Tensile Surface Structures
A Practical Guide to Cable and Membrane Construction

Michael Seidel

Materials

Design

Assembly and Erection

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Foreword

We have here a remarkable book. It represents the first exhaustive description produced on a scientific basis of all the knowledge and interactions required for construction with flexible structural elements, covering ropes and belts, fabrics, yarns and foils.

The word "construction" can be taken literally: the author Michael Seidel considers the processes of production and erection of tensile surface structures, their interactions with the design work of architects and engineers and also the quality of the final end-product "structure". He advances here into an area, which almost all specialists in lightweight construction recognise, but where they have no overview of the details and are clearly not proficient. The results of this lack can be seen almost daily: either the erection as intended is impractical or even impossible, and completed design work has to be altered or sometimes thoroughly reworked; perhaps even more seriously, the end-product "structure" cannot be built in the intended quality.

It has long been overdue that the manufacturing and assembly processes in construction with flexible structural elements be collected, categorised and evaluated. Not only the overview produced here is of great value to all those concerned with the construction of tensile surface structures, rather it is the presentation of the interactions between design, erection and the quality of the finished product, which makes the present book so important in filling a wide gap in the existing literature on lightweight construction.

Stuttgart, October 2007 *Werner Sobek*

for
Maggie & Esther Olivia

Preface

Scarcely a field in construction requires such close collaboration between all the parties involved in design, manufacture and execution as construction with textile materials. From the form finding and patterning to detailing and planning the erection, collaboration is essential between architect, engineer and the companies responsible for production and erection. This results above all from the particular mechanical behaviour of the materials used. Their composition and arrangement as load-bearing elements, the force relationships in the element and above all the capacity of such material to accept relatively high deformation all raise the question of the buildability of tensile surface structures – or membrane construction. This shows clearly how practicalities arising from the production of the materials and the erection of the structure exert a significant influence on the design process.

There has been continuous research and development for decades in the field of wide-span lightweight structures. The requirements placed on the design process by the needs of production and erection have in contrast only been investigated by isolated companies and consultants for application on particular projects. The present book is an attempt to remedy this lack of knowledge and, through the investigation of the current state of the art in the construction of tensile surface structures, represents an essential complement to the computer-aided calculation process of form finding and structural design.

The concentration on practical design details and their erection is used in this book to explain the basic interrelationship between manufacture and erection of flexible structural elements. Extensive specialist knowledge has been collected together and categorised in such a way as to be useful in practice. In some areas, optimisation potential has been pointed out for the process of designing membrane structures for practicality of erection.

Starting with the textile composition and internal structure of the flexible materials, the first part of the book explains their production processes, function and mode of operation as load-bearing and connecting elements. The mechanical behaviour of coated fabrics and the criteria for patterning are given special attention. Joint and connection methods for textile sheet elements and their special characteristics regarding manageability and buildability are also discussed.

In the second main part of the book, the importance of erection planning and its specific activities are explained with their economic and technological aims. This also includes measures to estimate and test erection activities and the scope of influence and purpose of erection planning in the individual phases of a project. The equipment used for erection is described, with an overview of the tools used for transport, lifting and tensioning processes. Tensioning systems for linear and sheet elements are described in detail.

Starting with production and construction technological parameters and their influential factors, procedures for the erection of some characteristic forms of mechanically pretensioned membrane structure are described and illustrated with examples from the practice. The description of the erection of flexible load-bearing elements includes essential activities like preparation, preassembly and erection on the construction site, and these are investigated and commented. The emphasis is on the process of introducing pretension into the membrane. Finally, there is an overview of methods for determining forces in flexible load-bearing elements.

The end result is a book, which will be of interest not only to architects and engineers concerned with the design and construction of membrane structures, but also students in relevant subjects, who should find the book useful as course material or for their own study.

It would scarcely have been possible to write this book without drawing on the experience of designers, manufacturers and builders. I would like to express my special thanks to all those who have supported me with suggestions and material in the past years.

I owe special thanks for personal interviews with Dr.-Ing. habil. Rainer Blum, Dipl.-Arch. Horst Dürr, DI Reiner Essrich and Univ. Prof. DI Dr. Karlheinz Wagner. I also wish to thank DI Peter Bauer, Dr.-Ing. E.h. Rudolf Bergermann, Ing. Christian Böhmer, DI Wilhelm Graf, Bruno Inauen, Stefan Lenk, DI Dr. Walter Siokola as well as DI Jürgen Trenkle.

Special thanks are also due for the expert support from O. Univ. Prof. i. R. DI Dr. Günter Ramberger in questions regarding wire rope manufacture.

I thank the following engineers for helpful correspondence: DI Dr. Herbert Fitz, DI Hansruedi Imgrüth, Ing. Wolfgang Rudorf-Witrin, DI Bernd Stimpfle, DI Rochus Teschner and DI Jörg Tritthardt.

Finally, personal thanks are due to those people and companies, who have supported and furthered the writing of this book by providing material.

These were Mag. arch. Silja Tillner, the engineers DI Christoph Ackermann, DI Benoit Fauchon, DI Knut Göppert, DI Hans Gropper, Udo Holtermann, DI Christian Jabornegg, Daniel Junker, DI Rudolf Kirth, DI Roland Mogk, DI Bruno Pirer, DI Michael Wiederspahn, DI Jürgen Winkler, DI Dr. Günther Zenkner, DI Dr. Rene Ziegler and also Tim Schubert and the following organisations: Arbeitskreis Textile Architektur, Bilfinger Berger AG, CANOBBIO SPA, CENO TEC GmbH, Covertex GmbH, Eichenhofer GmbH, Ferrari S.A., FIAB HF, Form TL Ingenieure für Tragwerk und Leichtbau GmbH, gmp – Architekten von Gerkan, Marg und Partner, Hightex GmbH, Histec Engineering AG, IF Ingenieurgemeinschaft Flächentragwerke, Inauen-Schätti AG, MERO-TSK International GmbH, Montageservice SL-GmbH, PFEIFER Seil- und Hebetechnik GmbH, Sattler AG, Schlaich Bergermann und Partner GmbH, Ingenieurbüro Teschner GmbH, Teufelberger GmbH, VSL Schweiz AG, Zeman & Co GmbH and Werner Sobek Ingenieure.

I also wish to thank at this point Em. O. Univ. Prof. Arch. Dipl.-Ing. Helmut Richter, the former head of the department Hochbau 2 at the Faculty of Architecture and Town Planning at the Vienna Technical University, whose confidence and stature as architect and teacher were an additional motivation for the creation of this work.

I wish to express heartfelt thanks to Ao. Univ. Prof. Dipl.-Arch. Dr. habil. Georg Suter for reading though the book and offering a critical discussion.

Vienna, August 2007 *Michael Seidel*

Contents

1 Introduction

To analyse, formulate and finally substantiate a theoretical model requires complex processes and decision-making. Even though such interacting processes with the intention to ***make*** or ***manufacture*** something are hard to illustrate with diagrams, solutions still have to be looked for and developed and the processes notionally fixed, illustrated and explained in advance.[1] In the construction industry, where materials are arranged to form structures, these processes are usually called conception, design and construction.

The term ***construction*** here means the route developed to materialise such theoretical models through the conception, design and construction process. The final structure therefore represents a considered and materialised entity. This book understands the construction process as the ***material arrangement of the environment*** and the materials required are found the appropriate space for consideration.

To reduce the rules of construction to the overcoming of materials and methods alone does not achieve the required purpose. The essential influence of manufacturing and erection methods in the determination of the most suitable type of construction or structure should not be underestimated. It makes more sense to regard the technology of construction as a fundamental source of income, which becomes richer with repeated use.[2]

1.1 The importance of manufacture and erection

The erection of a structure requires a wide-ranging consideration of methods, procedures and execution. The aim of these considerations is the creation of a qualitatively high-value structure and the achievement of short erection times. This can be achieved through a high degree of pre-fabrication and the development of efficient erection procedures.

To be able to reach the right decisions about the optimisation of time, cost and energy at each of the various project phases requires extensive technical knowledge and experience. The effective collaboration of all the specialists involved in the design and implementation is also vital. They are all significantly involved in the implementation of the physical design.

As a result of progress in the development of materials and components in construction, the understanding of the methods for producing and jointing materials and their technical specification is becoming ever more important for the engineers and architects involved in design. Manufacture and erection on site should therefore be regarded as core processes in the development of structural systems.

The respect for considerations of manufacturing and assembly has a long tradition in the design of construction components. Particularly in steelwork, timber and precast concrete construction, the layout of construction elements is influenced not only by architectural formulation and structural demands, but also by factors derived from the practicalities of production and assembly. The elements are prepared at the works, partially pre-assembled, numbered and transported to the construction site, where they are put together to form units for erection in a further preassembly process.

In the field of membrane structures, a specialised area of structural engineering where textile structures of fabric and ropes form wide-span roofs, this is also the usual practice on site. One reason for this is the stringent requirements on the manufacture and testing of the materials, which makes production on site impossible and demands particular erection technologies.

Membrane structures, on account of their external form and their light weight, are categorised under wide-span lightweight structures. Regarding their structural behaviour, they differ from conventional structures above all in that the external forces are transferred exclusively through tension. They are therefore described as form-active systems. With the appropriate choice of materials, curvature and force transfer, their structural form corresponds exactly to the line of the forces.[3]

Coated fabrics are usually used for the textile surface elements of mechanically tensioned membrane structures. To improve their material properties, they are made of composites of various materials. The wire ropes used as linear struc-

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[1] *Ferguson, E. S. (1993)*

[2] *Buckminster Fuller, R. (1973)*

[3] *Engel, H. (1997)*

tural elements and their connections are for functional reasons also composed of various components.

Surface and edge elements under tension have negligible bending strength; they are assumed to be flexible materials. Their geometrical arrangement and formation as bearing elements in a membrane structure, which permit relatively high deformations under the forces acting on the element and the capacity of the material, demand answers to the question of the "buildability" of such a structural design.

In addition to the local conditions on the construction site and the choice of suitable equipment, it is above all the rules of construction methodology for the erection of structural elements under tension, which require understanding of the internal composition and mechanical behaviour of the material to be used and enable the implementation of the chosen assembly method.

In contrast to conventional building methods, where assembly consists of the addition of further elements horizontally or vertically, a membrane structure only achieves sufficient stiffness in its structural elements and in the structural system after the application of pretension to the linear and surface elements.

The erection process to be used for a membrane structure is therefore decisively dependant on the production quality of the materials used. The original shape, the deflected shape and above all the jointing process have a strong interaction with the method of erection and offer important potential for optimising the way of constructing such a structure.

1.2 Ambition, aim and scheme of the book

The thousand-year history of building with membrane surfaces was restarted in the second half of the 20th century. In Europe, it was mainly the engineers, architects and scientists in the circle around the German architect Frei Otto, who between 1970 and 1985, as part of the widespread scientific cooperation in and outside Germany under the auspices of special research area 64 in Stuttgart, achieved a major contribution to the research and development of wide-span membrane structures. The companies who supported these developments should also be mentioned.

Since then, there has been further continuous development in membrane construction. The use of computer-aided calculation methods to solve problems of form finding and statics for thin-walled surfaces and also the development of new materials and methods of connection, taking basic parameters into account, today enable a mostly systematic design of membrane structures. If, however, one is looking for answers to questions about the practical implementation of membrane structures today, these are mostly only to be found in reports of completed projects, in which the site erection process is only briefly described. A few exceptional examples have been presented to the relevant specialists.

The purpose of the present book is therefore the systematic investigation of the current state of the technology for implementing the construction of wide-span lightweight surface structures.

The orientation on actual construction and its erection should allow basic interactions to be recognised; how the processes of production, delivery and jointing all influence one another and offer potential for the optimisation of the design process. Of special interest is the explanation of the interaction between the production of the individual materials.

Instruction in the methodology of the manufacture and erection of membrane structures is not part of this book. It also represents no simple compilation of descriptions of the technology. The emphasis is more the presentation of the complex areas of influence, dependencies and connections between the design and construction of membrane structures. Analytic questions of form finding, the economic aspects of resource planning, capacity management and estimating can only be described to a limited extent.

The book is divided into two main parts. The first of these describes the materials used to form structural elements and their production processes. The selection criterion is a categorisation of construction elements according to geometry and function. Starting from their material and structural composition, the materials used are described and their production processes are explained. Examples are given of their function as structural elements and the principal correlations between the requirements of geometry and bearing behaviour, and also details of their composition.

To make clear the complex material behaviour of coated fabrics, the basic mechanical properties of the most commonly used types of fabric are summarised and their influence on practical implementation in construction is explained.

Then possible details for surface joints, edges and connections to other components are discussed and illustrated with examples.

The second main part of the book deals with the erection of membrane structures and their load-bearing elements. Starting with the scheduling of the construction progress, the most important construction equipment is discussed. The emphasis here is on devices and equipment for tensioning wire ropes and membranes. Starting from the parameters influencing the principle of erection, methods of erecting membrane structures are described and erection operations investigated systematically. The characteristic stages of the individual processes are described and illustrated with diagrams. This is supplemented with photographs of erection work on completed projects.

Finally, the process of assembly and erection and the procedures on the construction site are explained. All the essential steps in the erection of structures are explained, from the preparation work and the pre-assembly through lifting, hanging and tensioning. The emphasis here is the process of introducing the forces into the membrane surface. In the last section, there is a summary of the methods and procedures for measuring forces in wire ropes and membranes.

The closing discussion comments on open questions and offers a view of possible developments in the future.

2 Materials for tensile surface structures

2.1 Introduction

The chief characteristic of surface structures is the large clear spans, which can be roofed over very economically without internal support. Construction forms, which transfer all external forces as tension, have proved most successful in this specialised area of construction, with the exception of shell construction. Form-active tension systems have the advantage compared with traditional structures that, given corresponding interaction of form, force and material, the volume used is minimised without reducing the strength, stiffness or stability of a structure.

Membrane surfaces installed in form-active structures are composed of load-bearing elements of varying materials, types of construction and geometry. Normally these are large jointed surface elements and linear edge elements. Both types of element can only bear loading in a particular shape (curved), and have to fulfil certain technical criteria. In addition to keeping the weather out, they have to be resistant against chemical and biological attack and must be non-flammable in case of fire. Concerning structural safety, they have to conform to specific weight and balance requirements and above all strength and stiffness requirements, and also enable the stress distribution to be matched to external loading conditions. Problems of force transfer have to be dealt with correctly considering the stiffness behaviour. The construction material of the load-bearing elements has to be formed and dimensioned to suit their purpose in accordance with these requirements.

The dimensions of the surface elements are exceptionally two-dimensional. Linear load-bearing elements are used to transfer loading though the edge. The mechanical material properties of both types of load-bearing element have to enable the load transfer from the multiply curved surface forms exclusively through high tension forces. The types of material used normally have high elongation stiffness and negligible bending stiffness. The mechanical behaviour of the materials in buckling and plate buckling is, depending on the loading, relatively ***flexible*** in comparison with the structural system.

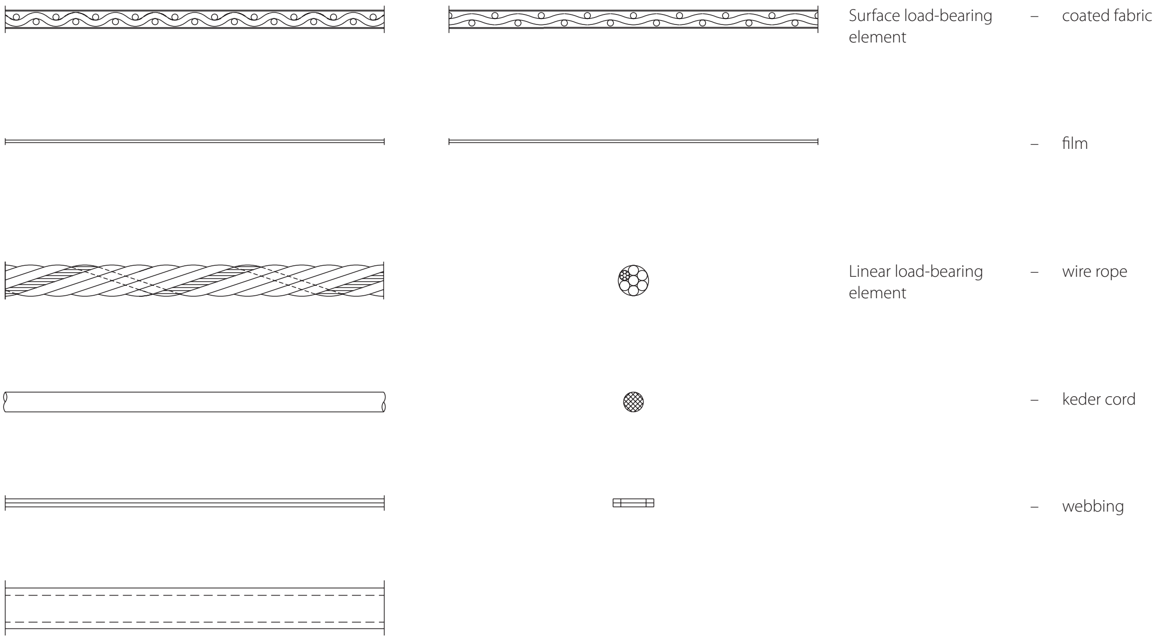

Fig. 1: Flexible load-bearing elements in wide-span surface structures

Two groups of material are mostly available today as membranes for planar load-bearing elements (Fig. 1). Either composite textile materials as coated or uncoated fabrics with synthetically manufactured and processed fibres, which are described as technical textiles; or fluorocarbon polymers as extruded films, which are described as technical plastics. The linear bearing elements can be tension members of steel wire rope, textile webbing or extruded keder cords. The above-named materials are normally processed into working material using industrial production processes like casting, forming and joining.

The behaviour of a material when used as a load-bearing element plays an essential role in the successful implementation of a wide-span surface structure. The important properties for the mechanical behaviour of a load-bearing element are the dimensions, material properties and composition. This leads to the conclusion that knowledge of the manufacturing process and material properties of the material to be used is a precondition for the production of a design with convincing layout and functionality.

The layout of the contents of the current chapter
This chapter is laid out according to the material of a flexible load-bearing element. The categories are divided according to the geometry and function of load-bearing building components. This division is intended to explain the complex interactions between production, joining and their influencing parameters on the mechanical behaviour of the material.

Starting with the composition and internal structure, the materials mostly used for the construction of wide-span surface structures are presented and their method of production explained. Details are given of the various states in the various manufacturing processes as well as the reciprocal effects of the mechanical properties between manufacture and erection.

To explain the complex material behaviour of the flexible surface element, the mechanical behaviour relevant for the characterisation of deformation of the commonly used coated fabrics is explained systematically under the effects of loading, time and temperature.

One design stage of the greatest importance for the practical implementation on site is the patterning, that is the calculation of the required shapes for pre-cutting. The constraints on the mechanics of the flexible surface element resulting from the shape, the load-bearing behaviour and the assembly are closely related to and are reciprocally affected by the type of pattern. Additionally, the topological, static, production and assembly criteria for the patterning of flexible planar elements are described and investigated for their buildability.

The various methods of transferring the forces into the membrane material require corresponding detailing of the edges and corners as well as special methods of fixing to the rigid construction elements in order to stabilise the membrane surface in the required form. The most important parameters and design principles for the geometry and type of the edging are also discussed, as is their effect on the load-bearing behaviour of the membrane surface. In addition to this, connection details to neighbouring elements at the edge and corners of partial surfaces and jointing techniques at assembly joints are described and illustrated with examples.

2.2 Structural composition and manufacture

2.2.1 Linear load-bearing elements

Membrane surfaces have to be stabilised in their location by closed edging. The tension forces acting in the plane of the membrane are transferred into adjacent elements, where they can be carried to the foundation. Flexible linear tension members can be installed as an edge detail to the surface, either to reinforce the edge or to be solely responsible for conducting the edge loads tangential to the edge curve of the membrane surface. This is then called a flexible edge. The axial dimension of such an inserted tension member is many times larger than its other dimensions. They are only stiff in the axial direction and are loaded uniformly over their cross-section and exclusively in tension. For wide-span structures, they are curved in two dimensions, or in special cases in three dimensions. With the appropriate geometry and detailing, deformation in the plane of the membrane can be partially resisted by the deformation of these flexible edge elements. These edge elements normally consist of spiral steel wire ropes and band-shaped textile webbing belts.

To reinforce the edge of a textile surface, this can also be constructed rigid. This is called a rigid edge. Cord-shaped plastic keders are used in such edge details for load transfer to the rigid metal fittings.

The following section gives an overview of the composition and the types of linear structural elements, which are used in wide-span planar structures, with a description of the industrial processes for their manufacture. Construction details for anchoring to adjacent construction components are also discussed.

2.2.1.1 Wire ropes

The wire rope is a machine element subject to a range of loadings.[1] It consists of aligned and stretched wires and can support tension forces constantly or dynamically.[2]

The highly flexible tension members used in materials handling, which run over rollers, sheaves or drums, are described as ***running ropes***. Running ropes would mostly only be used for convertible wide-span surface structures; these are not described in detail here. Cables or bundled wire ropes, as are used in bridge building, are not considered here either.

Tension members made of steel wires, which are used in construction to support static forces, are called ***static ropes.*** They can be use in two-dimensional and in three-dimensional tension systems. Wires with tension strength of up to about 1,770 N/mm² are used for standing ropes.[3] This is achieved through thermal and mechanical treatment during production. In addition to the high strengths available, the use of wire ropes has major advantages above all during erection. Efficient construction is possible under practically all climatic conditions.

In structures under tension loading, where at least a part of the loading is supported through the deflection of tension members, static wire ropes and bundles of wire ropes fulfil important roles as single structural elements and as part of systems. As tension elements for edges, stay ropes and supporting ropes, they must have the required construction and mechanical properties to fulfil the specification. Rope wires already undergo considerable loading during manufacture, a combination of tension, bending, torsion and compression. In the structure, static ropes have to show high strain stiffness for many decades, support any forces arising from deflection or shear compression and be sufficiently protected against corrosion. These requirements have led in the course of ongoing technical development to various constructional details, which are summarised and described below.

The already mentioned special research project 64 "Wide-span Lightweight Structures" made an essential contribution to research into the use of wire ropes in building structures in various project areas. The results from the special research project have been used repeatedly as the basis for German standards and guidelines.

Construction of ropes

Ropes consist essentially of wires, cores and strands.

The insert (core) lies in the centre of the strands and ropes and serves to bed and support the wires, strands or ropes. The two types are fibre inserts and steel inserts. Static ropes mostly have steel inserts, which ensure stiff bonding of the wires.[4]

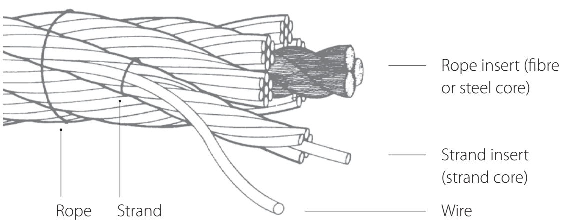

Fig. 2: Construction of a rope

The steel wire, the smallest component of the rope (dia. 0.5 – 7.0 mm) is mostly made of unalloyed carbon steel. The starting material for rope wires is rolled wire, which can be hardened by various shaping processes. These processes are cold drawing, die drawing or roll drawing. Controlled heat treatment before or between the individual drawing processes and subsequent quenching (patenting) produce higher strengths. The combination of both manufacturing processes and the intended surface quality considerably improves the quality of the rope wire.

Strands are spun helically around an insert (strand core) and consist of one or more layers of wires. Strand cores consist either of one wire (core wire) or of spun yarn.

The construction of the strands has a great influence on the properties of a rope. Strands can be categorised according

Fig. 3: Wire sections

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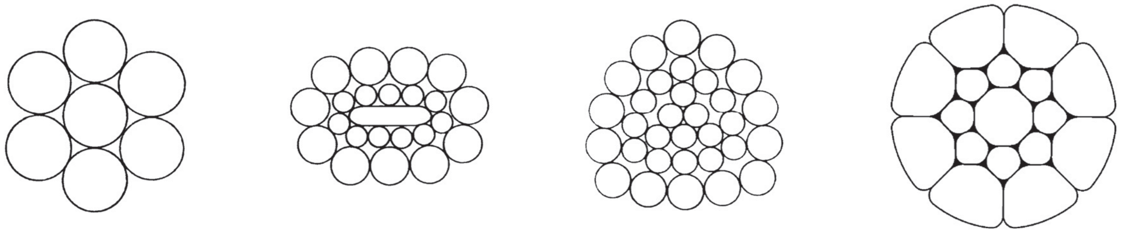
[1] *Stauske, D. (1990)*

[2] *Schefer, M. (1994)*

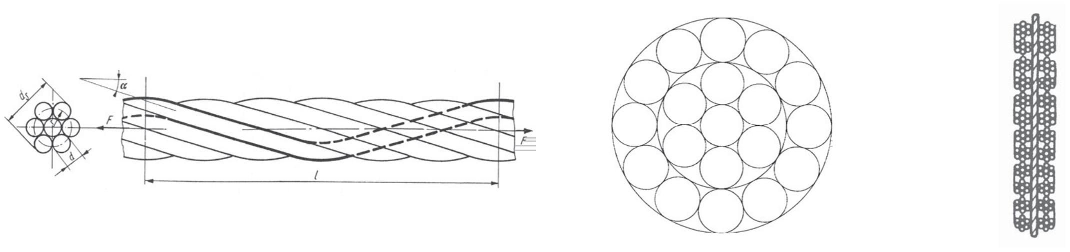
[3] *Stauske, D. (2000)*

[4] *Gabriel, K. (1990)*



round flat triangular compacted

Fig. 4: Types of strand



Basic layout of a round rope round rope flat rope

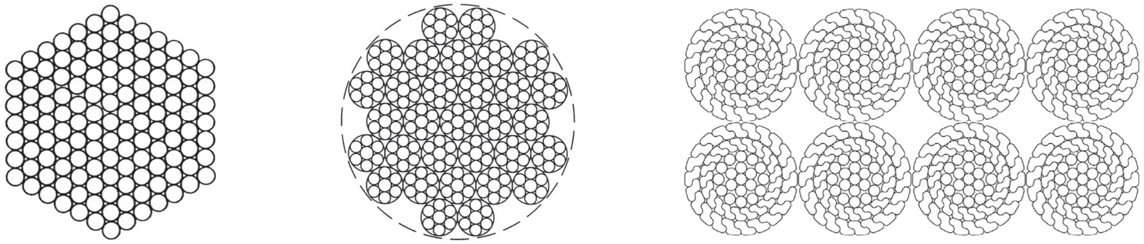
Fig. 5: Types of rope

to their shape into round strands, shaped strands and compacted strands.

Ropes consist of one or more layers of wires or strands, which are spun helically round a core. They can be categorised according to their shape into round ropes and flat ropes.[1]

Single parallel members of wires or strands, combined to form larger units, are called ***bundles.*** These can be categorised into parallel wire bundles and parallel strand bundles (strand bundles). Bundles are mainly used as suspension cables of bridges. On the construction site, parallel wire bundles are bound at intervals with soft iron round wire or clamped with clamps to hold the bundle together.

Parallel single members as ropes or bundles, combined to form larger units, can also be called ***cables*** (rope bundles). Cables are mostly used in building for larger spans, for example the perimeter rope bundle of a spoked wheel roof construction.



Parallel wire bundle Parallel strand bundle Cable as rope bundle

Fig. 6: Wire, strand and rope bundle

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[1] *Definitions according to the Austrian standard ÖNORM M 9500*

Lay type and direction

The method of rope making is also called spinning. Ropes are categorised according to the lay direction of the strands and the lay direction of the rope.

The ***lay direction*** of the strands (z or s) is the direction of the helical line of the outer wires with reference to the axial axis of the strand. The lay direction of the rope (Z or S) is the direction of the helical line of the strands, the outer wires in a spiral rope or the component parts of a cable-laid rope, related to the axial axis of the rope.[1] The terms s, S, z and Z are illustrated in Fig. 7.

The ***type of lay*** describes the lay direction of the wires in the strand and of the strands in the rope. Stranded ropes can be spun with regular lay (sZ or zS), where the wires in the strands have the opposite lay direction to the strands in the rope, or Lang's lay (zZ or sS), with the strand wires having the same lay direction as the strands in the rope.

Ropes with Lang's lay are exceptionally hardwearing and more flexible than regular laid ropes. Ropes with regular lay have less tendency to twist and spring, are less susceptible to damage by dirt and deformation and less flexible than ropes with Lang's lay.

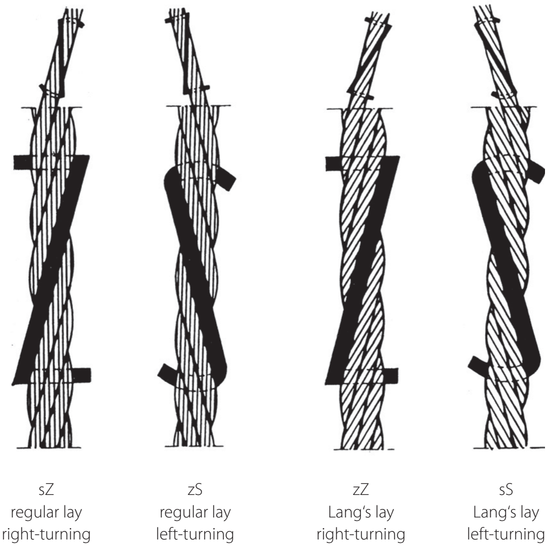
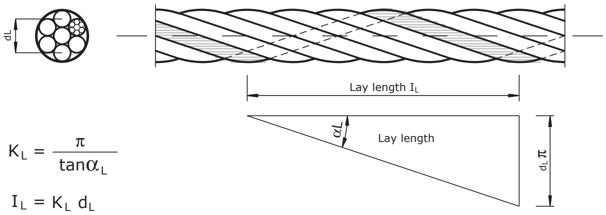

sZ regular lay right-turning
zS regular lay left-turning
zZ Lang's lay right-turning
sS Lang's lay left-turning

Fig. 7: Lay type and direction

Lay length and lay angle

The ***Lay length*** describes the length of wire in one rotation about the rope axis. There is the following relationship between the lay l_L and the lay angle α_L:



$$K_L = \frac{\pi}{\tan\alpha_L}$$

$$I_L = K_L\, d_L$$

Fig. 8: Lay angle and lay

The lay number K_L is the quotient of the lay length and the diameter measured to the strand centres.

Types of rope

The tension members of cold-drawn high-strength steel, which are used in the construction of lightweight surface structures, are divided into spiral ropes and stranded ropes. The following types are mostly used:

Open spiral strands (OSS) consist of spirally spun round wires with almost identical diameters, which are spun round a core wire in many layers, usually spun in alternate directions. They have a medium density (proportion of steel area to the overall cross-section) and, dependant on wire diameter, a more or less uneven surface. Open spiral strand ropes are produced with up to 91 single wires. With a higher number of wires, the geometrical strength of the rope bonding is considerable reduced, and fully locked ropes are better. Open spiral strands are suitable for light to medium forces and are frequently used for edge ropes in membrane construction and as supporting ropes or in rope truss construction.

Half-locked spiral strands (HVS) have a half-locked layer of round and waisted wires. They were a precursor of the fully locked ropes and are seldom used for static ropes nowadays.

Fully locked spiral strands (VVS) consist of a core of round wires and one or more layers of shaped wires. The mostly Z-shaped form of the external wires results in a dense locked surface, resulting in good preconditions for corrosion protection measures. They have an extremely flat external contour to protect the inside of the rope from water ingress or aggressive media and also prevent leaking of the rope filling. The external arrangement of shaped wires also improves the mechanical protection. The higher metal cross-section permits the support of higher loads with low dead weight.

Because of their construction, they can be manufactured practically non-rotating. For permanent structures, they are used mainly as carrier and tensioning ropes for lightweight structures or as stay ropes for masts.[2]

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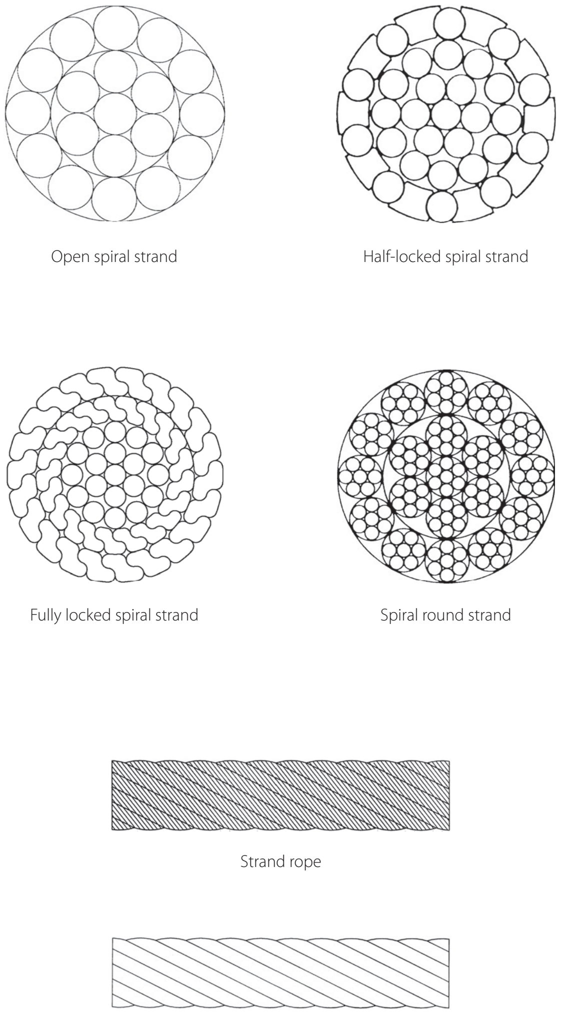
[1] *Definition according to European Standard EN 12385-2*

[2] *Westerhoff, D. (1989)*



Open spiral strand

Half-locked spiral strand

Fully locked spiral strand

Spiral round strand

Strand rope

Spiral rope (strand)

Fig. 9: Types of wire rope

Round spiral strand ropes are formed of many strands, which are spun spirally in regular or Lang's lay in one or more layers around an insert. Strands running next to each other can have opposing lay directions. Round spiral ropes are mostly used when more flexible ropes are required. They have, however, a relatively low density and a fissured surface, which makes them easy to handle, but they are more susceptible to corrosion and wear than spiral ropes.

Round spiral strand ropes are often used on account of their easy handling as bracing, stay wires and low-level truss tension members for temporary buildings, or as handrail ropes in stairs, balconies and bridge parapets.

Rope inserts: For static wire ropes, steel inserts are normally used. Running ropes normally have fibre inserts arranged between the individual layers, in order to prevent the strands sliding against each other.[1]

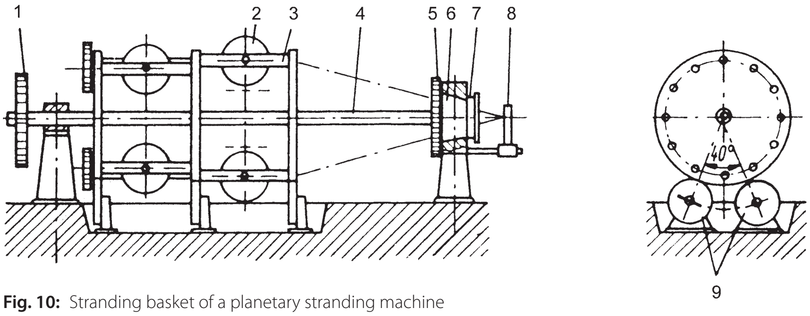
Manufacture of static ropes and bundles

Metal tension members must have high strain stiffness, must not come apart at the defection location and have to be protected against corrosion. They must therefore be manufactured with as high a packing density as possible.

The manufacture of wire ropes takes place in stages. The individual processes range from unwinding the wire through stranding the wires and spinning the strands to the preparation of the final product for delivery. This requires great care, production controls and extensive quality assurance measures art every stage of production.

Spinning process and type

Ropes are made by twisting wires in layers around a core wire. This process is called spinning. The process of ***spinning*** is done with a strander, where the wires are formed to a spiral. According to the type of rope, rope cross-section and required production speed, this can be done using prefabricat-



1 main drive
2 bobbin
3 stranding spider
4 hollow spindle
5 drive for pull-out
6 stranding head
7 separating plate
8 closing die
9 support rollers

Fig. 10: Stranding basket of a planetary stranding machine

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[1] Gabriel, K. (1990)