



PEF2603
Estruturas na Arquitetura III -
Sistemas Reticulados e Laminares



"Tensoestruturas"

("Estruturas Reticadas ", Redes de Cabos e Membranas)

(29/05/2017)

Professores

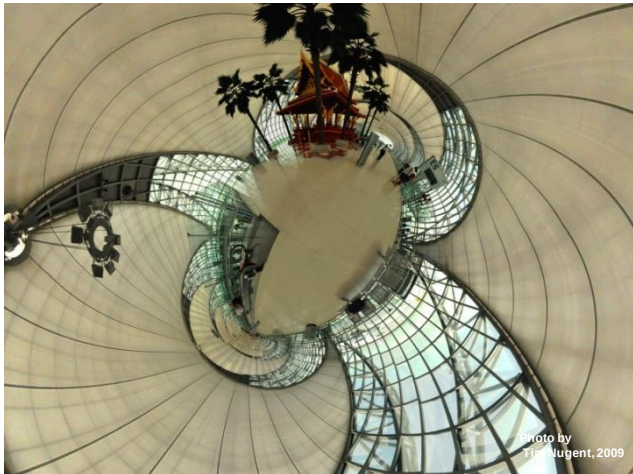
Ruy Marcelo O. Pauletti , Leila Cristina Meneghetti, Luís Bitencourt Jr.

1º Semestre 2017

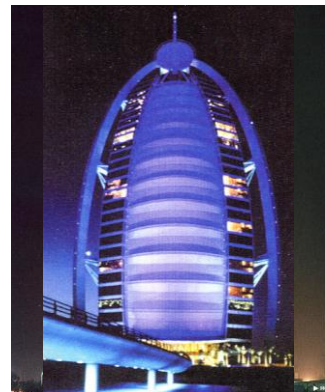


Estruturas luminosas ("Light structures, structures of light" – H. Berger)

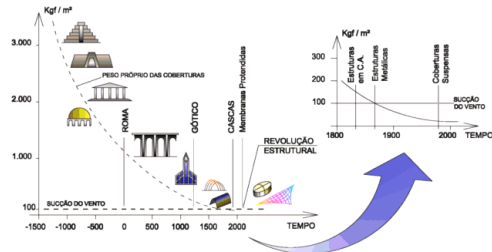




'Estruturas luminosas' ("Light structures, structures of light" – H. Berger)

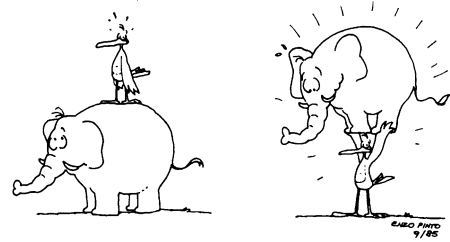


'Estruturas leves' - "Light structures"



Adaptado de R. Serger, "Structures nouvelles in architecture", in Cahiers du centre d'études architecturales, n. 1, 1967, p. 42.

'Estruturas leves' - "Light structures"



"Peso portante << Peso portado"
(Majowiecki, 1994)
Desenho de Enzo Pinto, Nápoles, 1985.

Estruturas Retesadas ("Tensoestruturas"):

aquelas que, para funcionarem a contento, dependem de seus elementos estarem retesados, e não frouxos.

Retesar (v.t.): entesar, tornar tenso ou retesado, esticar, enrijar; pôr a direito. **Retesado** (adj.): entesado, enrijado, tenso, hirt, bem teso. **Retesamento** (s.m.): ato ou efeito de retesar.

[Caldas-Aulete, 1956]

Adufe: s.m. (s. XV) Tipo de pandeiro quadrado, de origem árabe, feito de madeira leve, com **membranas retesadas** de ambos os lados, usado especialmente em festas folclóricas portuguesas e brasileiras"

Dicionário HOUAISS da Língua Portuguesa, Círculo de Leitores, Portugal, 2001

Estruturas retesadas são 'flexíveis' :



(a) uma estrutura 'rígida', como uma viga, não muda drasticamente de forma, ao variar do carregamento

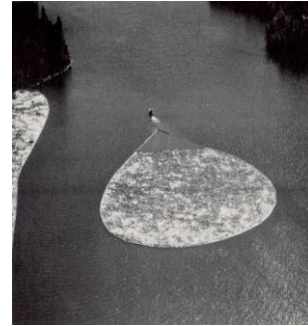
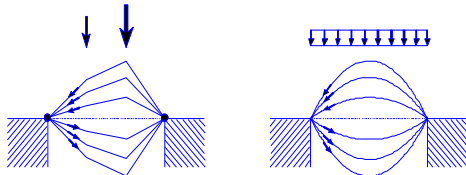


(b) uma estrutura 'flexível', como um cabo, muda drasticamente de forma, ao variar do carregamento

*Estruturas flexíveis devem se conformar às
formas funiculares:*

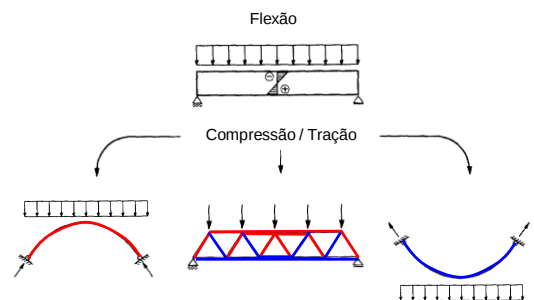
Aquelas que equilibram um conjunto de cargas, sem o surgimento de esforços de flexão.

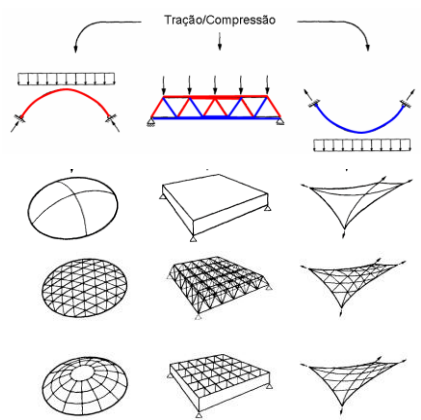
** Cabos e arcos:*



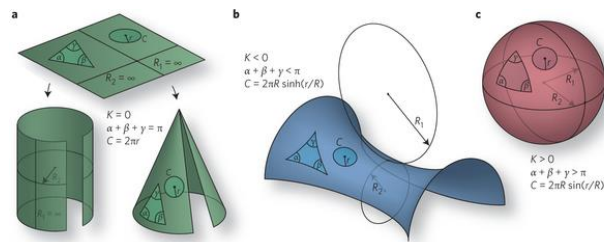
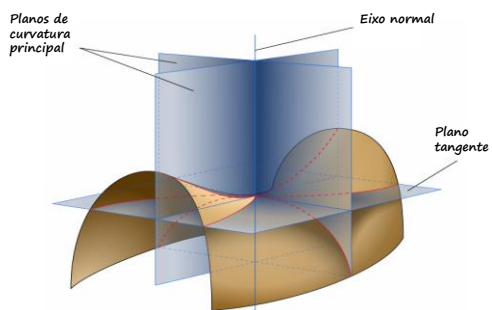
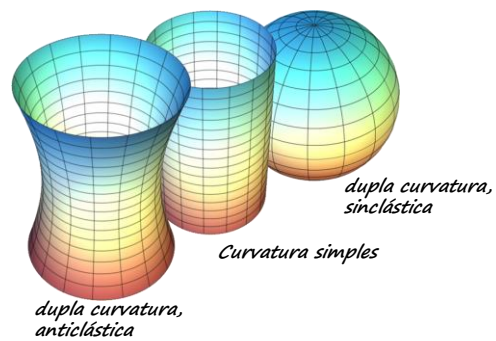
Estados de Solicitação Interna

- Barra curta em compressão:
- Barra esbelta em compressão: Flambagem!
- Barra esbelta em tração:
- Barra sujeita à flexão:





Superfícies de dupla curvatura:



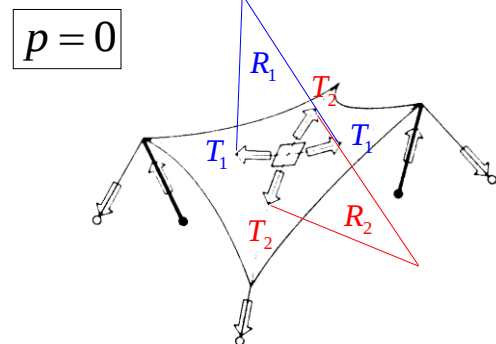
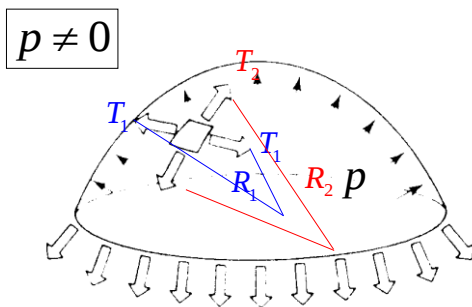


*Equação de Laplace-Young
(equação das bolhas de sabão, ou das membranas):*

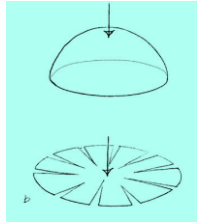
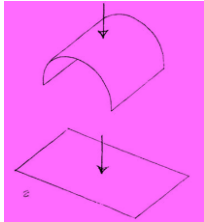
$$\frac{T_1}{R_1} + \frac{T_2}{R_2} = p$$

$$T_1 = t\sigma_1, \quad T_2 = t\sigma_2$$

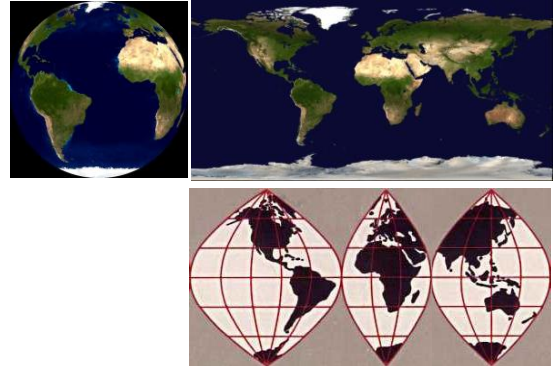
Units: $\left[\frac{\text{KN}}{\text{m}^2} \right]$ for p and $\left[\frac{\text{KN}}{\text{m}} \right]$ for T_1, T_2 .



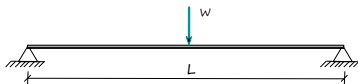
Planificação



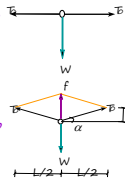
- a) Superfícies com uma curvatura apenas podem ser planificadas sem distorção;
- b) Superfícies de dupla curvatura sofrem distorção ao serem planificadas.



Rigidez Geométrica



- o equilíbrio na configuração indeformada é impossível:



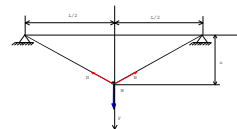
- o equilíbrio na configuração deformada é possível:

$$\left\{ \begin{array}{l} W = f = 2T_0 \sin \alpha \\ \text{pequenos deslocamentos:} \\ f \approx 2T_0 \tan \alpha = \frac{4T_0}{L} u \end{array} \right.$$

- Rigidez geométrica, em torno da configuração inicial:

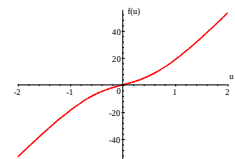
$$f = k_0 u = \left(\frac{4T_0}{L} \right) u$$

Corda entre dois apoios fixos, carregada transversalmente, numa posição deformada



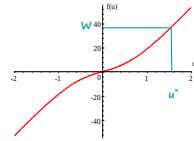
$$k = \frac{EA}{\ell_r} \quad \ell_r < L$$

$$f(u) = 4k \left(1 - \frac{\ell_r}{\sqrt{L^2 + 4u^2}} \right) u$$



Problema não-linear do equilíbrio:

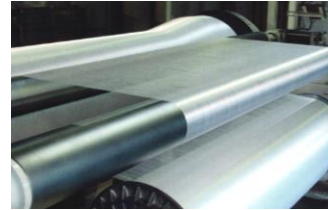
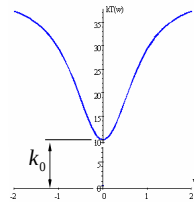
Dado W , u^* tal que
 achar
 $g(u^*) = f(u^*) - W = 0$



Método de Newton

$$u_{i+1} = u_i - \left(\frac{dg}{du} \Big|_{u_i} \right)^{-1} g(u_i)$$

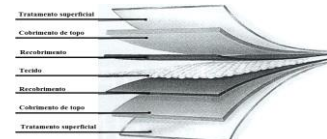
Rigidez tangente $k_i = \frac{dg}{du} \Big|_{u_i}$



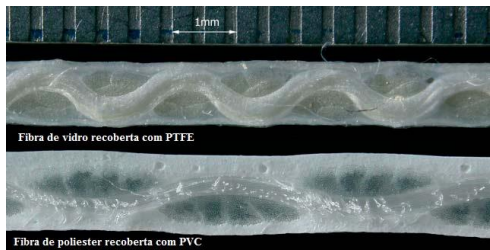
Production of a fiberglass fabric
 Pudenz (2004)



Covering with PTFE
 Pudenz (2004)

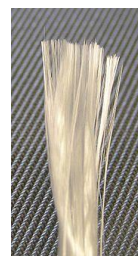


Diferentes camadas de um tecido técnico
 Blum et al (2004)

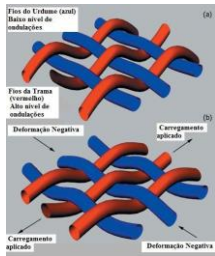


Cross-section of fiberglass and polyester fabrics
 (BRIDGENS et al, 2004).

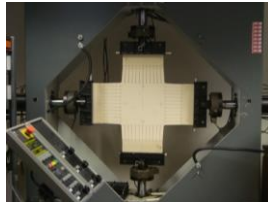
PTFE-covered fiberglass fabric (1969)
 DuPont, Birdair, Chemfab & Owens-Corning



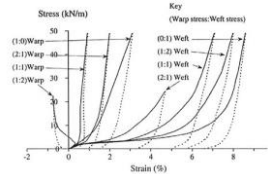
Neil Armstrong's Suit
 Apollo 11 Project (1969)



Crimp Interchange, Bridgens et al. (2004).

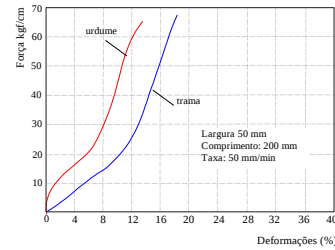


Biaxial test (Chivante, 2009)

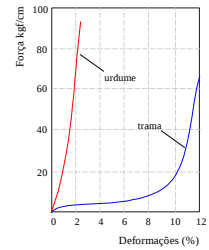


σ - ϵ curves for a PTFE-fiberglass fabric (warp = urdume; weft = trama), Kato et al (1999)

Ensaio uniaxiais (DIN 53354)



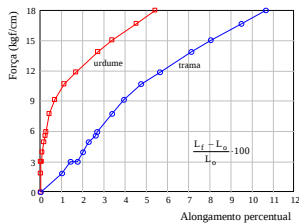
Poliéster revestidos com PVC^(a)



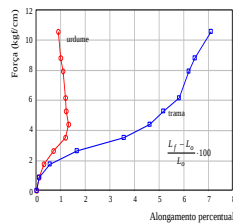
Fibra de vidro com PTFE^(b)

Curvas típicas de força-deformação de ensaio de tração uniaxial

Ensaio biaxiais



Poliéster pretensionado revestido com PVC



Fibra de vidro com PTFE

Curvas típicas de força-deformação de ensaio de tração biaxial

Classification of PTFE-covered fiber-glass fabrics

Type	G1	G2	G3	G4	G5	G6	G7
Tensile strength warp/weft (kN/m)	26/22	43/28	70/70	90/72	124/100	140/120	170/158
Filament diameter (micrometer)	9	6	3	6	3	3 or 6	3
Surface weight (g/m ²)	500	420	800	1 000	1 200	1 500	1 600
Trapezoidal tear warp/weft (N)			300/300	300/300	400/400	500/500	450/450



Fonte:

PVC-covered polyester fabrics

Type	1	2	3	4	5
Surface weight (g/m²)					
French design guide	720	1 000	1 200	1 400	2 000
WG Messe Frankfurt	800	900	1 050	1 300	1 450
Yarn linear density (dtex)					
French design guide					
WG Messe Frankfurt	1 100	1 100	1 670	1 670	2 200
Tensile strength warp/weft (kN/m)					
French design guide	60/60	84/80	110/104	120/130	160/170
WG Messe Frankfurt	60/60	88/79	115/102	149/128	196/166
Trapezoidal test warp/weft (N)					
French design guide					
WG Messe Frankfurt	310/350	520/580	800/950	1 100/1 400	1 600/1 800
Yarn number per cm warp/weft					
French design guide					
WG Messe Frankfurt	9/9	12/12	10.5/10.5	14/14	14/14

Comparison between different types of structural fabrics

	PVC coated polyester fabrics	PTFE coated glass fabrics	Silicone coated glass fabrics	PTFE coated PTFE fabrics
Tensile strength warp/weft (kN/m)	115/102	124/100	107/105	84/80
Fabric weight (g/m²)	1200 (type 3)	1200 (type G5)	1100	830
Trapezoidal tear warp/weft (N)	800/950	400/400	960/700	925/925
Visible light transmission (%)	10-15	10-20	< 80	19-38
Flexibility/crease recovery	high	low	high	high
Fire reaction	M2 (NFP 92 503) B1 (DIN 4102)	M1 (NFP 92 503) B1/A2 (DIN 4102)	A (ASTM E-108) no toxicity of smokes	
Cleaning	easier with top coats	self cleaning	self cleaning	self cleaning
How to make the seams	by high frequency	thermally	vulcanisation	stitching
Life span (years)	> 15-20	> 25	> 25	
Cost	low	high	high	

Comparison of uses and costs of tension structures according to different fabric types

Fabric type	Typical use	Cost comparison*
PTFE-coated fiberglass	Large scale permanent structures Class A ASTM E-108	\$75 – 100 per ft.²
Silicone-coated fiberglass	Large scale permanent structures Class A ASTM E-108	\$75 – 100 per ft.²
Vinyl-coated polyester	Temporary and permanent structures	\$50 – 75 per ft.²
Woven PTFE	(More pliable than standard PTFE) Retractable roofs, structures	\$85 – 125 per ft.²
ETFE	High transparency (97%) Atria, indoor parks, biospheres, skylight applications	\$100 – 125 per ft.²
HDPE (High Density Polyethylene)	Shade structures/systems	\$25 – 50 per ft.²
Laminates	Tents, awnings & canopies	\$35 – 50 per ft.²

*2008 dollars. Surface area X cost per ft² = Budget. Plan area (length X width) X Shape factor (H) = Surface area

Fabric Architecture 2009 Sourcebook



O Processo de Projeto das Estruturas retesadas

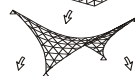
INTENÇÃO ARQUITETÔNICA:



PROJETO / ANÁLISE:

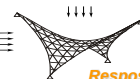


Forma inicial, inviável



Forma final, viável

Padronagem e panificação

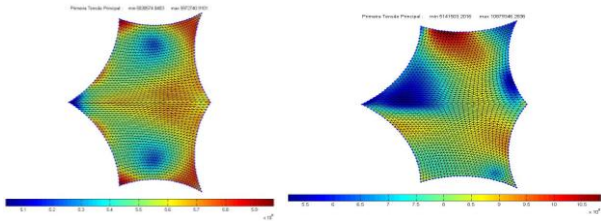
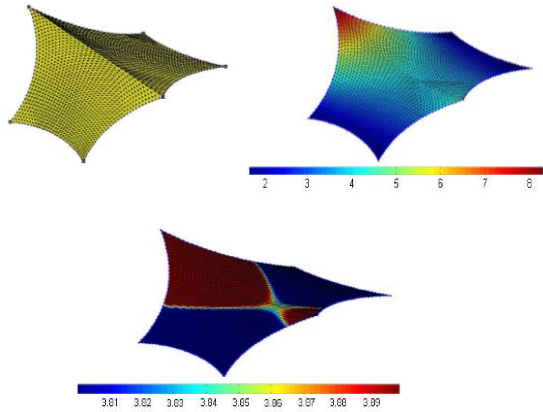


Resposta aos carregamentos

SOLUÇÃO DE PROJETO



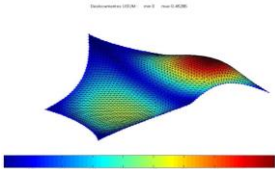
The membrane roof of the “Memorial dos Povos” of Belém do Pará



Maximum first principal stresses along the membrane (S1), for the prestress load case

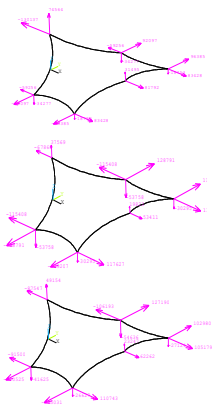
Maximum first principal stresses along the membrane (S1) for the Y-wind load case

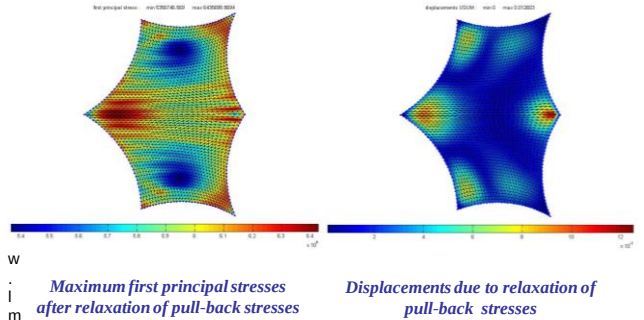
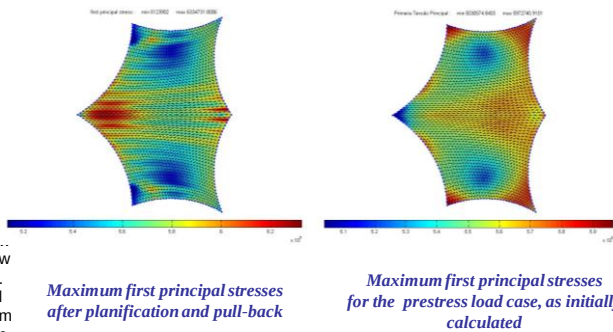
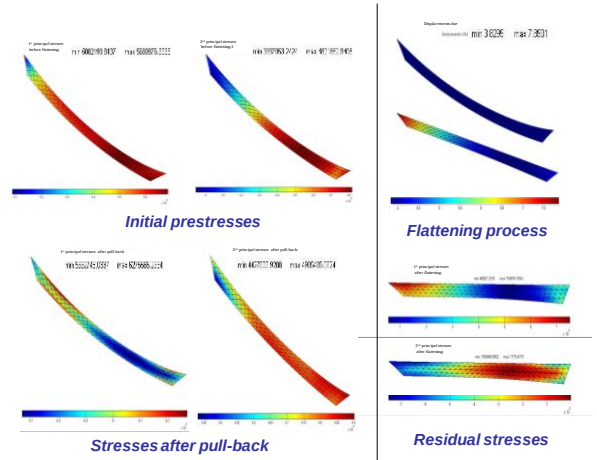
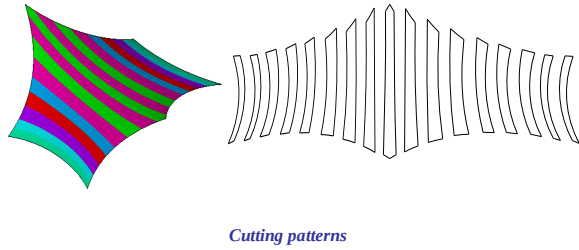
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displacement norms, for the Y-wind load case

Anchor reactions for prestressing and X and winds





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Cobertura em
Membrana Retesada
**Igreja Batista Central
Fortaleza
(2004)**

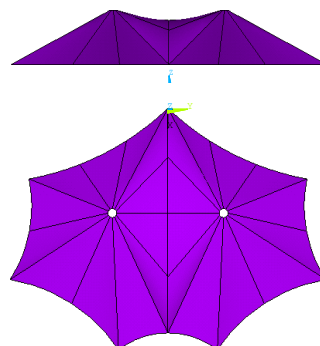


Concepção Arquitetônica:
Nasser Issa Arquitetos Associados

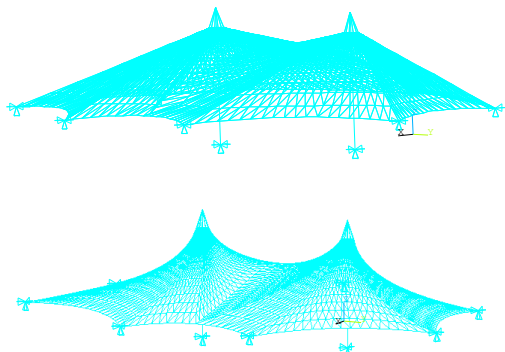
Projeto e Análise Estrutural da Membrana:
Ruy Marcelo Pauletti
Reyolando M.L.R.F. Brasil

Estrutura Metálica:
Paulo André Barroso

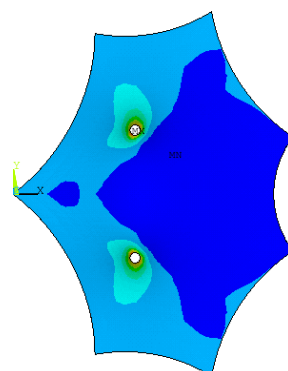
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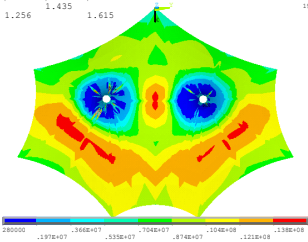
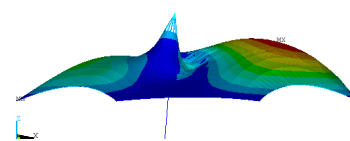
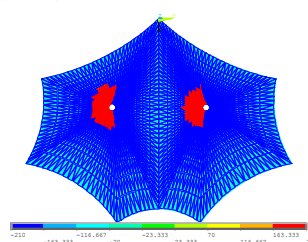
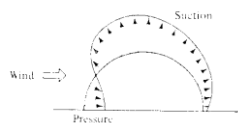
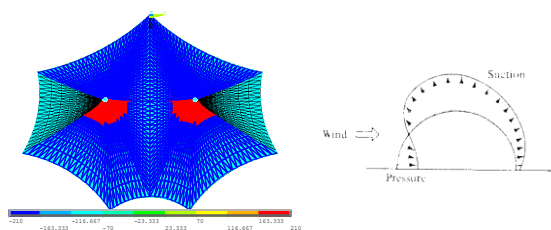
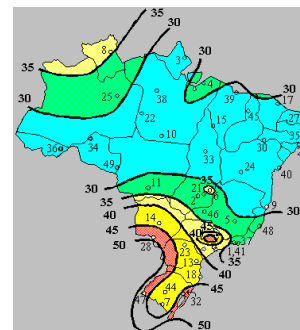
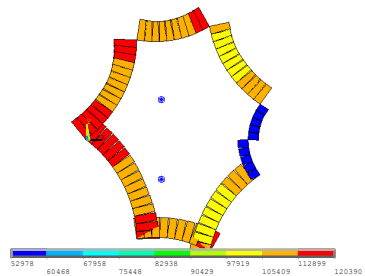


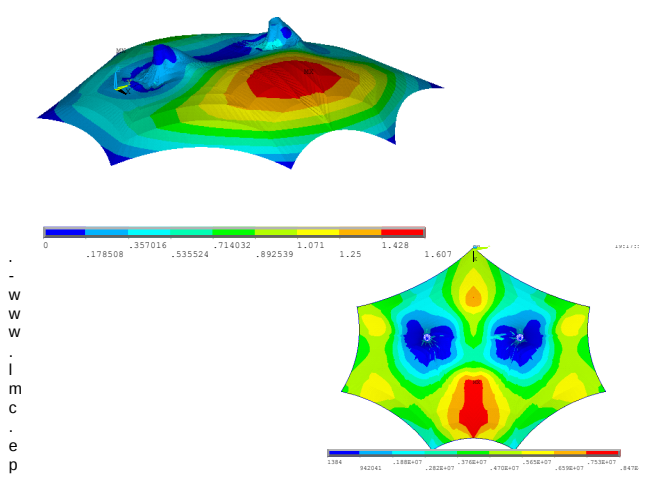
STEP=2
SUB =1
TIME=2
S1 (AVG)
DMX =.247158
SMN =.235E+07
SMX =.162E+08



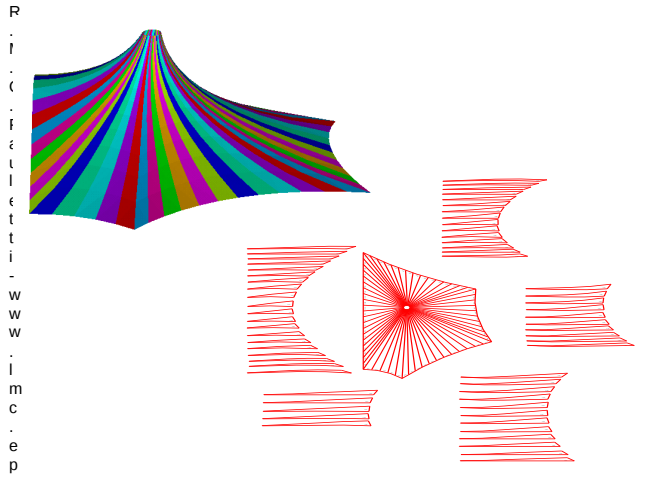
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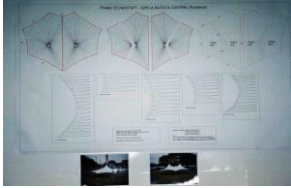


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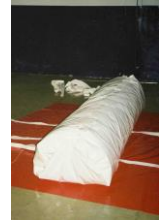


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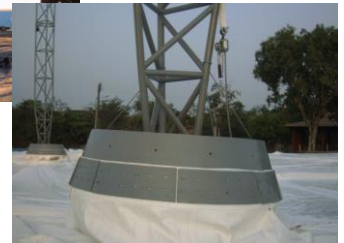
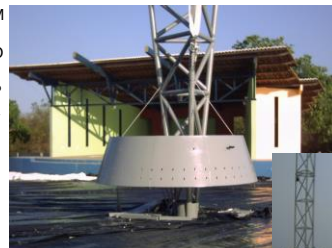
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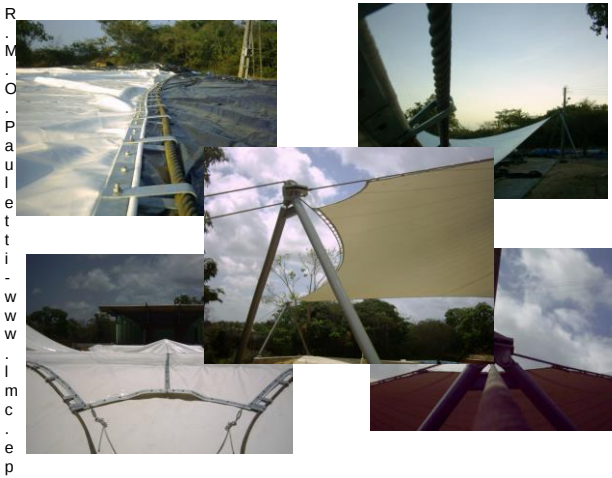


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Ruy Marcelo de Oliveira Pauletti

Polytechnic School of the University of São Paulo

Design and Construction of Goiânia's Open Market



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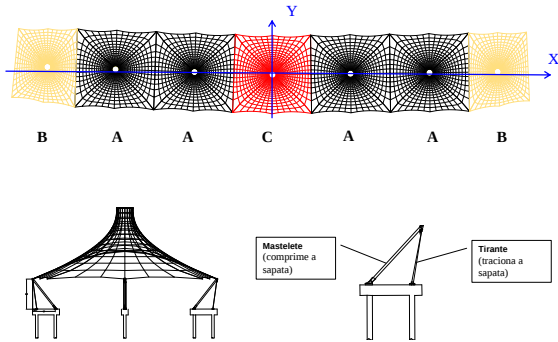


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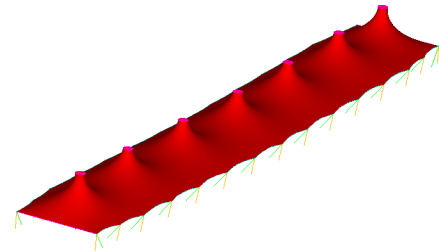


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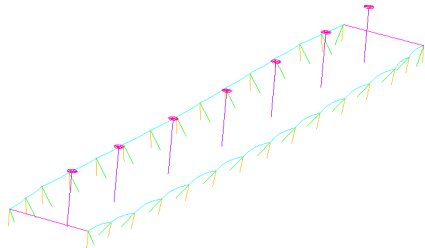




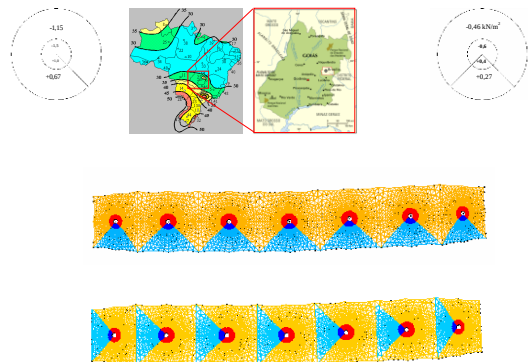
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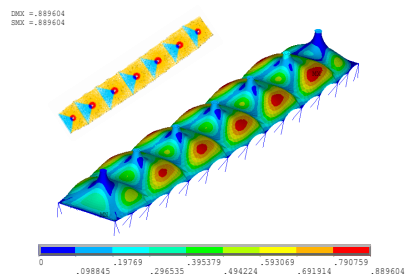
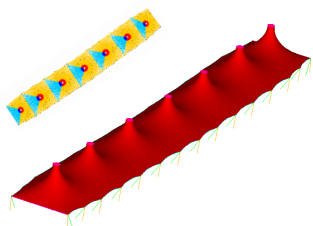
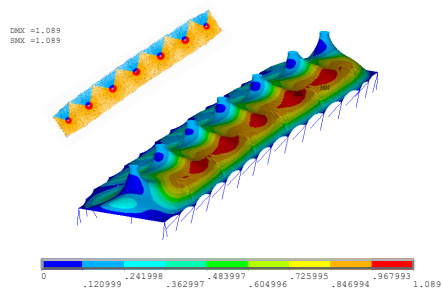
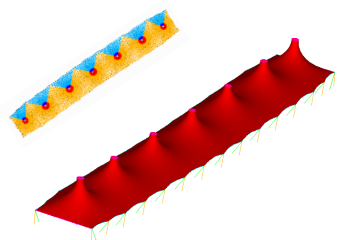


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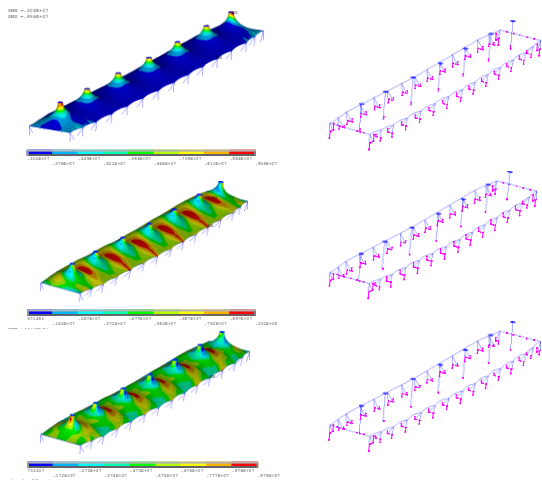


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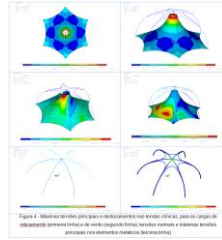




"Feira da Cidade de Ananindeua, PA (2006)
Arch. José Maria Coelho Bassalo and Flávio Campos do Nascimento

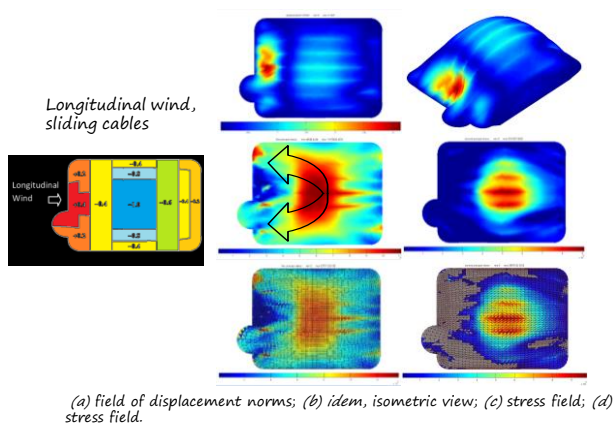
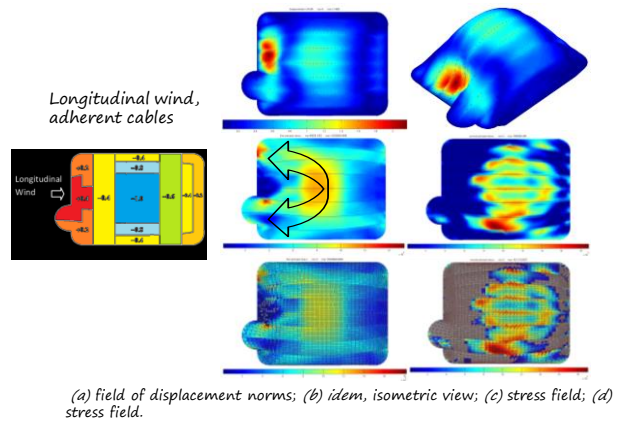


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CENPES II

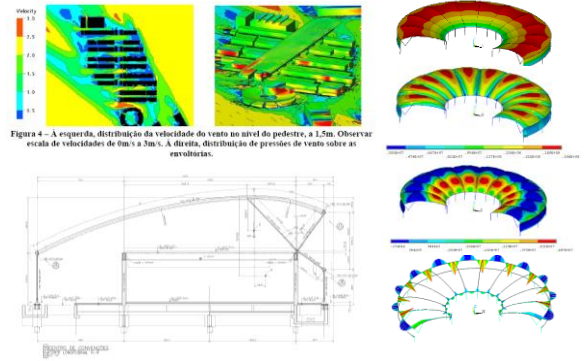
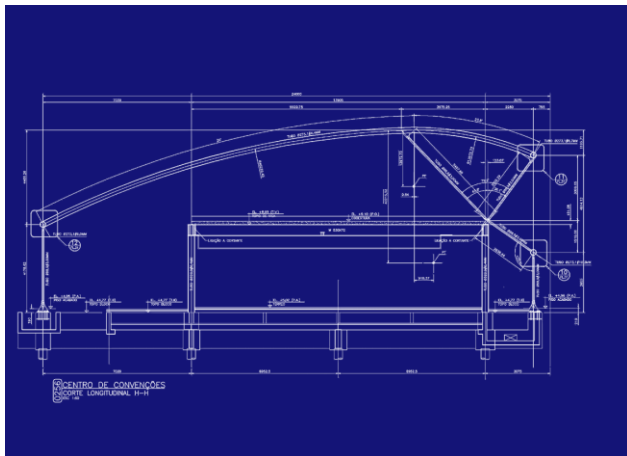
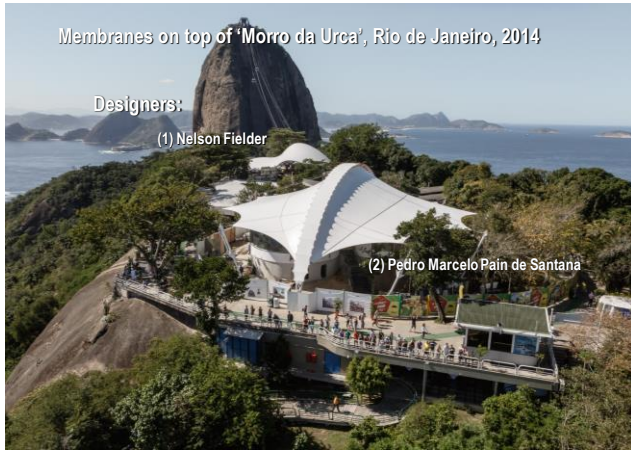


Figura 4 – À esquerda, distribuição da velocidade do vento no arvel do pedente, a 1.5m. Observar escala de velocidades de 0m/s a 2m/s. À direita, distribuição de pressões de vento sobre as envoltórias.





Sede do Campo Olímpico de Golfe / RUA Arquitetos
(Pedro Évora, Pedro Rivera) 2015/2016



Sede do Campo Olímpico de Golfe / RUA Arquitetos
(Pedro Évora, Pedro Rivera) 2015/2016



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(Pedro Évora, Pedro Rivera) 2015/2016*

