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Industry CPD

Demystifying cable assemblies: a guide to full locked coil and open spiral strand cables

This CPD module, sponsored by Fatzer, aims to support readers to develop an understanding of the engineering behind critical cable structures.

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Introduction

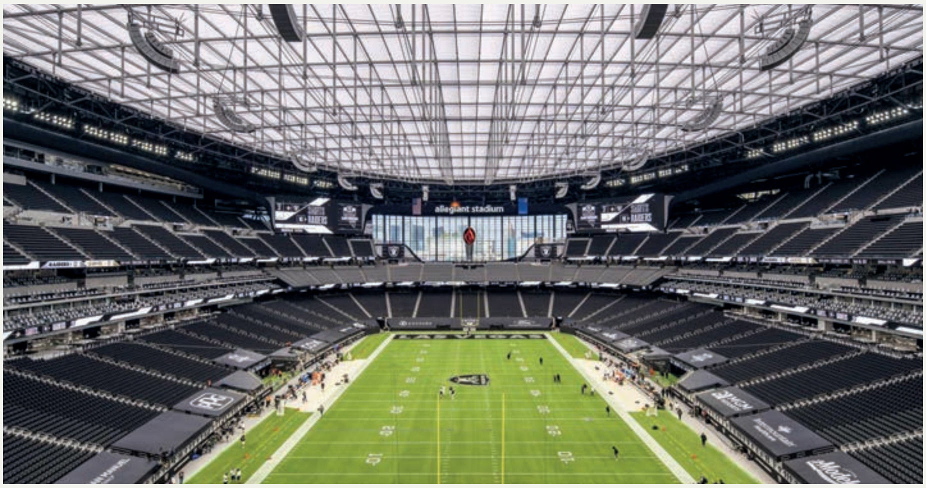
Cables and cable assemblies (cables with end connections) are well known structural elements and are used across a range of structures, yet the intricacies of their design and function often remain obscure to those outside the specialised field of tensile structures. This article aims to demystify two prominent types of cable assemblies: full locked coil (FLC) cables **(Figure 1)** and open spiral strand (OSS) cables. By exploring their production, strengths and limitations, and typical applications, we provide engineers and industry professionals with a clear guide to selecting the optimal assembly for their specific requirements.

High-strength tension members like FLC and OSS assemblies offer significant structural and architectural advantages by combining efficient load paths with high-performance materials. This synergy yields an exceptional strength-to-weight ratio, making these elements ideal for long-span, column-free applications **(Figure 2)**. A primary efficiency of these assemblies stems from the form-finding process, in which the structural geometry is determined by a state of natural equilibrium. Unlike rigid steel members that must resist gravity through flexural strength, a cable adopts a funicular shape – such as a catenary curve – to distribute loads through pure axial tension. In most cases, when the requirement to resist bending moments or shear forces is eliminated, as should be the case for FLC and OSS cable applications, these systems can bridge significant spans with a fraction of the material required for a comparable truss or beam.

↗FIGURE 1: Packed FLC cables ready for transport

Furthermore, the impact of second-order effects can serve to enhance overall structural stability. While second-order phenomena, such as the *P*-delta effect, are typically deleterious in compression members due to the risk of buckling, they provide a stabilising influence in tension-dominant systems. This manifests as geometric stiffness – a principle conceptually parallel to a tensioned guitar string, where the resistance to lateral displacement increases in direct proportion to the applied tension. In these systems, increased tensile force results in a non-linear increase in lateral resistance. Consequently, under dynamic conditions such as wind loading, the resulting deformation further increases internal tension, inherently stabilising the structure against additional displacement.

FIGURE 2: High-strength tension members are commonly applied in long-span applications



a) FLC cables deployed in stadium roof

b) Cables deployed in suspension bridge

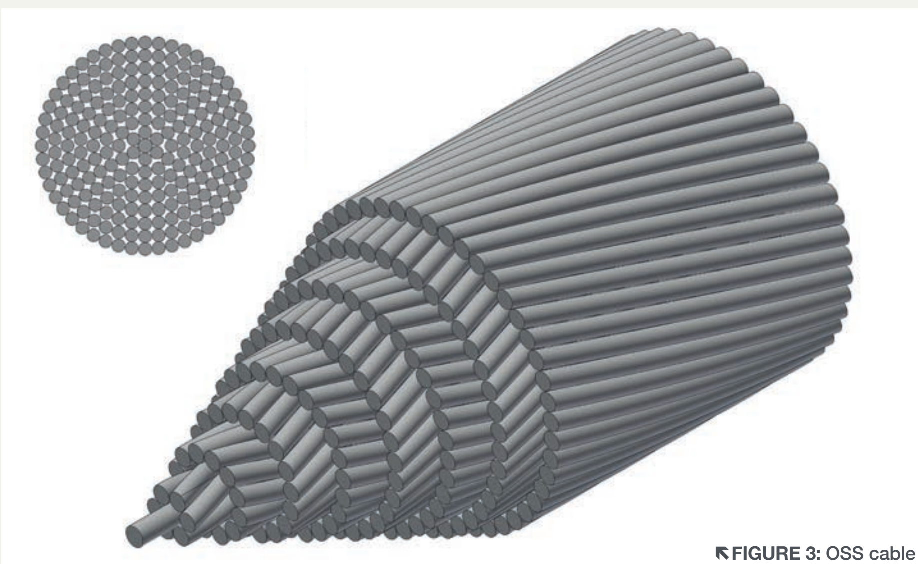


FIGURE 3: OSS cable

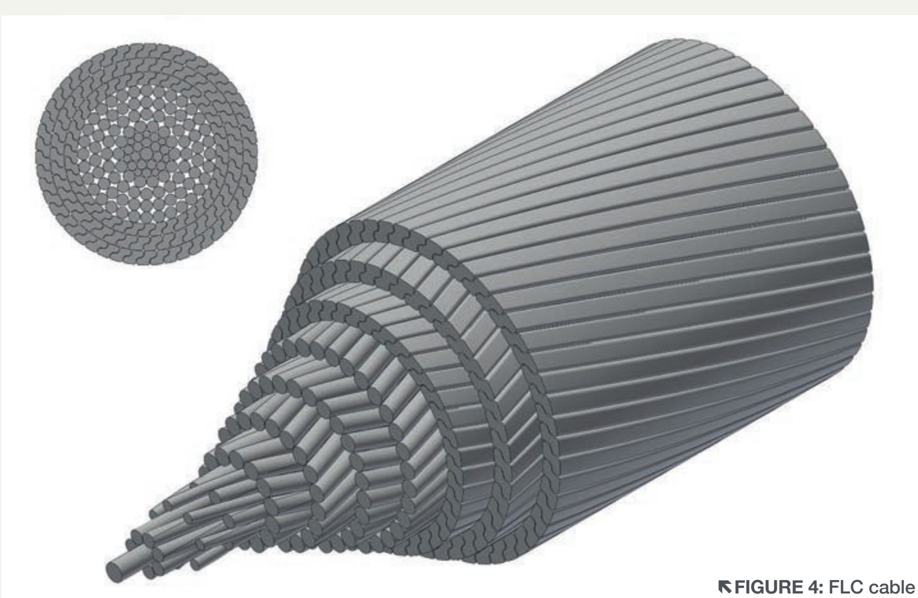


FIGURE 4: FLC cable

However, this beneficial effect is contingent on dynamic oscillations remaining non-governing. Cables, if exposed, can be susceptible to wind-induced vibration, which may necessitate mitigation measures such as supplementary mechanical damping, aerodynamic surface modifications (e.g. helical ribs on HDPE sheathing), or structural interventions such as cross-ties between adjacent cables.

Despite the inherent mechanical advantages of these systems, the nuances of their production and the specific criteria for their design remain specialised knowledge. The following sections address these complexities, providing a technical framework for understanding the manufacturing and application of FLC and OSS cables.

Cable production

Both OSS and FLC cables are produced by helically stranding wire layers around a central core, with each layer wound in the opposite direction (cross-laying) to prevent untwisting. Their main difference lies in the wire profiles:

- **OSS:** built entirely from concentric layers of round wires **(Figure 3)**.
- **FLC:** features a round-wire core surrounded by interlocking Z-profile wires that form a smooth, sealed outer layer – hence the term full locked coil **(Figure 4)**.

Beyond geometric configuration, the assemblies usually differ in their material strengths. The round wires used in both OSS and FLC constructions have a characteristic tensile strength of 1770N/mm^2, whereas the Z-profile wires employed in FLC cables have a tensile strength of 1570N/mm^2. These values are defined in EN 1993-1-11, which governs the design of tension elements.

Furthermore, the corrosion protection systems vary by cable type. FLC cables are generally regarded as providing a more robust system, particularly when manufactured in accordance with the recommendations of EN 1993-1-11, which recommends the use of an internal spinning compound (which is often zinc pigmented) which fills the interstitial voids to provide an additional chemical and physical barrier against oxidation. The internal round wires are hot dip galvanised (HDG) and the outer Z-profile wires have a zinc–aluminium coating (Zn95Al5) which can provide up to three times the protection of standard HDG, while the interlocking nature of the Z-profile wires provides a mechanical seal, adding a further layer of protection to the assembly. OSS cables, on the other hand, usually contain no spinning compound with all wires having a Zn95Al5 coating. If additional protection for either type of cable is sought, HDPE sheathing can be deployed.

While EN 1993-1-11 notes the possibility of spinning compounds leaking from FLC cables – a phenomenon commonly referred to as 'bleeding ropes' – research indicates that the primary catalyst for this issue is the chemical composition of the compound rather than an insufficient number of Z-profile wire layers. Indeed, if a poor-quality spinning compound is deployed, the addition of a third or fourth interlocking layer will have negligible impact on the cable's tendency to leak.

However, increasing the number of Z-profile layers remains a valid design choice for other mechanical reasons; specifically, the axial stiffness of the cable is increased by virtue of the greater effective cross-sectional area for a given diameter and higher fill factor associated with shaped wires.

Cable assemblies

Once end connections are attached to a cable, the system is referred to as a cable assembly rather than a cable. Achieving this requires several critical manufacturing processes.

The structural designer must confirm the cutting length for each cable, together with the corresponding reference temperature and load, consistent with the analysis model, and this is also ideally aligned with the installation methodology. This information is communicated to the cable supplier and represents an important stage gate in the manufacturing process. Upon receipt, the supplier can proceed with pre-stretching, marking, cutting and socketing of the end connections.

Role of pre-stretching

Pre-stretching is a critical phase in the assembly process, during which a controlled form of geometric yielding is induced as the helical wires bed down against one another. This process eliminates the constructional stretch inherent in newly manufactured OSS and FLC cables, allowing a stable and reliable modulus of elasticity (*E*) to be established. Without pre-stretching, cables exhibit significant initial elongation as wires adjust, slide and compact under load – behaviour that is largely non-elastic and therefore

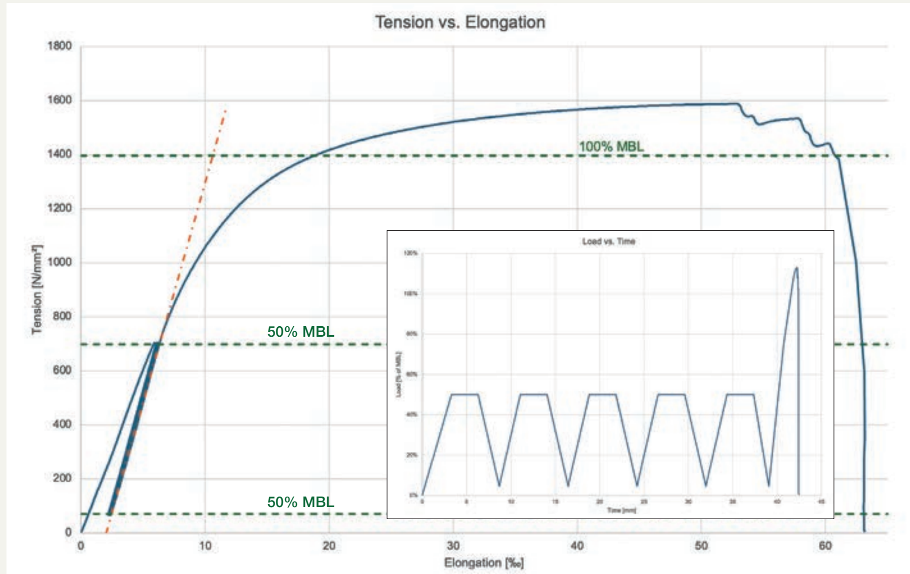


FIGURE 5: Load/strain diagram for FLC cable

> **WITHOUT PRE-STRETCHING, CABLES EXHIBIT SIGNIFICANT INITIAL ELONGATION AS WIRES ADJUST**

not captured by the design modulus. Once this initial settlement has been removed, the modulus within the pre-stretched load range can be treated as effectively constant, providing the designer with a high degree of analytical certainty **(Figure 5)**.

If a cable is installed without adequate pre-stretching, it will consequently exhibit greater elongation than assumed in the analysis, leading to a lower-than-intended tension force which can result in a redistribution of forces among the remaining cables.

At Fatzer, the standard pre-stretching procedure applies at least five load cycles between 5% and 50% of the cable's minimum breaking load (MBL), a range that slightly exceeds the recommendations set out in EN 1993-1-11. Under this standard, the maximum allowable design tension – the limit tension F_{Rd} – is 67% of the MBL. Pre-stretching within the 5–50% range ensures that the cable is sufficiently stabilised for service, even though its operational tension may extend beyond the pre-stretching level.

When the design results in high axial forces, larger-diameter cables become necessary. In such cases, the manufacturer's pre-stretching capability becomes critically important: the higher the achievable pre-stretch load, the greater the portion of the cable's service range

FIGURE 6: Brush formation

that can be stabilised within the linear-elastic domain before installation. If the available pre-stretching capacity is insufficient, a significant part of the in-service tension range may remain effectively 'unstabilised', which may lead to additional settlement during installation and early service life.

Marking and cutting of cables

Cable marking is generally carried out while the rope is held under load. Best practice is to combine a high degree of automation with a climate-controlled environment, allowing the relationship between load and temperature specified by the designer to be maintained.

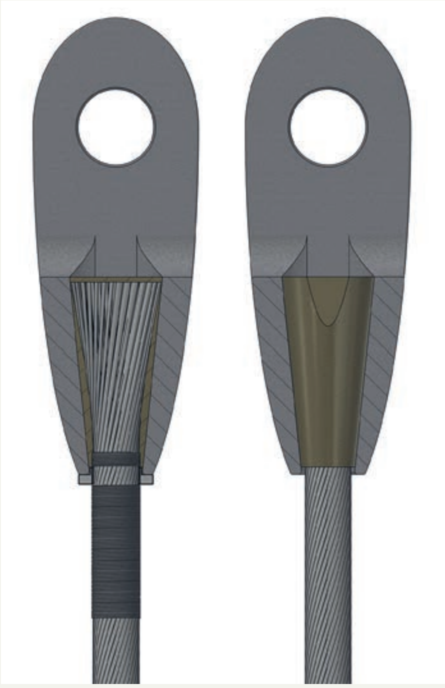
Because marking is performed only after pre-stretching – once the rope exhibits linear elastic behaviour – the resulting length markings achieve a high level of precision. This accuracy is essential both for maintaining the correct relationship between geometry and force in tensile structures and for ensuring that clamps and other fittings can be installed with the required positional precision.

Socketing

FLC cables are typically terminated using cast (spelter) sockets. After cutting the rope to length, the sockets are positioned several metres from each end. The wire ends are then splayed into a 'brush' **(Figure 6)**, after which the sockets are advanced over the splayed wires and temporarily secured. The socket cavity is subsequently filled with either a polyester resin (e.g. WIRELOCK®) or molten zinc (Zamak). Upon curing, this forms a solid conical termination **(Figure 7)** capable of transferring at least 100% of the rope's MBL, although such load levels are not intended under service conditions.

Zamak casting requires heating of both the alloy and the end fitting, increasing process complexity and extending handling times – typically up to 10 hours per end for cables above 100mm – without offering a mechanical advantage over resin-based socketing and can create schedule pressure on large projects.

Pressed (swaged) end connections, where a steel sleeve is mechanically compressed around the rope are also available, but normally only for OSS cables up to 36mm in diameter. A key difference between these two solutions is that for pressed end connections, a reduction factor (K_e = 0.9) is used when calculating the characteristic breaking strength F_{uk} and the limit tension force F_{Rd}. K_e for cast connections is 1.0.



↗FIGURE 7: Casting of socketing material around brush within end connection

The output of the socketing process is a ready to install cable assembly, much like a very heavy Lego piece.

While additional sealing at the cable–socket interface, or supplementary protection such as gaiters installed over the sockets, is not typically adopted for FLC and OSS cable assemblies, such measures can provide an additional barrier to water ingress.

Table 1 provides a comparison of some key features of OSS and FLC cables.

FLC cables are preferred over OSS when higher stiffness per diameter or greater corrosion resistance is required. Their flatter outer surface also provides better clamp contact, allowing smaller or fewer clamps to achieve the same performance. Since clamps can be costly, an FLC-based solution can often be more economical overall than an OSS configuration.

Table 1: Comparison of FLC vs OSS cables

Aspect	Full Locked Coil (FLC)	Open Spiral Strand (OSS)
Classification per EN 1993-1-11	Group B tension members	Group B tension members
Resistance to fatigue loading	Comparable (dependent on detail category and termination)	Comparable (dependent on detail category and termination)
Axial stiffness	Higher (dense, compact cross-section)	Lower (more open construction)
System cost without clamps (for connecting cables to one another)	Higher (due to Z-profile wires)	Lower
System cost with clamps	Can be lower: a smoother cable surface increases contact area between clamp and cable, allowing a smaller clamp for a given force	Can be higher
Corrosion protection – outer wires	Z-profile wires: Zn95Al5 coating	Round wires: Zn95Al5 coating
Corrosion protection – inner wires	Round wires: hot-dip galvanised	Zn95Al5 coating
Additional corrosion measures	Internal spinning compound; mechanical interlocking of Z-profiles limits moisture ingress	None inherent to geometry; relies primarily on coatings
Additional corrosion protection possibilities	HDPE sheathing Painting (multiple-layer system) Taping (2 layers butyl rubber)	HDPE sheathing Painting Taping
Surface and sealing	Near-closed surface; good barrier effect	Open surface; greater exposure to environment

EN 1993-1-11: Tension components

EN 1993-1-11 provides specific design provisions for tension components within Eurocode 3 and is widely adopted as the principal reference for the design of tensile structures. The current edition (2006) remains in force; however, it is soon to be superseded by an updated version.

The forthcoming revision introduces several changes. In particular, it aims to provide sufficient information for designers to determine key parameters such as F_{min}, F_{uk} and F_{Rd} directly using the formulae provided, addressing a key limitation of the current edition. Additional guidance on clamp design and testing, along with revisions to fatigue resistance provisions will be provided.

At present, when determining cable strength in accordance with the code, the following expressions are used:

(1.3.8) Breaking force factor $K = \pi fk/4$.
f = fill factor of the rope
k = spinning loss factor

(1.3.9) $F_{min} = Kd^2R_r/1000$ (kN) (F_{min} can be considered the strength of the cable independent of end connections).

(6.2) F_{Rd} (Design resistance of cable) = min $\{F_{uk}/1.5\gamma_R\ ;\ F_k/\gamma_R\}$.

(6.4) $F_{uk} = F_{min}k_e$ (F_{uk} can be considered the strength of the cable assembly with end connections).

Despite the code saying otherwise, the variables k and f are not available to the designer, which makes calculations using information contained within the code alone impossible. Until the next edition of EN 1993-1-11 is released, which will suggest values of 0.92 and 0.85 for k and f respectively, designers can liaise with cable manufacturers for support in this regard.

Tension elements: different options

The choice of tension element depends on a range of design, fabrication and installation considerations. While tension rods or tubular sections may be familiar and convenient for shorter spans or moderate loads, they quickly become impractical as lengths and forces increase. By contrast, cable assemblies are often delivered as coils, making the transport of long, high-capacity elements routine and efficient.

Tension rods, tubular sections and FLC/OSS cable assemblies share a key advantage: they are typically delivered to site as finished products requiring no further fabrication. In the case of FLC/OSS cables, on-site activities are generally limited to installation and tensioning, with all critical manufacturing processes completed under controlled factory conditions. This enables a consistently high level of quality and reliability.

For parallel strand cable systems, the finished cable is not delivered to site in its final form. While this approach can be advantageous from a transport perspective, it requires more extensive on-site assembly and installation activities. Consequently, greater effort is typically required on site to achieve an equivalent level of quality control compared to fully prefabricated systems. Although these solutions may offer a lower initial production cost, this advantage can be offset by the additional assembly and quality-assurance effort required on site.

A notable manufacturing boundary of FLC cables is that they are generally not manufactured in diameters exceeding approximately 152mm. Where design loads exceed the capacity achievable within this diameter range, either multiple FLC/OSS cables need to be deployed or alternative systems such as parallel strand cables must be considered. However, due to the internal voids inherent in parallel strand construction, significantly larger overall diameters are required to achieve equivalent load capacity. **Figure 8** illustrates the comparative diameters required for given design loads for both systems.

F_{Rd}	Full Lock Coil (no HDPE)	Full Lock Coil (HDPE)	Parallel Strand system (HDPE)
~ 1320kN	45mm	61mm	110mm
~ 3406kN	75mm	91mm	160mm
~ 8085kN	110mm	126mm	200mm
~ 15600kN	150mm	166mm	315mm

↗**FIGURE 8:** Comparison between different cable solutions

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Questions

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1) A contractor installs a cable assembly without adequate pre-stretching. What is the most likely structural consequence?
a) Increased stiffness leading to higher design forces
b) Reduced relaxation losses under service conditions
c) Excess elongation and redistribution of forces within the cable system
d) Immediate failure at the end connections

2) When comparing cast (spelter) sockets with pressed (swaged) end connections, which design implication should be considered?
a) Pressed connections provide higher fatigue resistance
b) Cast sockets require a reduction factor on strength calculations
c) Pressed connections require a reduction factor (K_e = 0.9) in strength calculations
d) Cast sockets cannot achieve full cable strength

3) A project requires a tension system with high stiffness per diameter and optimised clamp performance. Which option is most appropriate?
a) OSS cables due to their open structure
b) Parallel strand cables due to smaller diameters
c) Tubular steel members due to bending resistance
d) FLC cables due to higher stiffness and improved clamp contact

4) Why must the temperature and load state, consistent with the analysis model, be defined for determining cable cutting lengths?
a) To enable accurate prediction and control of long-term relaxation and creep effects in the cable
b) To ensure the fabricated cable length reflects the strain state defined by the analysis model
c) To verify that the cable forces remain within allowable limits during installation and initial tensioning
d) To ensure that the cable achieves its specified stiffness under all service temperature conditions

5) Why is the pre-stretching capacity (i.e. maximum achievable load level) of a cable manufacturer important?
a) It ensures that pre-stretched large-diameter cables exhibit linear-elastic behaviour over a wider range of applied load
b) It ensures more accurate marking of the cables under low loads
c) Pre-stretching can be carried out more quickly
d) Less tensioning is required during cable installation

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