TEXTILE ROOFS 2017
THE TWENTY-SECOND INTERNATIONAL WORKSHOP, BERLIN

Textile Roofs 2017, the twenty-second International Workshop on the Design and Practical Realisation of Architectural Membranes, took place on 15–17 May, 2017 at the Archenhold Observatory Berlin, and was chaired by Prof. Dr.-Ing. Rosemarie Wagner (Karlsruhe Institute of Technology, KIT) and Dr.-Ing. Bernd Stary (Berlin Academy of Architectural Membrane Structures, AcaMem). It was attended by 83 participants from 13 countries covering two continents. Once again, the attendance demonstrated the success of the event, which has become firmly established since it was first held in 1995.

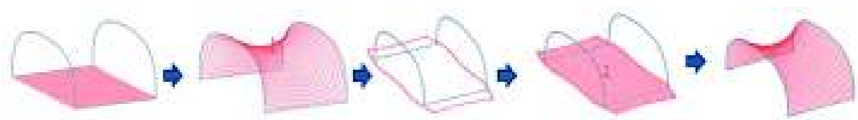


Figure 1. Boundary mapping in the form finding procedure leads to optimal stressed membrane structures, a useful capability for equidistant cable meshes.

Computational modelling of lightweight structures

Dieter Ströbel, technet GmbH.
http://technet-gmbh.de/index.php?id=74&L=1

A complete overview of the software product "Easy" by "technet GmbH" was presented by Dieter Ströbel, including the company profile and the features of the system for the analytical form finding, statical analysis and cutting pattern generation of membranes together with their fundamentals. He also highlighted different possibilities such as the boundary mapping in the form finding procedure (Fig. 1) and the capability of analyzing different behaviours under loads with different material directions of warp and weft. Regarding applications, he highlighted the optimization of textile halls with precise 3D models, considering the interaction between the steel or aluminium frame and the membrane.
In summary, D.Ströbel formulated that computer models collect information from many experts and have to be correct, precise, complete, generated in a fast way and used for mass production if necessary. He finally announced the "PreDesigner" free software for modelling.

The lightweight design approach

Jürgen Hennicke, IL - University of Stuttgart & Danube University, Krems.

Jürgen Hennicke began his lecture emphasizing that lightweight structures are not new. Slides included the Bedouin tent, the retractable roof of the Pompeii amphitheatre, radiolarian, spider webs, grid shells and bubbles. They satisfy the same physical and natural laws as our contemporary designs, that are much more rough and primitive. He provided different examples

Figure 2. Trees collecting forces and bringing them down at the Sagrada Familia basilica, Barcelona 2008.

of simple structural concepts such as the Stonehenge standing stones and lintels (3.000 ~ 2.000 BC), the trussed constructions that minimize the flexural-resistant structures and the tree-shaped supports that collect forces and bring them down (Fig. 2).
The possibilities of grid shells and inflated tubes were also illustrated, mentioning particularly the Mannheim Multipurpose Hall and Restaurant at the Federal Garden Exhibition 1975 designed by C.Mutschler with F.Otto and O.Arup, in danger of extinction. Believe it or not, the city council of Mannheim decided in June 2016 by a large majority the demolition of the multihall if it should not be possible to collect a significant amount by end of 2017.
The conclusion referred to lightweight and membrane structures as everyday architecture which can satisfy all our needs as living beings in a built environment, increasing our physical, mental and social quality of life in harmony with the natural environment as a reconciliation between man and nature and with himself.

Figure 3. Ingenhoven & Partner, Architects, 2002: Kapuzinercarrée, Aachen. The Texlon® ETFE system accommodates a much larger range of structural movement than conventional cladding systems so that the overall structural weight is reduced by decreasing the stiffness.

Ageing behaviour of ETFE foils

Carl Maywald, Vector Foiltec.
http://www.vector-foiltec.com/

Stability of ETFE was the main topic and conclusion of Carl Maywald's lecture. First application was the 1982 Burger's Zoo in Arnhem enlarged by the Mangrove Hall 35 years later. He mentioned a series of applications, including the Desert Hall (Burger's Zoo, Arnheim 1982), where the size of the cushions was limited because of road transportation limitations, the Chelsea Hospital (London 1990), where ETFE was adopted because it was cheaper than glass, and the Aachen Kapuzinergraben 2002, where the historic façade was protected without need of columns, saving steel compared to the glazed solution (Fig. 3).
He listed ETFE main characteristics as high transparency, UV stability, flexibility, low weight, long lifetime, self cleaning, outstanding fire performance, recyclable, high chemical resistant and provides acoustic comfort. Regarding longevity, he showed several tests that reveal extraordinary stability and no chemical degradation under environmental conditions.
He finally left a couple of lapidary sentences for posterity: "Innovation comes from the industry" and "Let's turn innovation into education!"

Detaling

Josep Llorens, School of Architecture, Barcelona. http://sites.upc.es/~www-ca1/cat/recerca/tensilestruc/portada.html

J. Llorens' presentation was a kind of academic master class about detailing textile roofs and structural membranes emphasizing that detailing is a significant part of the design process. It is critical to the overall conceptualization and the resulting structure, because details are not only derived from the general idea, but end up defining the result. They are essential to the requirements of the entire structure, including behaviour, materials, geometry, installation, durability, maintenance and visual expression.

A typology of details for fabric structures in architecture was presented. It included seams, edges, corners, high and low points, ridges and valleys, cables, fittings, and anchors. Many examples were shown and discussed keeping in mind that:

a) Details cannot be directly transplanted from a repertoire, since they have to be adapted to the requirements of each case. Solutions are successful when they meet the specific requirements of every application. Changing the requirements means that the design must be changed.

b) Detailing has to be taken into account from the beginning of the design process. It is not an independent step, because it is also essential to the general requirements of the whole structure. Details are not an afterthought.

In addition, the professor presented a data base to facilitate the coordination between the fittings that converge usually in most connections, which can be visited at the above address.

Fifty years of relaxation

David Wakefield, Tensys Limited, Bath. http://www.tensys.com/

David Wakefield. another veteran rider, summarized his extensive experience in membrane engineering including form finding, load analysis, patterning, dynamic fluid flow simulation, hydrostatic loading, ponding assessment, installation, failure propagation analysis, and supervision. The fields of applications have not been limited to mechanically prestressed membranes. They also include pneumatic cells, kites, lighter than air systems and balloons illustrated by a wealth of examples (Fig. 4).

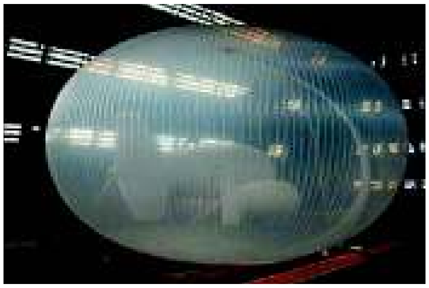


Figure 4. NASA super pressure balloon, Tensys.

Figure 5. Seybold biogas pneumatically tensioned storage system.

Membrane biogas storage systems

Christopher Seybold, H.Seybold GmbH & Co. KG, Düren. http://www.seybold-dueren.de/

The number of biogas plants in Germany has grown from 3.711 in 2007 to 8.075 in 2016 and the installed electrical power from 1,3 to 4,1GW. The biogas is stored in cylindrical enclosures roofed by pneumatically or mechanically tensioned structures, which have opened a new field of application to the structural membranes. The pneumatically tensioned storage system consists of a double layered spherical cushion that can be flat (1.000m^2), quarter ball (2.300m^2) or hemisphere (5.800m$^{2)}$ with air pressures ranging from 2,5 to 4,5mbar (Fig. 5).

Two approaches were presented for the cutting pattern: radial or parallel. The radial cut mobilizes stress concentration in the centre. It is used for hemispheres because they have 45% to 48% height/diameter ratios. The almost parallel cut is suited for shapes up to a height of 30% of the tank diameter. It does not concentrate the stress in the middle and its production is more cost-effective.

A research programme has been launched by Seybold, KIT, technet and Wacker Ingenieure to study the interactions between external weather conditions and internal plant operating parameters for the safe and adequate calculation, dimensioning and manufacturing of biogas storage systems.

Tensile Structures: welding and structural integrity

Wojciech Staniszewski, FIAB, Sp.z o.o.Sp.k. http://www.FIABmachines.com

Professional building machines were presented together with a live demonstration by Wojciech Staniszewski in the garden and auditorium of the Archenhold Observatory, Berlin (Fig. 6).

One of the most outstanding works welded with the machinery presented during this session was Leviathan, an inflated sculpture by Anish Kapoor at Grand Palais, Paris: https://www.youtube.com/watch?v=12Ni0c4D27Y

Figure 6. FIAB welding machine live demonstration at Textile Roofs 2017.

World Cup Membrane Structures.

Martin Glass, gmp Architekten. http://www.gmp-architekten.de

Martin Glass began by recalling the general philosophy of gmp Architekten designs summarized by simplicity, clear solutions, variety, uniformity, distinctiveness and structural order avoiding monotony. He profusely illustrated these principles and highlighted two outstanding examples: the Al Bayt Stadium in Al Khor City, Qatar and the new retractable roof for the Verona's Roman arena.

The Al Bayt Stadium in Al Khor City, Qatar design is based on the Bayt Al Sha'ar, a black and white tent used traditionally by nomadic people in Qatar as a welcome symbol of hospitality for desert travelers (Fig.7). Changes of scale, materials and building solutions are noticeable, particularly the trussed steel structure and air conditioning.

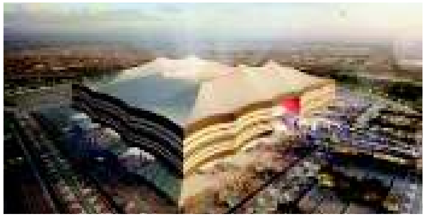


Figure 7. gmp Architeckten, 2022: Al Bayt Stadium, Al Khor City, Qatar.

The other example is a risky intervention on a historic building, the Verona Roman amphitheatre. An international competition was launched with demanding requirements. The controversial winner scheme is a 12.000m^2 foldable membrane sliding through a radial set of cables, hidden and stored beneath the compression ring, when not in use. The solution claims to be "a subtle intervention that will not take focus away from the architecture of the historical arena" (Fig. 8). But main unknowns are the compatibility between the structure required by such a roof and how its foundations should be executed without substantially affecting the existing building.

Figure 8. gmp & sbp, 2017: convertible roof over the Roman Amphitheatre, Verona.

Membrane structures in Russia

Vladimir Ermolov,
Moscow Institute of Architecture & Verteco.

The most comprehensive presentation of this edition of Textile Roofs was undoubtedly that of Vladimir Ermolov. A universe of membrane structures was shown starting from the antecedents found in ancient Russia icons and drawings. Before 1917, textile roofs were found in fairs, markets and circus tents. The outstanding case of early tensile structure engineer and architect was Vladimir Shukhov (1853-1939) for his steel tents at the 1896 All-Russia industrial and art Exhibition in Nizhny Novgorod (Fig. 9). During the last century there were no significant advances until 1991 with the reformation engaged by the Perestroika. It caused everyone to start their own firm. Starting from this period, the lecturer presented some of the works done by several companies and finally focused on his realizations with Verteco Co Ltd, Balashikha (Fig. 10).

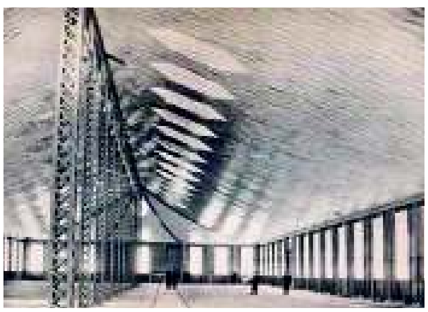


Figure 9. Vladimir Shukhov, 1896: Rectangular Pavilion at the All-Russian Exhibition, Nizhny Novgorod.

Figure 10. Vladimir Ermolov: Membrane structure in Russia made by Verteco.

Large-sized dome-shaped constructions.

Andrej Moroz, Lommeta, Novosibirsk.
http://www.lommeta.com/

Lommeta presents itself as a company devoted to unique challenges and innovative solutions that disregards the possibility of using the word "impossible". The presentation of Andrej Moroz was about to confirm such a daring assertion. Large-sized domes have been designed to cover neither more nor less than open pit mines to turn them into conditioned cities, recovering the 1960 idea of Buckminster Fuller for a two-mile-wide dome over Manhattan to save energy and make a better city. More realistic was the "Allianz Arena" style façade made of multi-layered ETFE cushions framed by tubular sections. And even more realistic was the automated solution for storage of equipment, vehicles and aircraft: a lightweight and robust aluminum frame lined with a high-strength architectural PVC material (Fig. 11).

Figure 11. Automated solution for storage by Lommeta.

Lightweight Membrane Structures postgraduate MEng programme

Robert Roithmayr, formfinder GmbH.
https://www.formfinder.at/

Robert Roithmayr presented the "Lightweight Membrane Structures" postgraduate MEng programme 2017 to be held at the Donau University Krems, for individuals working in the field of lightweight membrane structures and related fields, ranging from design and architecture, engineering, business administration, manufacturing, installation, textile industry and related sciences. The curriculum of the course includes guiding principles, architecture and engineering, tools for design, materials, details, management, manufacturing, installation and master's thesis. It is supported by "formfinder", the computer assisted design of Lightweight Membrane Structures, and its data bases. For the reasonable amount of €16.900, participants will join the professional team of experts and practitioners led by R.Blum, J.Hennicke, H.Dürr, and R.Roithmayr himself. They will be prepared for a rapidly changing and challenging future with new skills and experience. More information at: www.donau-uni.ac.at/dbu/membrane

Natural light, acoustic and thermal comfort in membrane structures

Farid Sahnoune, Serge Ferrari S.A.S.
www.sergeferrari.com

Farid Sahnoune addressed four challenges for membranes in architecture: durability, acoustics, thermal insulation and natural light. Regarding the durability, he presented the performance of the highly durable and recyclable "Précontraint TX30", a new generation of composite materials to match the requirements of the most demanding projects. This technology combines a Crosslink PVDF surface treatment highly resistant to photo-oxidation, a 30 year PVC coating formula engineered to resist erosion for more than 30 years and an outstanding dimensional stability thanks to the Précontraint technology. Accelerated ageing has been measured and correlated with monitored natural ageing.

Concerning the acoustic comfort, he introduced Batyline Aw with its calibrated micro-texture that ensures sound absorption, highly uniform acoustic behaviour and significant reduction in reverberation time. It can be adapted to slopes, curves, and complex shapes fulfilling the comfort requirements of buildings receiving the public. Its most outstanding application is the acoustic improvement of swimming pools, restaurants, sport halls, ice rings and the like absorbing, on average, 65% of the noise without the need for other absorbent materials such as mineral wool or plastic foam (Fig. 12).

Figure 12. Batyline Aw and Silcord swimming-pool tensioned ceiling.

Testing

Rosemarie Wagner
Karlsruhe Institute of Technology.
https://www.kit.edu

Professor Rosemarie Wagner started her lecture commenting on fundamental equations for numerical static and dynamic simulations (Fig. 13). She addressed then the uniaxial and biaxial testing of textile membranes exploring the effects of coating, directions of warp and weft, load speed, load ratios, cyclic loading, compensation values, creep, material constants, damping and fatigue to obtain estimations applicable to the numerical analysis. She finally presented the current research on folding and inflating membranes for tanks.

Figure 13. Dynamic simulation by J.Bender, Karlsruhe Institute of Technology.

TransProof. New opportunities for weather protection

Tobias Raithel, ETTLIN, Ettlingen.
http://www.ettlin-smartmaterials.de/produktlinien/transproof/

Since 2008 ETTLIN produces innovation products for application areas with a high change potential such as smart materials for lighting, electronics and architecture. The lecture was dedicated to the new development TransProof, a special fabric for outdoor shading presented by R.Wagner at textile Roofs 2016. T.Raithel introduced the advisable properties of textile shading systems as: good shading, low or no air permeability, no transparency, weather protection and waterrepellence. The new material TransProof adds to them protection against moisture and rain, good sight and cooling shadow without heat accumulation. The structure of TransProof is characterized by the grid of the fabric with narrow and elongated adjustable openings (Fig. 14), black colour (or customized from 2.000m^2), water-repellent, good transparency and air permeable. There are three independent thread systems with strength and strain properties adjustable in warp and weft directions with low deformations due to the straight yarns (Fig. 15).

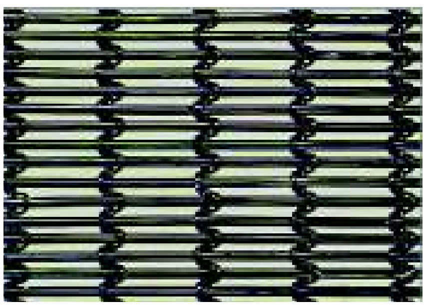


Figure 14. Structure of TransProof: a fabric with narrow and elongated openings.

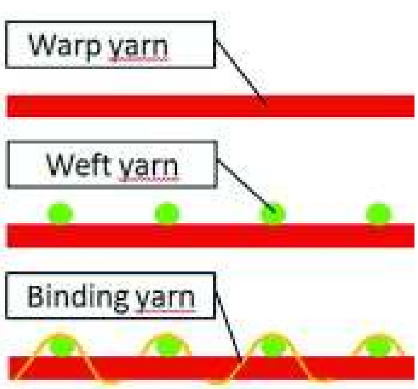


Figure 15. Three independent thread systems of TransProof.

Its suitability as a prestressed and curved textile membrane for outdoor shading has been thoroughly tested at the Karlsruhe Institute of Technology. The parameters for the load capacity, use, assembly and fixing have also been determined concluding that the fabric is quite suitable for the textile membrane construction. However, in designing the construction, the properties of the fabric must be considered and the assembly and fixing technology of the textile fabric may be performed with the classical procedures such as melting and sewing.
Finally, further development of TransProof was envisaged consisting of customizing the tightness and porosity by means of an adjustable special water-repellent finish. Thus, the respective properties such as shading, air permeability, transparency and water-repellence can be adjusted in each direction.

Wind membrane interaction

Alexander Michalski, str.ucture GmbH, Stuttgart.
http://www.str-ucture.com

After a philosophical approach, Alexander Michalski presented a fluid-structure-interaction simulation suitable for highly elastic membrane structures, such as applications where the structural response of wide span membrane structures is affected by added mass and damping effects of the surrounding air. This methodology has been developed by str.ucture especially for lightweight structures and validated at a real-scale test of a 29m umbrella prototype in cooperation with SL.Rasch. Among other examples, he commented on the Norway pavilion for the Shanghai Expo supported by 15 tree elements made of laminated timber spanned by a PTFE membrane. The membrane covers an area of 2.500m² with a maximum span of 11m (Fig. 16).

Figure 16. Helen & Hard, 2010: Norway Powered by Nature pavilion, Shanghai.

Tensile structures in India, Abdul Sathar,

nospan Structures Pvt Ltd. Bangalore.
www.technospan.co.in

Before entering the membrane structures in India, Abdul Sathar introduced a short history of roofing systems in India with straws, coconut leaves and clay tiles (Fig. 17). Membrane structures were first implemented in India in automobiles and tents. Textile roofs started being executed in 2004. There were less than 2 or 3 companies until 2008. Today there are more than 150 companies but only 5 in grade A fully integrated. Most of the structures are designed without any engineering with prices that

Figure 17. Roofing system with straws, India.

start from €30 - €100 for the complete structure (?). Failures are common due to poor engineering and bad detailing aggravated by the stormy weather. Fortunately, the company Technospan, with a history of 18 years in the field of roofing structures in India, bought in 2007 the "Easy" suite of programmes and met Matti Orpana (Fig. 18).

Figure 18. Technospan, 2015: Infosys Chennai Amphitheatre.

Temporary structures / Circus tents

Rogier Houtman, Tentech BV, Utrecht.
http://tentech.nl

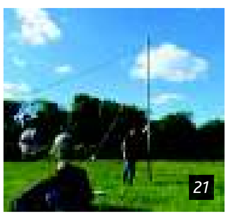
Rogier Houtman started showing some historic temporary structures, particularly hangars and circus tents as an introduction to his own works as a leader of Tentech, an innovative design and engineering consultancy founded in 1997 as a spin-off from the Faculty of Civil Engineering at Delft University of Technology specialized in lightweight structures. Their architects and engineers focus on membrane structures, temporary structures, complex geometries and the use of distinctive materials (Fig. 19). In addition to fabric, steel, wood and aluminum, Tentech explores the implementation of cardboard, synthetic materials and bamboo.

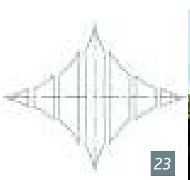
Figure 19. Special Tentech structure. Rose Garden. Tomorrowland 2016.

Joint participants' project

Stev Bringmann, 3dtex GmbH
http://www.3dtex.de

A four point sail was designed and erected by the participants led by Stev Bringmann and Jürgen Hennicke with the collaboration of Serge Ferrari, Karsten Daedler e.K., FIAB, Pfeifer Seil und Hebetechnik GmbH and technet GmbH. The entire manufacturing and installation process was carried out (Fig. 20 to 25). Phases involved were: "easy" modelling (form finding, structural analysis, and patterning), manufacture, foundations, assembly (masts, edge cables, corner plates, erection, and tensioning), and discussion.





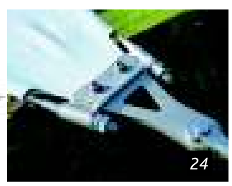


Figure 20. Form finding by physical modelling
Figure 21: Erection of masts.
Figure 22: Top of the mast detail.
Figure 23: Cutting patterns.
Figure 24: Corner.
Figure 25: The four point sail completed.

Textile Roofs 2018 will be held on 15-17 May 2018. Its format will be similar to that of TR 2017, with seminar-style lectures and hands-on activities. It will be preceded by the student seminar and sponsored by Serge Ferrari, Pfeifer and technet, and supported byTensiNet, KIT and gmp.
http://www.textile-roofs.de

NON-LINEAR ANALYSIS SOFTWARE FOR MEMBRANE STRUCTURES

Introduction

In the analysis of traditional building structures, we tend to use linear calculation. What does this mean? It means that results (reactions, stresses, displacements and deformations) are proportional to loads (actions).

So, if we get a 3mm deflection on a steel beam when we apply a load of 50kN, no need to re-calculate to find out what will be the deflection of the beam in the case we apply a load of 100kN. It will be 6mm. And if the load is -50kN, then the deflection will be -3mm. This is the basic concept of linear analysis.
But there are cases which behave differently. In these cases, we use a **non-linear analysis**, also called **second order analysis**. And tensile structures is one of them. There are various types of non-linearity. We are going to comment on the four most common ones.

1. Geometric nonlinearity: The movement of a structure is very large and balance depends on the final form which is unknown.
2. Mechanical non-linearity: Elements. Some parts of the structure "disappear" during the deformation. For example, cables that get shorter.
3. Mechanical non-linearity: Materials. Some materials behave differently as they deform.
4. Mechanical non-linearity: Loads. Some live loads (wind, snow…) change if the shape of the structure changes.

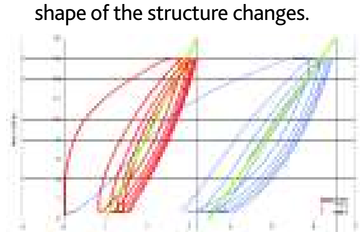


Figure 1. Example of a stress-strain graphic.

A simple example of previous point 3 can be found to obtain the modulus of elasticity of a typical membrane used in textile structures. Stress-strain graphics are complex and depend on many factors: type of biaxial load, load history, etc. (Fig. 1)
A more detailed information at:
http://www.wintess.com/modulo-de-elasticidad-de-una-membrana/

In all these cases, analysis is made in an iterative way. This means that after calculation balanced forces are checked. If the structure is not balanced we calculate again using unbalanced forces. And we must repeat this procedure as many times as necessary until we get balanced forces for the corresponding deformation. If forces are balanced quickly we say that the procedure has good convergence. On the contrary, if it takes a lot of iterations to get balanced forces or it never happens, the procedure has very bad convergence or no convergence.
Most of the times, a bad convergence means an unstable structure, at least under the loads applied. Of course it might be a problem of the procedure (software), but if so, bad convergence would appear in all cases.
(http://www.wintess.com/calculo-no-lineal/)

Integrated calculation

One of the advantages of non-linear analysis is that studying complex structures (formed by clearly differentiable parts) is possible in a single unit. In most of cases this results in a more economical structure and, mainly, in a more precise analysis.

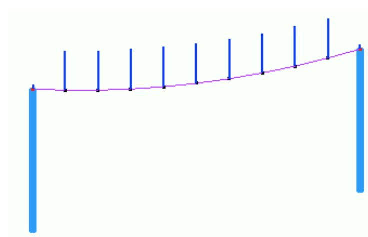


Figure 2. Analyse of cable structure - forces.

To illustrate this problem, we will perform the calculation of the following structure: Structure to be analysed: It's a 10m chord cable, 50cm sag, hanging from the top of two columns formed by steel tubes. A load of 5kN/m is applied on the cable, so there are 9 forces with a total of 45kN (Fig. 2).

Cable analysis is very easy, even manually. We get reactions at both ends: vertical (half the vertical loads) and horizontal depending as well from sag. With these

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