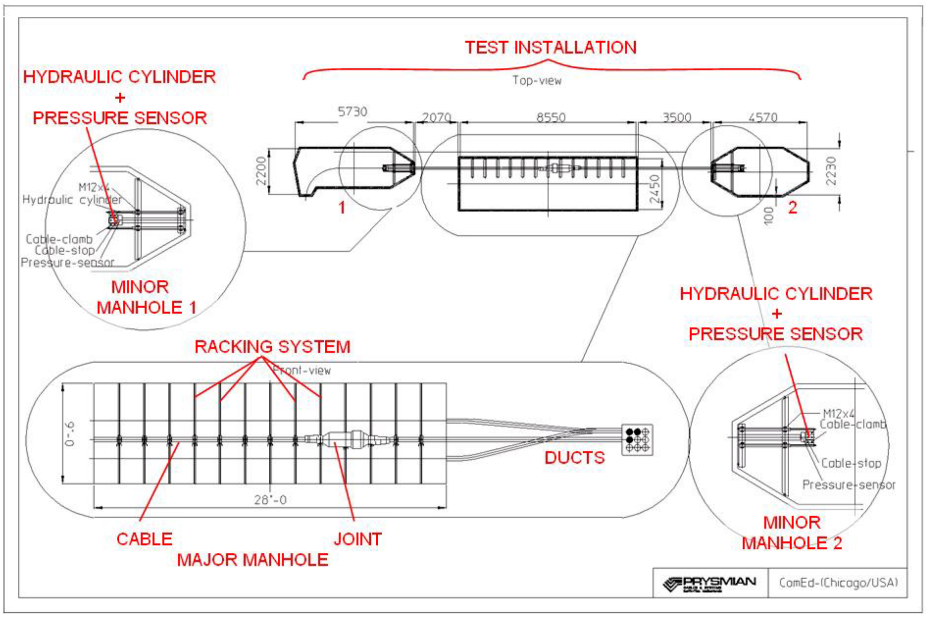

Figure 5: Drawing of the test facility for the characterization of racking systems.

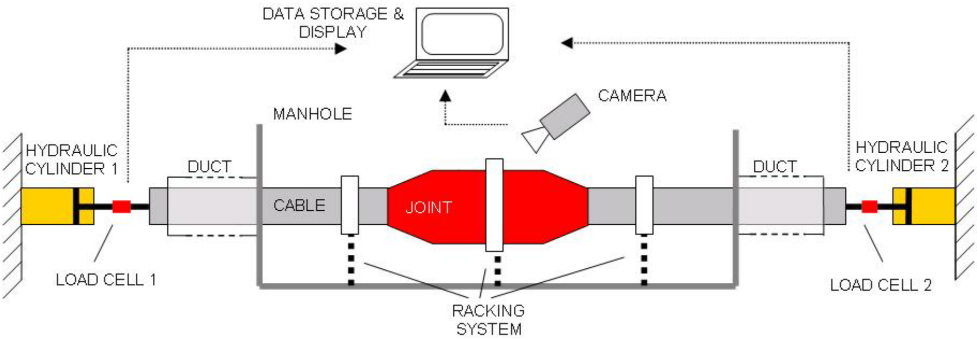

Figure 6: Schematic diagram of the test set-up.

CALCULATION OF THE MAXIMAL LOAD

Firstly, the load to be applied to the cable needed to be calculated. This has been done considering the worst possible case the cable system can experience during operation.

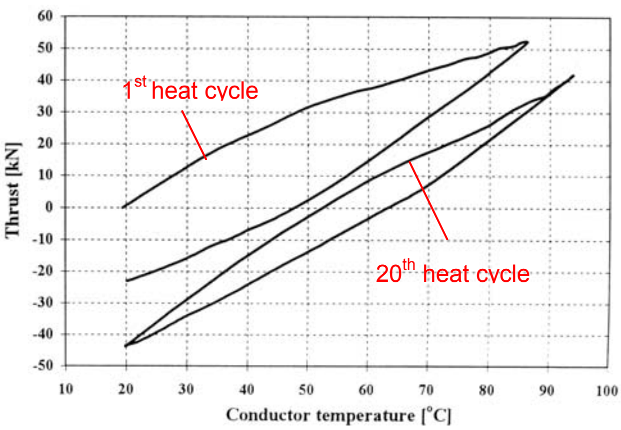

Figure 7: Plot of thrust forces as function of the temperature during heat cycles.

Practice has shown that the heaviest load occurs during the first heating cycle [4]. After this, a reasonable reduction of the mechanical stress occurs. In Figure 7 an example of this phenomenon is shown. Therefore the load at the first cycle has been considered for the calculation, together with the most critical temperature conditions. In addition, being the clearance between the actual cable and duct is relatively small, the load has been calculated assuming the installation is fully rigid.

By considering all those features, a maximal load, of approximately 50 kN has been estimated.

TEST PROCEDURE AND TEST CONDITIONS

Test procedure

Two different types of load have been tested in this investigation: symmetric and asymmetric load.

Symmetric load means that the cable system is equally compress at both cable ends.

Asymmetric load means the pressure applied at one cable ends is different from the other. In this situation the stress unbalance is taken by the cable cleats. Asymmetric load will

Return to Session

occur in practice when bends and/or slopes are present in the cable circuit. Another situation that may lead to asymmetric load is that in which the manholes are not equally distant along the cable route.
During both types of load, the cable cleats will experience lateral forces due to the fact that the cable system partially yields under the applied load.

During testing, the load was applied gradually, in steps of a few kN's, allowing a short time between them to let the structure stabilize on the new stress level. At the end of the each test, the original position of the cable system was restored. This was done by pulling back the pistons into the hydraulic cylinder.

Test conditions

All tests have been performed at ambient temperature. However, since the rigidity of the cable system depends on temperature, tests at elevated temperature have been scheduled for the close future.

PRELIMINARY RESULTS

Initially, a light version of the racking system has been tested. This was done in order to determine the weak spots of the structure. In this way improvements can be implemented in the final design of the structure. All results presented here are relative to the light version of the racking system.

Symmetric load

Tests performed with a symmetrical load, did not show any major movement of cable. Moreover, no visual disturbance could be observed at the racking system. This result demonstrates that the structural requirements for the system are moderate when symmetric loading conditions exist.

Asymmetric load

Asymmetric load led to two main consequences.
Firstly, under a load with a 10 kN asymmetric unbalance, (60kN – 50kN), the horizontal beam holding the joint moved in the direction of the unbalance. It is to be noticed the horizontal beam holding the cable joint is not supported by a vertical beam. This is shown in Figure 7. In the picture, the disconnected vertical beam is used as a reference.

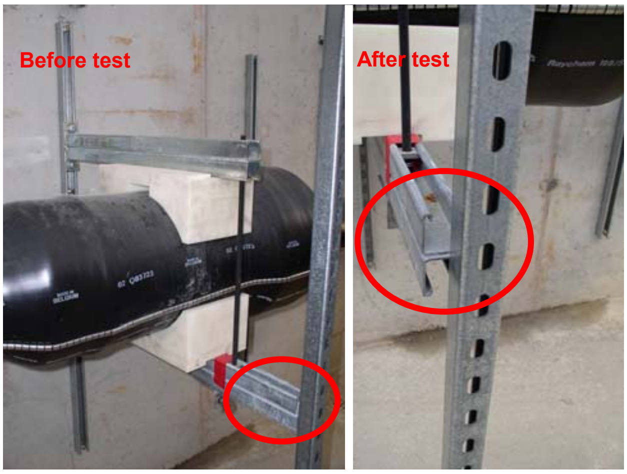

Figure 7: Movement of the horizontal joint support under the effect of an asymmetric load. (Horizontal joint support and vertical beam not connected)

Another consequence of asymmetric loading was found. The vertical beams connected to the horizontal cable supports bent when an unbalanced force of 10 kN was applied (applied forces at cable ends: 50 – 60 kN). Figure 8 shows this phenomenon.

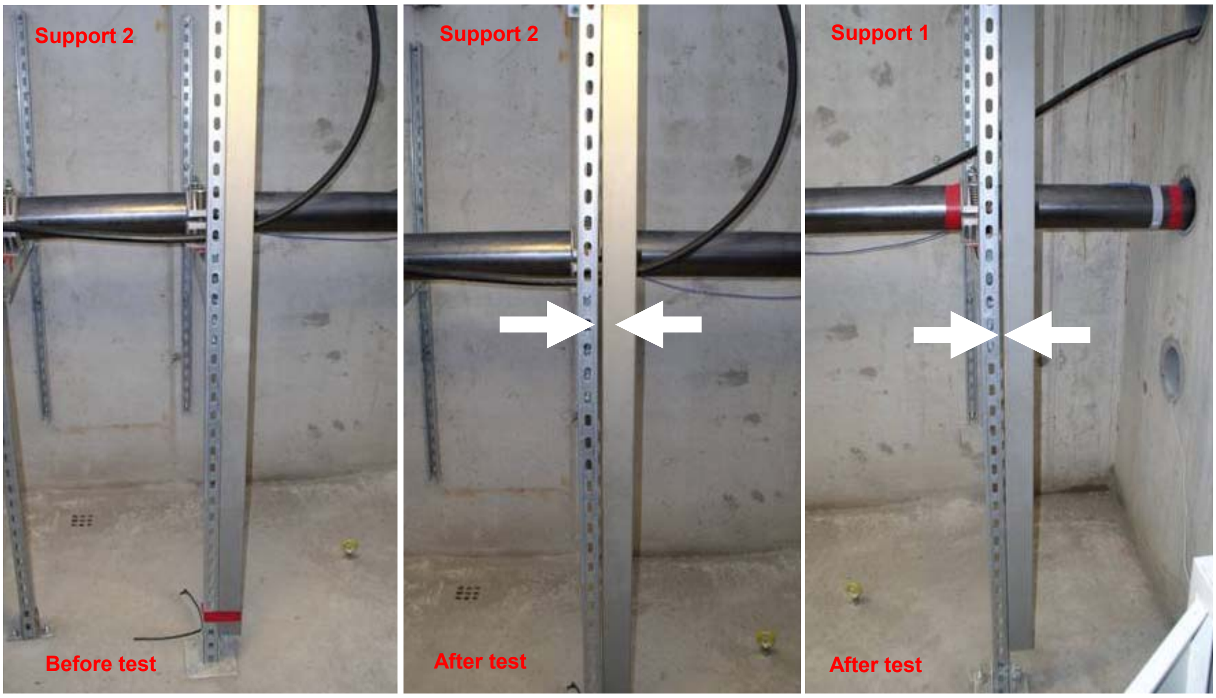

Figure 8: Bending of vertical beams under the effect of 10 kN asymmetric load (50 – 60 kN).

When the structure was asymmetrically loaded, an interesting result was found. Once the load unbalance is applied, the structure reacts in such a way to minimize it. In fact the higher force measured at one end of the cable decreased in time, while the lower force measured at the other cable end increased. This let believe that, in practice, asymmetric load will have minor consequences than what observed during the test, since the mechanical loads takes several hour to develop in the reality.

Nevertheless, it is important to prevent movements of the cable as a result of asymmetrical forces to affect the interface between cable and joint. This can be achieved by a proper coordination between cable system and racking and/or by locking the conductor inside the joint (core locking mechanism).

CONCLUSIONS

The suitability of racking systems for the fixation of HV cable systems in duct/manholes can be assessed by means of the experimental approach described in this paper.
In particular, the presented test installation is able to detect eventual weak spots of the supporting structure. Thanks to this information, improvements can be included in the final design of the racking system.
Preliminary results point out that the tested structure experiences the most critical stresses when the cable system is subjected to asymmetric load.

Prysmian Cable and Systems is considering upgrading the present test installation and defining new test conditions. In particular the behaviour of new types of racking systems will be investigated when the cable system experiences elevated temperatures and during long-lasting load cycles.

REFERENCES

[1] WG 21.01, *"Laying and installation of high voltage extruded cables systems – literature evaluation data comparison"*, Electra 156, 1994

[2] J. van Rossum – Cigre', Group Ref. B1, Pref. Subject 1, Question No 3, 2006.

[3] Insulated Cable Engineers Association, Inc. *"Standard for extruded insulation power cables rated above 46 through 345 kV"*, ICEA S-108-720-2004, 2004.

[4] D. Boende, H. Geene, W. Sloot, "400 kilovolts over the cable", Energie Techniek No 10, jaargang 1999.