

Ars Pontificia et Scientia: alcune riflessioni

WEBINAR – 2 luglio 2021

UN MIRABILE CONNUBIO TRA ARTE SCULTOREA E SCIENZA DELLE COSTRUZIONI: IL PONTE MUSMECI SUL BASENTO

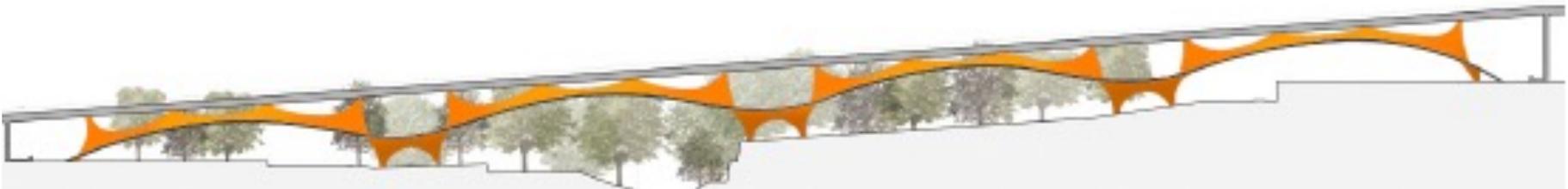
Luciano Rosati

Dipartimento di Strutture per l'Ingegneria e l'Architettura

IL PONTE SUL BASENTO DI SERGIO MUSMECI

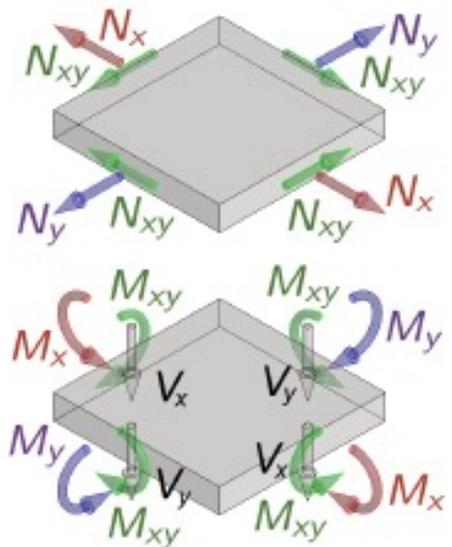


- Luogo: Potenza
- Progetto: Sergio Musmeci
- Costruzione: 1971-76
- Materiale: calcestruzzo armato
- Luce: 4 x 69,2 m
- Larghezza: 16 m (impalcato)
- 12 m (sommità)
- 10,4 m (base)
- Dita: 16 x 17,3 m (sommità)
4 x (10,4 + 58,8) m (base)



LA FORMA DEL GUSCIO IN CA

Componenti di sforzo nei gusci



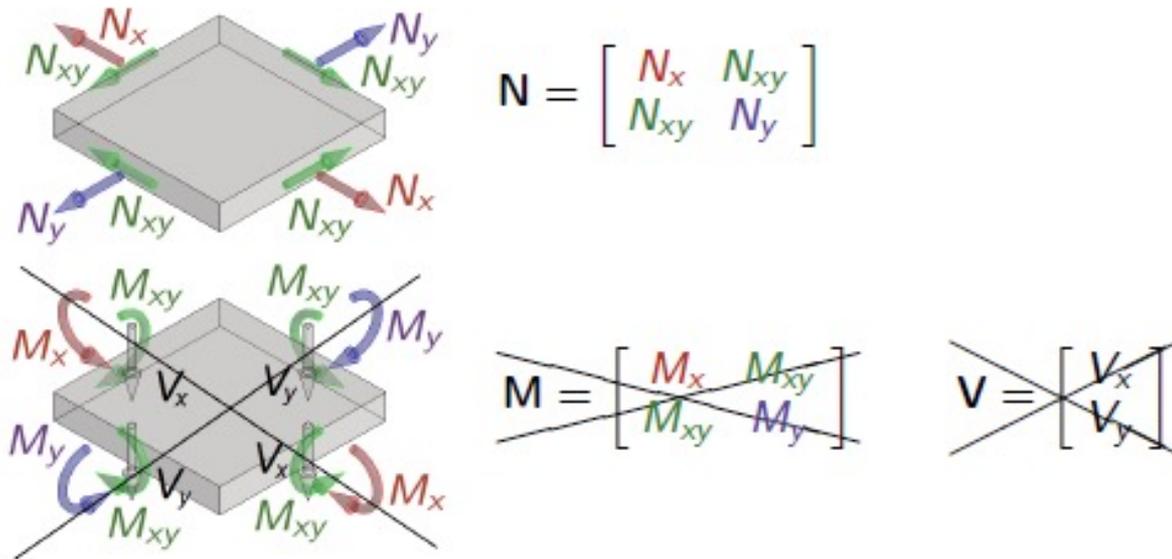
$$\mathbf{N} = \begin{bmatrix} N_x & N_{xy} \\ N_{xy} & N_y \end{bmatrix}$$

$$\mathbf{M} = \begin{bmatrix} M_x & M_{xy} \\ M_{xy} & M_y \end{bmatrix}$$

$$\mathbf{v} = \begin{bmatrix} V_x \\ V_y \end{bmatrix}$$

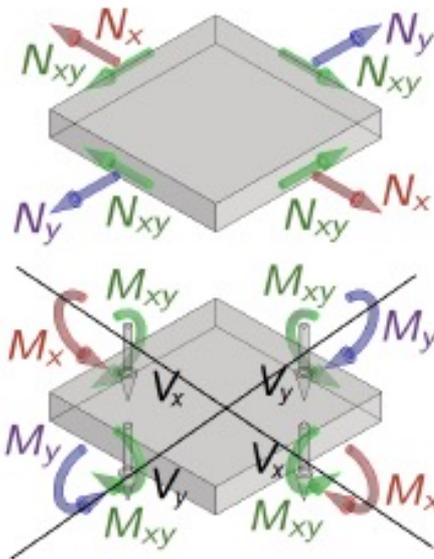
LA FORMA DEL GUSCIO IN CA

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LA FORMA DEL GUSCIO IN CA

Componenti di sforzo nei gusci



$$N = \begin{bmatrix} N_x & N_{xy} \\ N_{xy} & N_y \end{bmatrix}$$

~~$$M = \begin{bmatrix} M_x & M_{xy} \\ M_{xy} & M_y \end{bmatrix}$$~~

~~$$V = \begin{bmatrix} V_x \\ V_y \end{bmatrix}$$~~

PROGETTAZIONE (1967-70)

- Guscio in CA che regge l'impalcato con sforzi membranali
- Determinazione della forma che genera solo sforzi membranali
 - Vincoli geometrici (sotegni dell'impalcato e delle fondazioni)
 - Vincoli funzionali (Passaggio pedonale)
 - Strumenti computazionali limitati
 - FEM utilizzato solo in ambito aeronautico
 - Scheck inventa il FDM nel 1974

PROGETTAZIONE (1967-70)

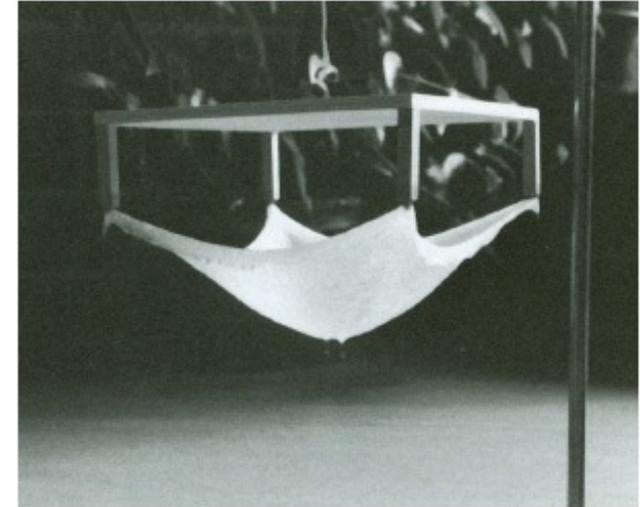


Gaudì – Sagrada Familia (1882 – in consegna)

PROGETTAZIONE (1967-70)



Gaudí – Sagrada Família (1882 – in consegna)

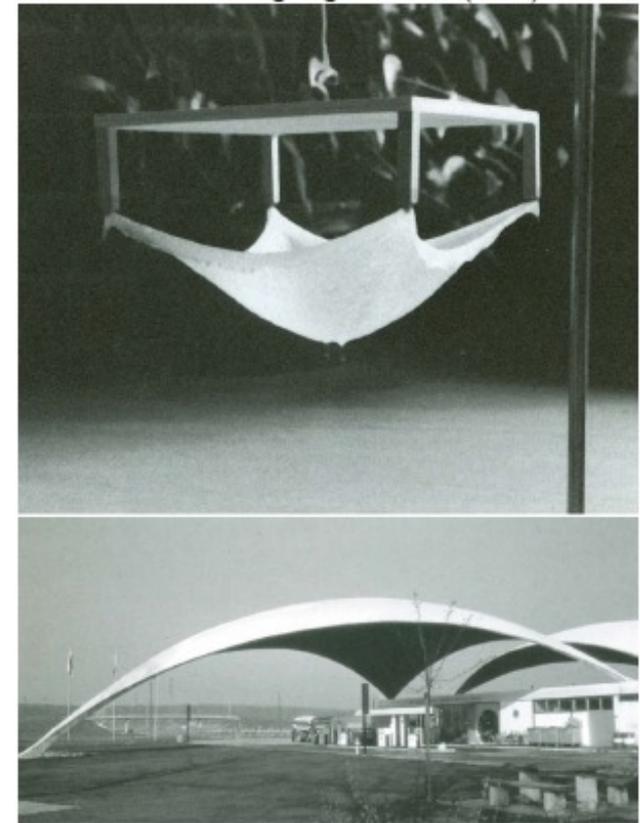


Isler - Dietlingen gas station (1968)

PROGETTAZIONE (1967-70)



Otto - Tanzbrunnen (1957)

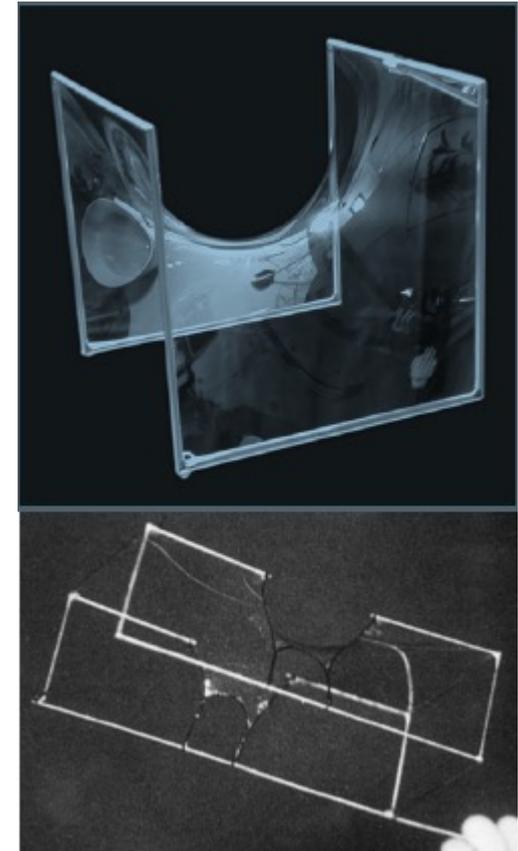


Isler - Dietlingen gas station (1968)

PROGETTAZIONE (1967-70)



Otto - Tanzbrunnen (1957)



Musmeci - Ponte sul Basento

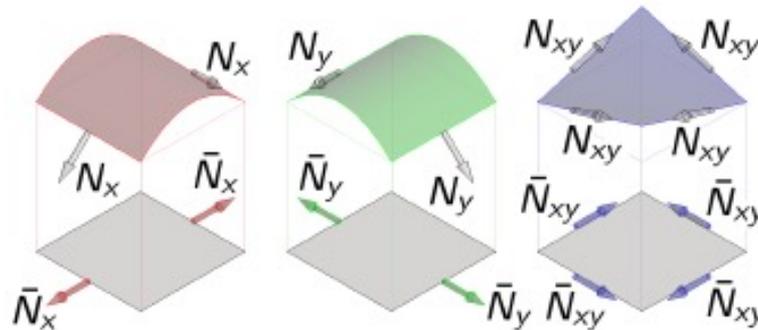
PROGETTAZIONE (RICERCA ANALITICA DELLA FORMA)

Teoria membranale dei gusci (Pucher)

La geometria dei gusci è descritta da una funzione del tipo $z(x,y)$

La funzione z , i carichi agenti sulla membrana e le tensioni di membrana sono legati dall'equazione

$$\bar{N}_x \frac{\partial^2 z}{\partial x^2} + \bar{N}_y \frac{\partial^2 z}{\partial y^2} + 2\bar{N}_{xy} \frac{\partial^2 z}{\partial x \partial y} = \bar{p}_z$$



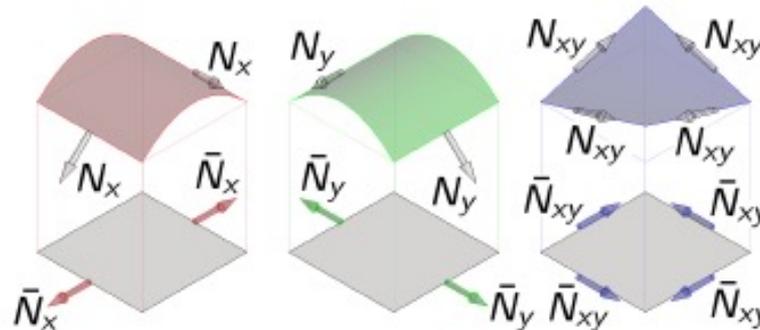
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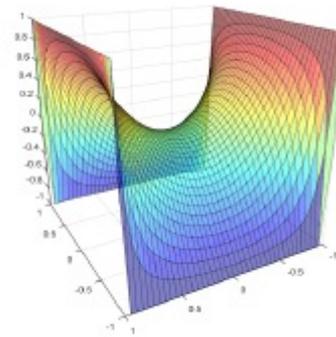
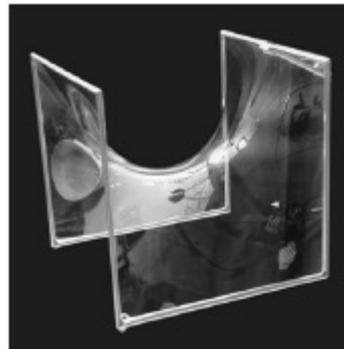
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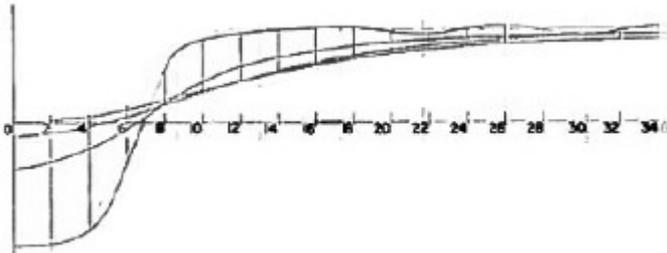
$$\bar{N}_x \frac{\partial^2 z}{\partial x^2} + \bar{N}_y \frac{\partial^2 z}{\partial y^2} = 0$$



PROGETTAZIONE (RICERCA ANALITICA DELLA FORMA)

Teoria membranale dei gusci (Cond. Dirichlet/Neuman/Bordo libero)

Le soluzioni di Musmeci

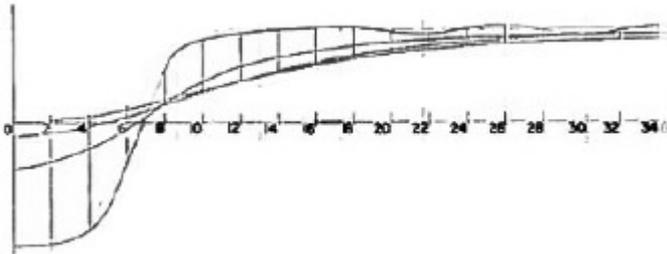


Soluzione con condizioni di Dirichlet

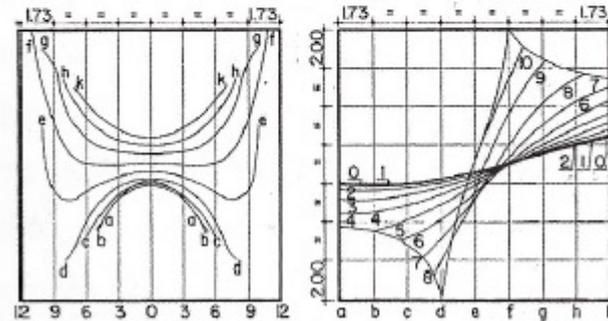
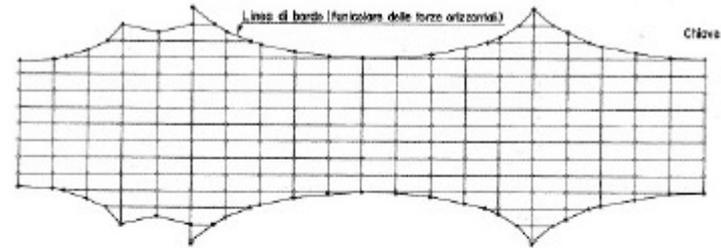
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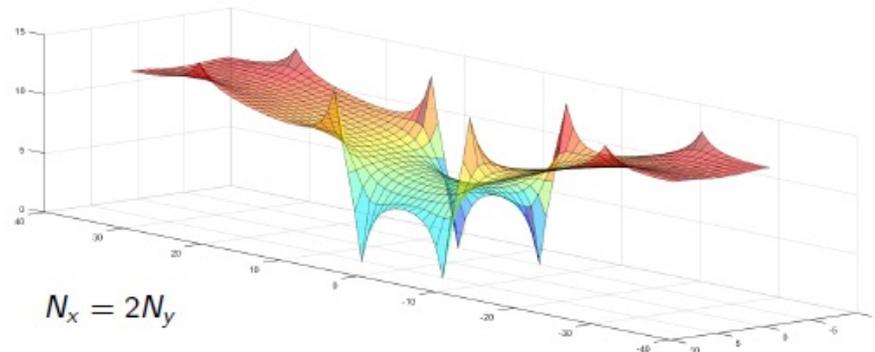
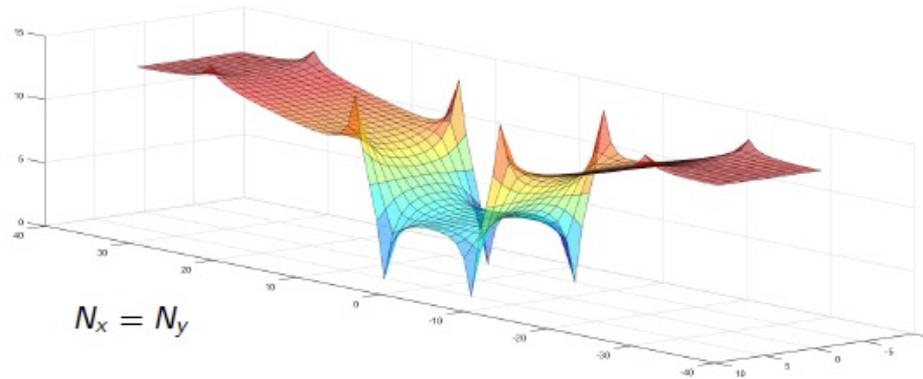
Soluzione con condizioni di Dirichlet



Soluzione con bordo funicolare

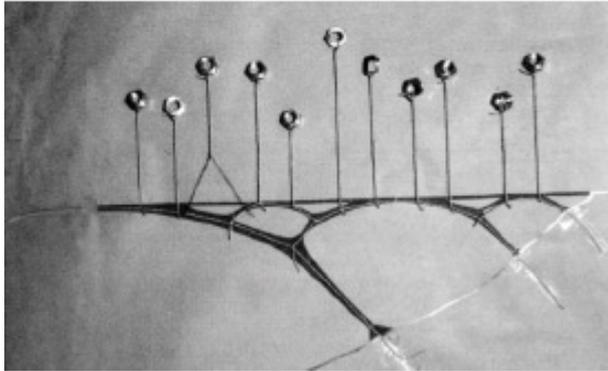
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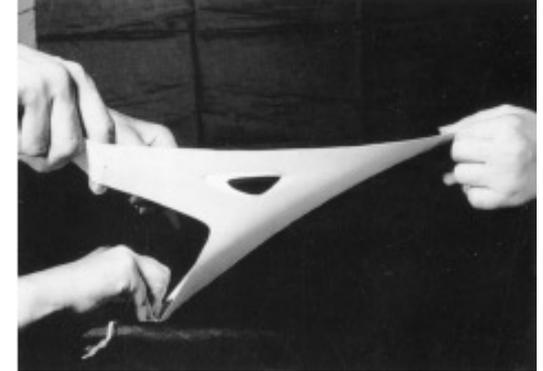


PROGETTAZIONE (RICERCA SPERIMENTALE DELLA FORMA)

Membrane in neoprene



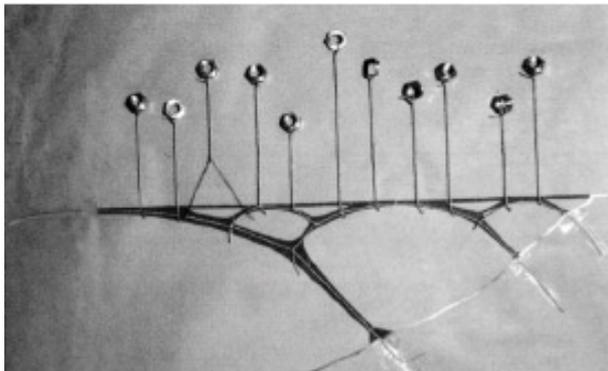
Studio per il ponte sul fiume Astico (1956)



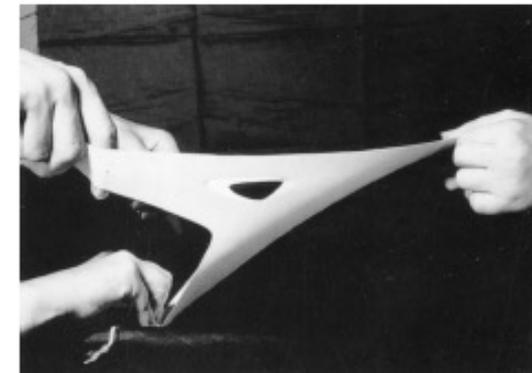
Studio per il viadotto di Tor di Quinto (1959)

PROGETTAZIONE (RICERCA SPERIMENTALE DELLA FORMA)

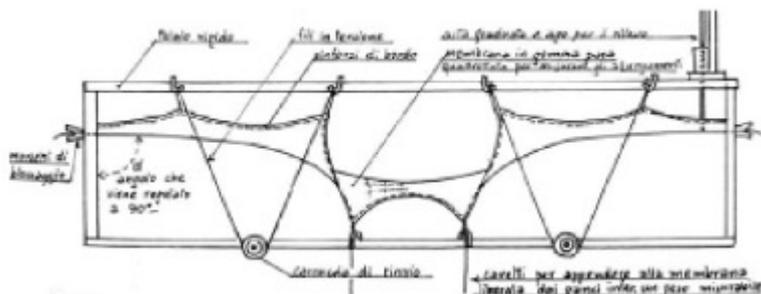
Membrane in neoprene



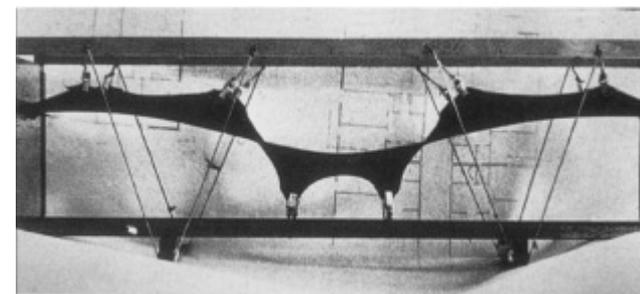
Studio per il ponte sul fiume Astico (1956)



Studio per il viadotto di Tor di Quinto (1959)



Sistema di cavi e carrucole

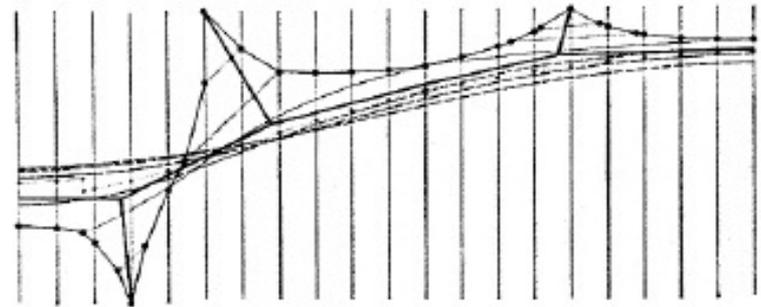


Modello in Neoprene in scala 1:100

Necessità di ringrossare i bordi liberi del guscio!

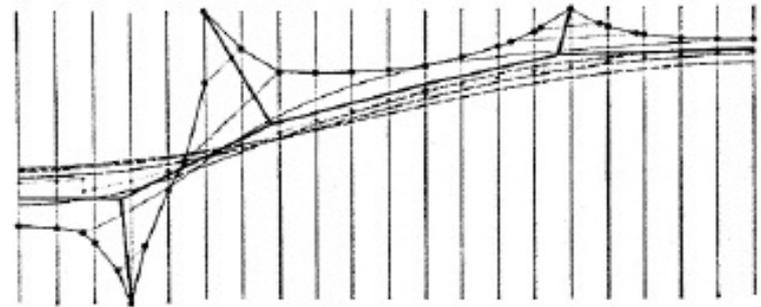
PROGETTAZIONE (VALUTAZIONE DEGLI SFORZI)

Schematizzazione a elementi monodimensionali

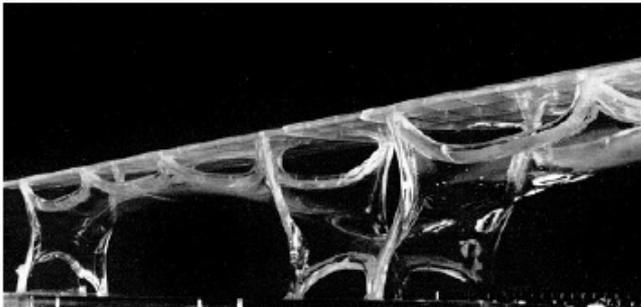


PROGETTAZIONE (VALUTAZIONE DEGLI SFORZI)

Schematizzazione a elementi monodimensionali



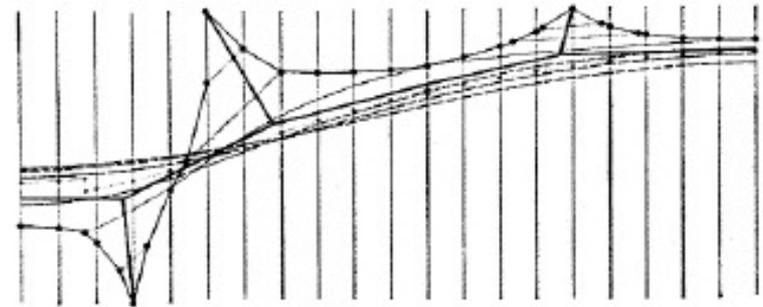
Modelli sperimentali



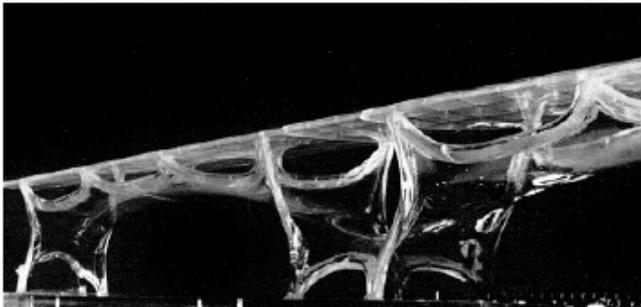
Modello in metacrilato in scala 1:100
strumentato con estensimetri

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Schematizzazione a elementi monodimensionali



Modelli sperimentali

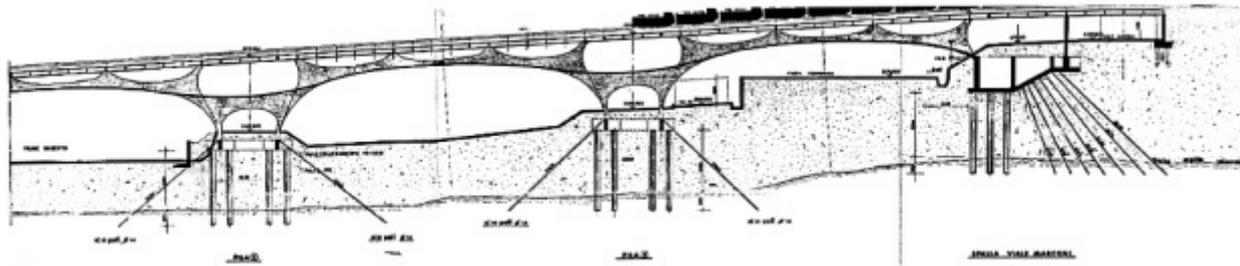


Modello in metacrilato in scala 1:100
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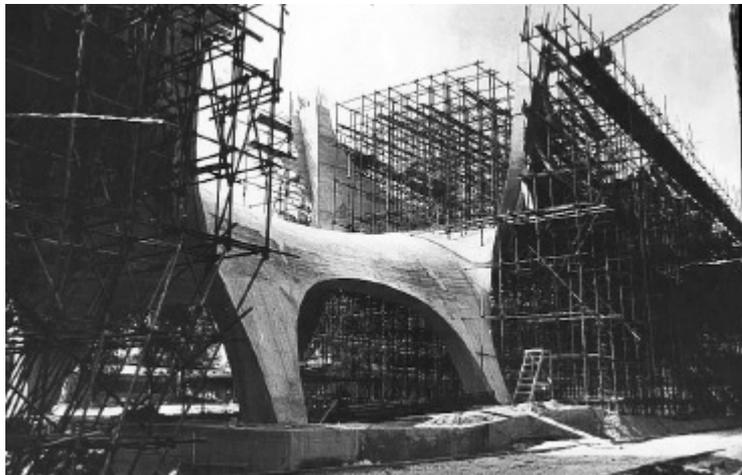
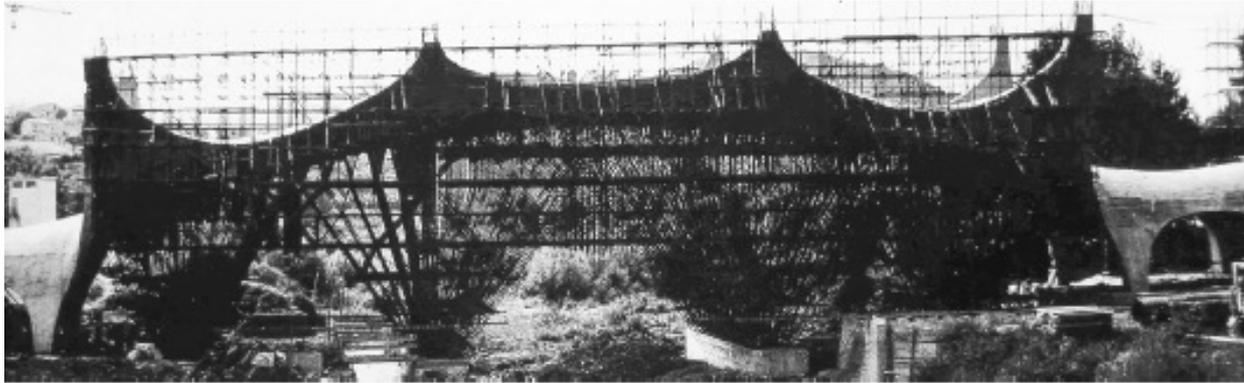
Prototipo in scala 1:10 (ISMES, Bergamo)
richiesto dal Consiglio Superiore dei Lavori Pubblici
Moltiplicatore limite: 2,18 (rottura fondazione)

COSTRUZIONE (1971-1975)



- Gettato in opera
- Utilizzo di modelli in gesso
- Tavolato con sezioni disegnate al vero
- NO prefabbricazione parziale per ridurre banchinaggi tubolari
- Fondazioni su pali (3 4 plinti da 4 pali, spalle su 15 pali e 144 Micropali inclinati)
- Banchinaggio speciale per le campate sul Basento e sui binari ferroviari
- Ritardo per la campata sui binari ! ancoraggio campata adiacente con barre DIWIDAG

COSTRUZIONE (1971-1975)



Impresa: Edilstrade, Forlì

Collaudo: prof. Carré, ing. Brancaccio

- **Carico:** 9,2 ton/m eccentrico

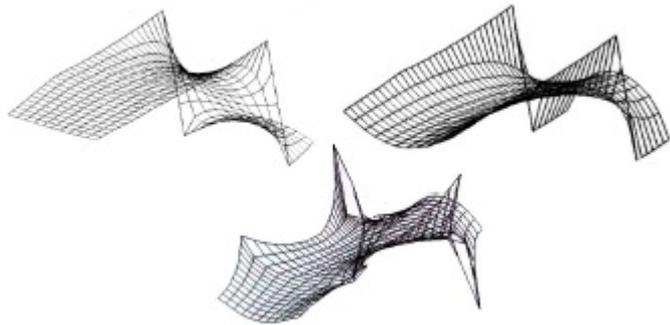
- **Spostamento:** 20 mm

Passaggio pedonale: mai realizzato!

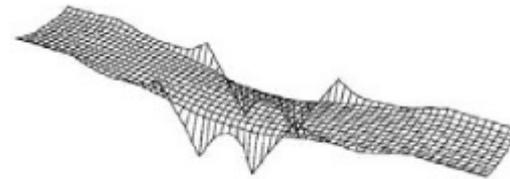
UN ESEMPIO ITALIANO DEL FORM FINDING



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Abbruzzese & Tursi, 2003

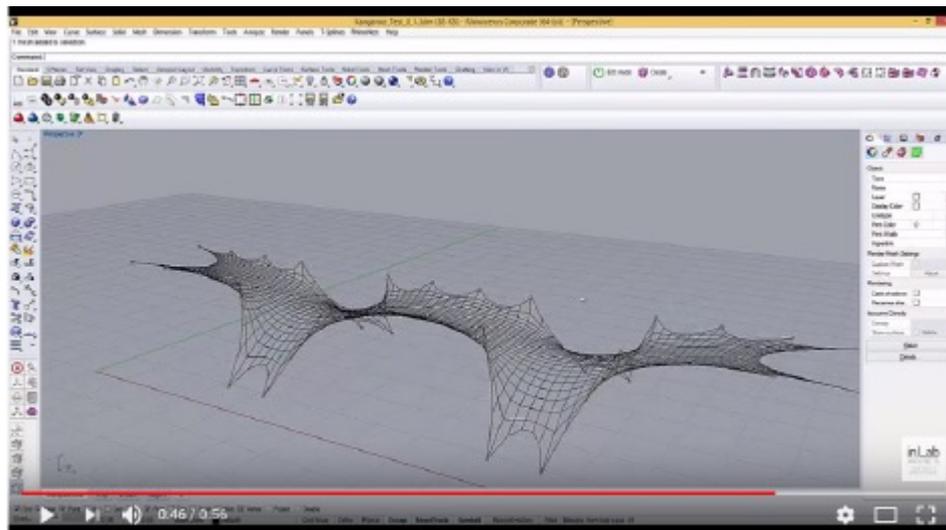


Adrienssens et al., IASS, 2015

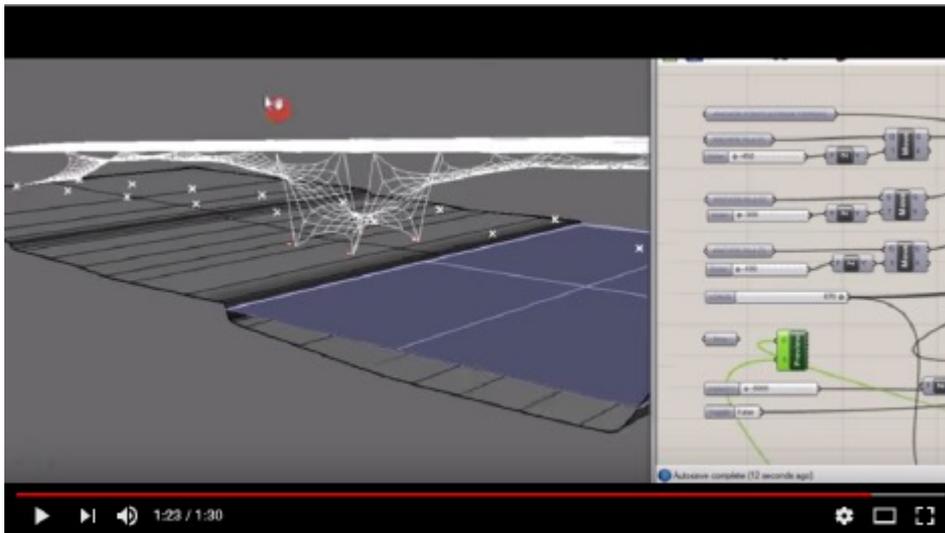


Magrone et al., S&A, 2016

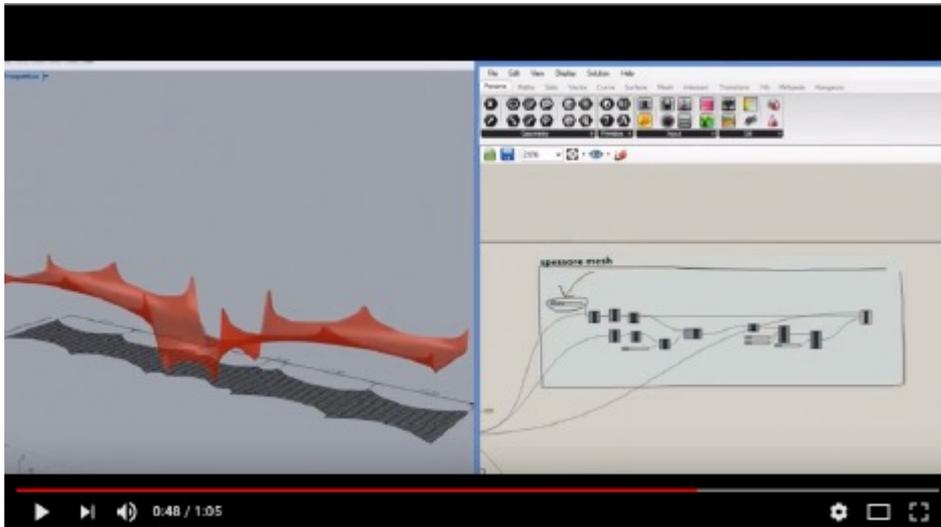
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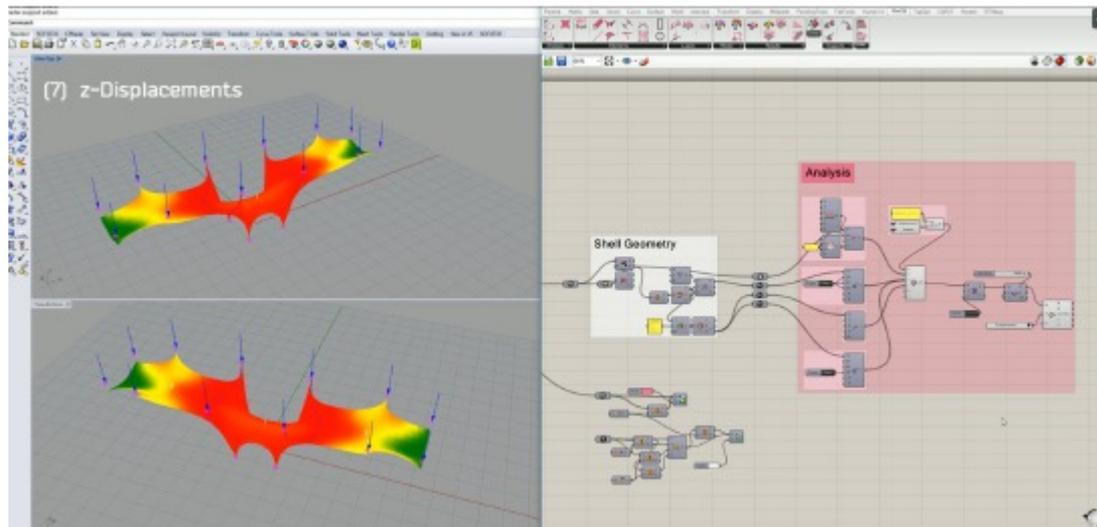
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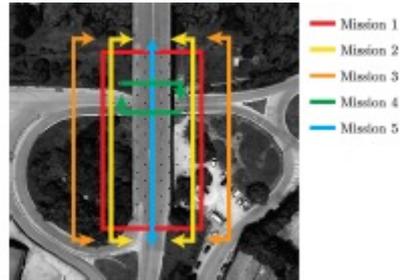
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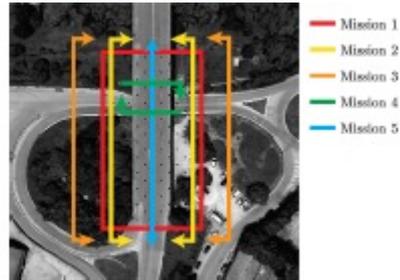
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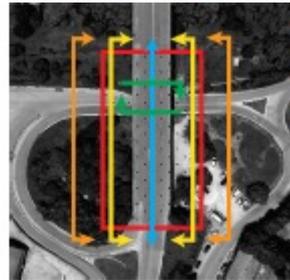
RILIEVO FOTOGRAMMOMETRICO MEDIANTE UAV



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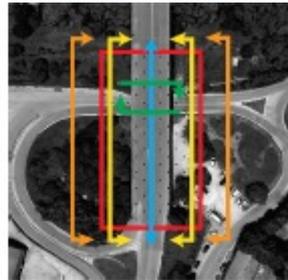
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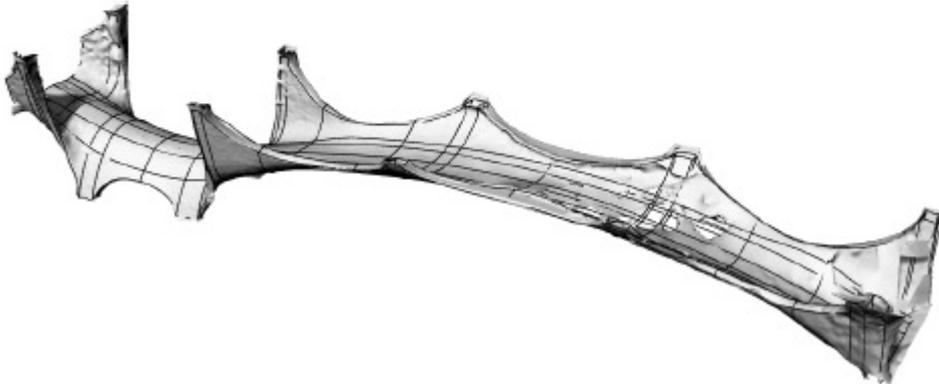
- Mission 1
- Mission 2
- Mission 3
- Mission 4
- Mission 5



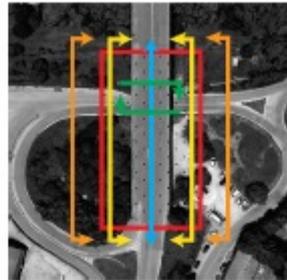
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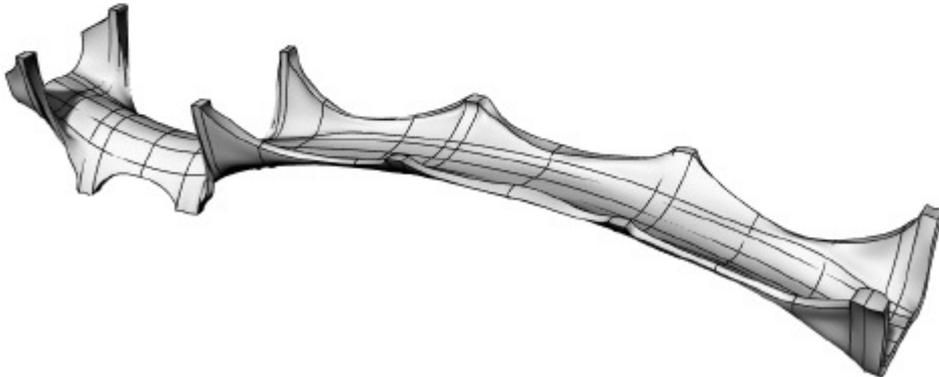
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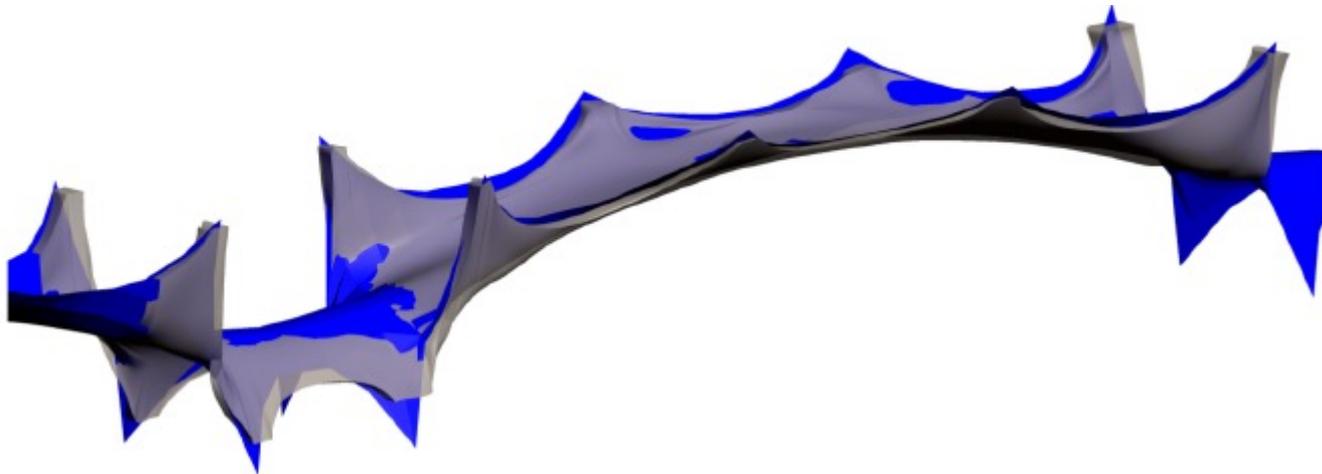
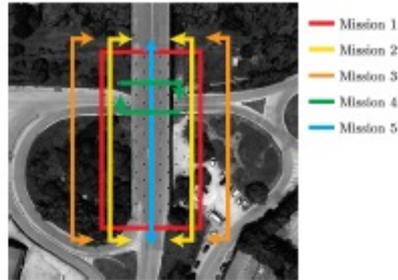
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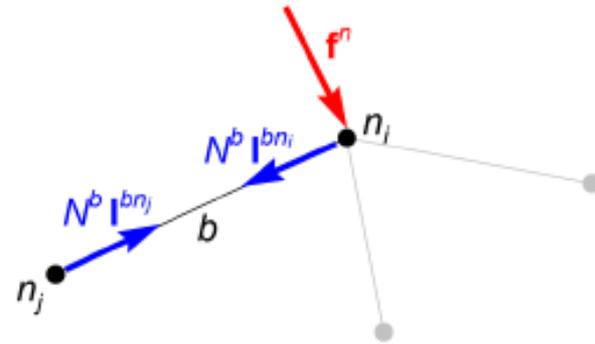
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IL METODO DELLE DENSITA' DI FORZA

$$\sum_{b \in B^n} N^b |^{bn} = f^n$$

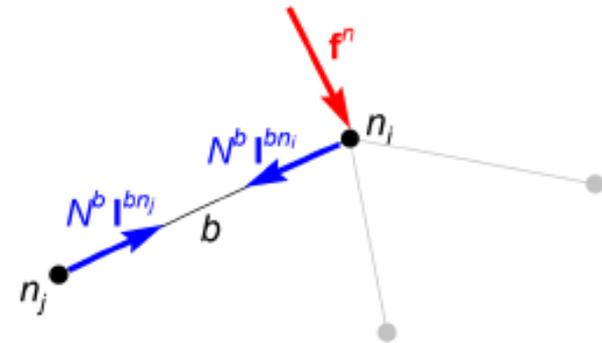
$$|^{bn_i} = \frac{\ell^{bn_i}}{\ell^b} = \frac{x^{n_i} - x^{n_j}}{|x^{n_i} - x^{n_j}|} \rightarrow \text{versore di } b \text{ verso } n_i$$



IL METODO DELLE DENSITA' DI FORZA

$$\sum_{b \in B^n} N^b l^{bn} = f^n$$

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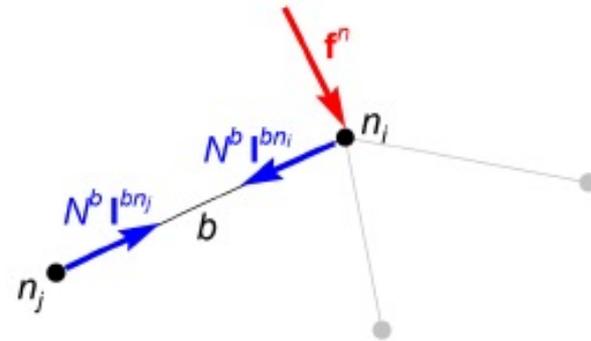
$$\sum_{b \in B^n} \frac{N^b (x^{n_i} - x^{n_j})}{|x^{n_i} - x^{n_j}|} = f^n$$

IL METODO DELLE DENSITA' DI FORZA

$$\sum_{b \in B^n} N^b \mathbf{l}^{bn} = \mathbf{f}^n$$

$$\mathbf{l}^{bn_i} = \frac{\ell^{bn_i}}{\ell^b} = \frac{\mathbf{x}^{n_i} - \mathbf{x}^{n_j}}{|\mathbf{x}^{n_i} - \mathbf{x}^{n_j}|} \rightarrow \text{versore di } b \text{ verso } n_i$$

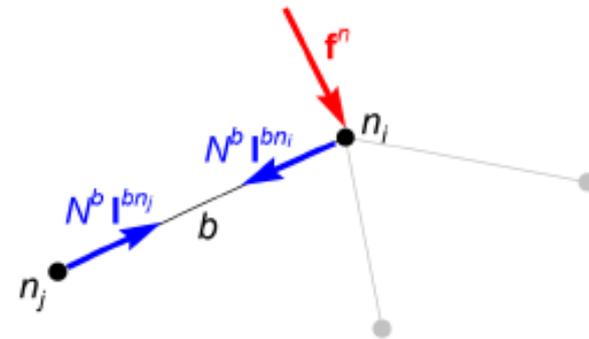
$$\sum_{b \in B^n} \frac{N^b (\mathbf{x}^{n_i} - \mathbf{x}^{n_j})}{|\mathbf{x}^{n_i} - \mathbf{x}^{n_j}|} = \mathbf{f}^n \quad \left(D^b = \frac{N^b}{|\mathbf{x}^{n_i} - \mathbf{x}^{n_j}|} \right)$$



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$$\sum_{b \in B^n} N^b \mathbf{l}^{bn} = \mathbf{f}^n$$

$$\mathbf{l}^{bn_i} = \frac{\ell^{bn_i}}{\ell^b} = \frac{\mathbf{x}^{n_i} - \mathbf{x}^{n_j}}{|\mathbf{x}^{n_i} - \mathbf{x}^{n_j}|} \rightarrow \text{versore di } b \text{ verso } n_i$$

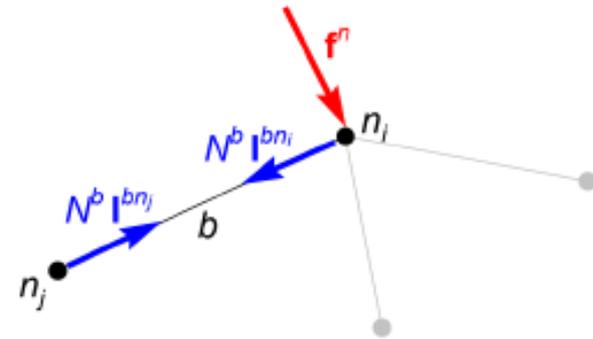


$$\sum_{b \in B^n} \frac{N^b (\mathbf{x}^{n_i} - \mathbf{x}^{n_j})}{|\mathbf{x}^{n_i} - \mathbf{x}^{n_j}|} = \mathbf{f}^n \quad \left(D^b = \frac{N^b}{|\mathbf{x}^{n_i} - \mathbf{x}^{n_j}|} \right) \rightarrow \sum_{b \in B^n} D^b (\mathbf{x}^{n_i} - \mathbf{x}^{n_j}) = \mathbf{f}^n$$

IL METODO DELLE DENSITA' DI FORZA

$$\sum_{b \in B^n} N^b |^{bn} = f^n$$

$$|^{bn_i} = \frac{\ell^{bn_i}}{\ell^b} = \frac{x^{n_i} - x^{n_j}}{|x^{n_i} - x^{n_j}|} \rightarrow \text{versore di } b \text{ verso } n_i$$



$$\sum_{b \in B^n} \frac{N^b (x^{n_i} - x^{n_j})}{|x^{n_i} - x^{n_j}|} = f^n \quad \left(D^b = \frac{N^b}{|x^{n_i} - x^{n_j}|} \right) \rightarrow \sum_{b \in B^n} D^b (x^{n_i} - x^{n_j}) = f^n$$

Force Density Method

$$Dx = f$$

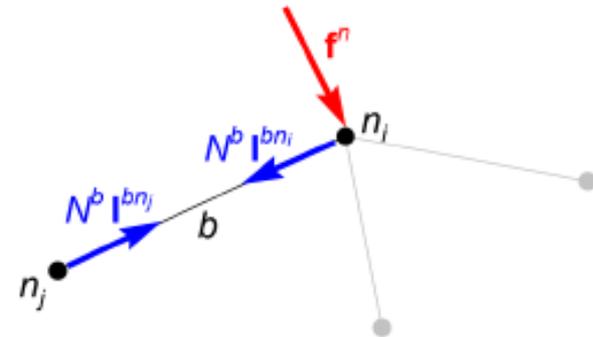
$$D = A_b \begin{bmatrix} D^b & -D^b \\ -D^b & D^b \end{bmatrix}$$

$$D^b = \frac{N^b}{\ell^b}$$

IL METODO DELLE DENSITA' DI FORZA

$$\sum_{b \in B^n} N^b \mathbf{l}^{bn_i} = \mathbf{f}^n$$

$$\mathbf{l}^{bn_i} = \frac{\ell^{bn_i}}{\ell^b} = \frac{\mathbf{x}^{n_i} - \mathbf{x}^{n_j}}{|\mathbf{x}^{n_i} - \mathbf{x}^{n_j}|} \rightarrow \text{versore di } b \text{ verso } n_i$$



$$\sum_{b \in B^n} \frac{N^b (\mathbf{x}^{n_i} - \mathbf{x}^{n_j})}{|\mathbf{x}^{n_i} - \mathbf{x}^{n_j}|} = \mathbf{f}^n \quad \left(D^b = \frac{N^b}{|\mathbf{x}^{n_i} - \mathbf{x}^{n_j}|} \right) \rightarrow \sum_{b \in B^n} D^b (\mathbf{x}^{n_i} - \mathbf{x}^{n_j}) = \mathbf{f}^n$$

Finite Element Method

Force Density Method

$$\mathbf{Kd} = \mathbf{f}$$

$$\mathbf{Dx} = \mathbf{f}$$

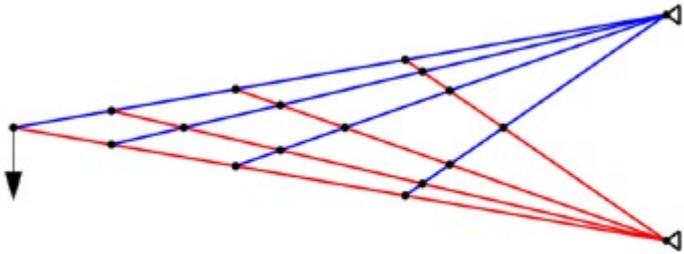
$$\mathbf{K} = \mathbf{A}_b \mathbf{R}^T \begin{bmatrix} K^b & -K^b \\ -K^b & K^b \end{bmatrix} \mathbf{R}$$

$$\mathbf{D} = \mathbf{A}_b \begin{bmatrix} D^b & -D^b \\ -D^b & D^b \end{bmatrix}$$

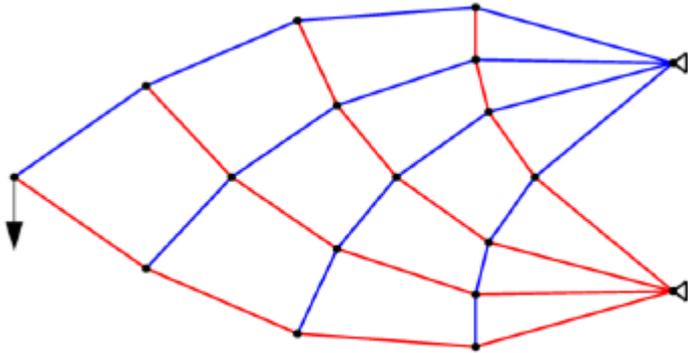
$$K^b = \frac{E^b A^b}{\ell^b}$$

$$D^b = \frac{N^b}{\ell^b}$$

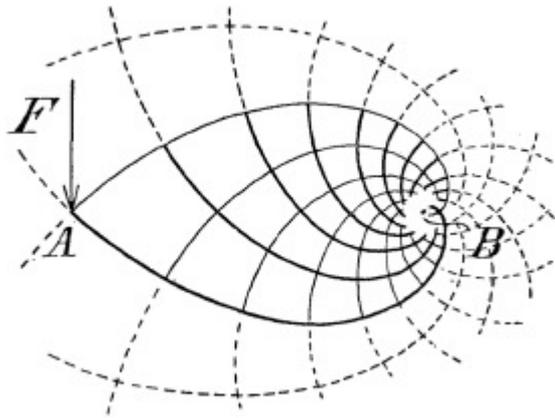
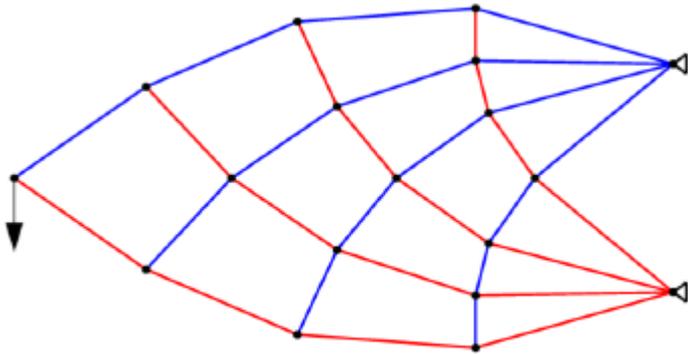
IL METODO DELLE DENSITA' DI FORZA



IL METODO DELLE DENSITA' DI FORZA

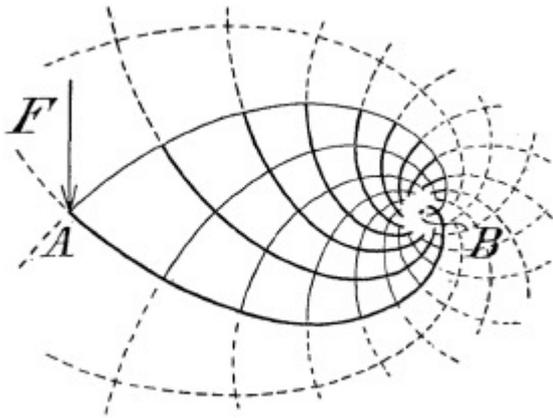
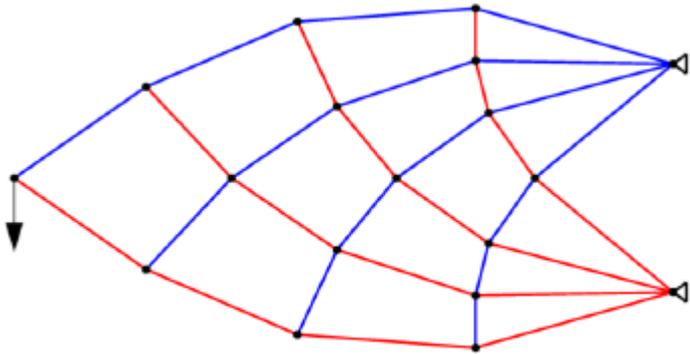


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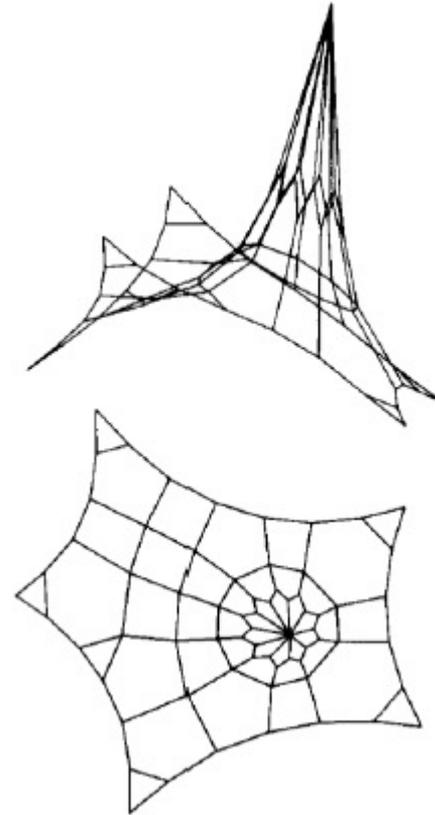


Michell, The limits of economy of material in frame-structures. Lond.Edinb.Dubl.Phil.Mag., 1904

IL METODO DELLE DENSITA' DI FORZA

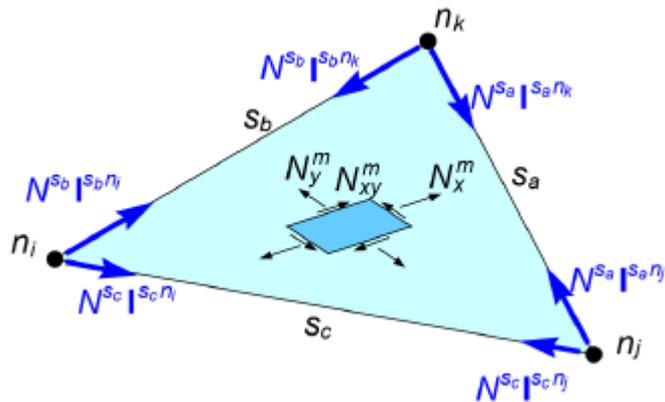


Michell, The limits of economy of material in frame-structures. Lond.Edinb.Dubl.Phil.Mag., 1904



Schek, The force density method for form finding and computation of general networks. CMAME, 1974

ELEMENTI TRIANGOLARI



Gli sforzi di membrana $\mathbf{N}^m = (N_x^m, N_y^m, N_{xy}^m)$ vengono proiettati lungo i lati dell'elemento

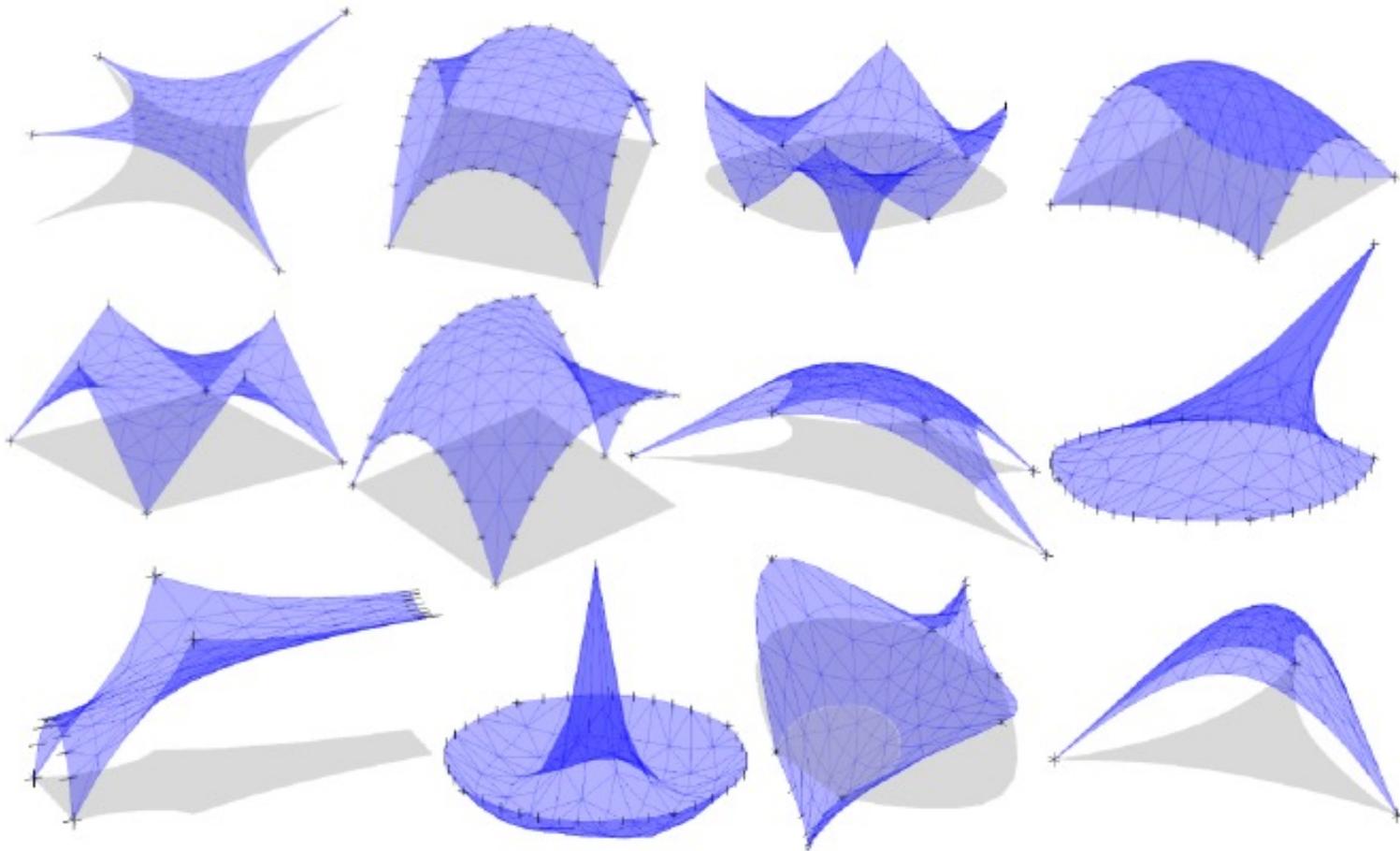
$\mathbf{N}^s = \mathbf{A}^m \mathbf{R}^{-t} \mathbf{N}^m \rightarrow$ sforzi normali lungo i lati dell'elemento

$\mathbf{R} \rightarrow$ cambio di riferimento: $\mathbf{N}^m = \mathbf{R} \mathbf{N}^s \quad \mathbf{N}^s = \mathbf{R}^{-t} \mathbf{N}^m$

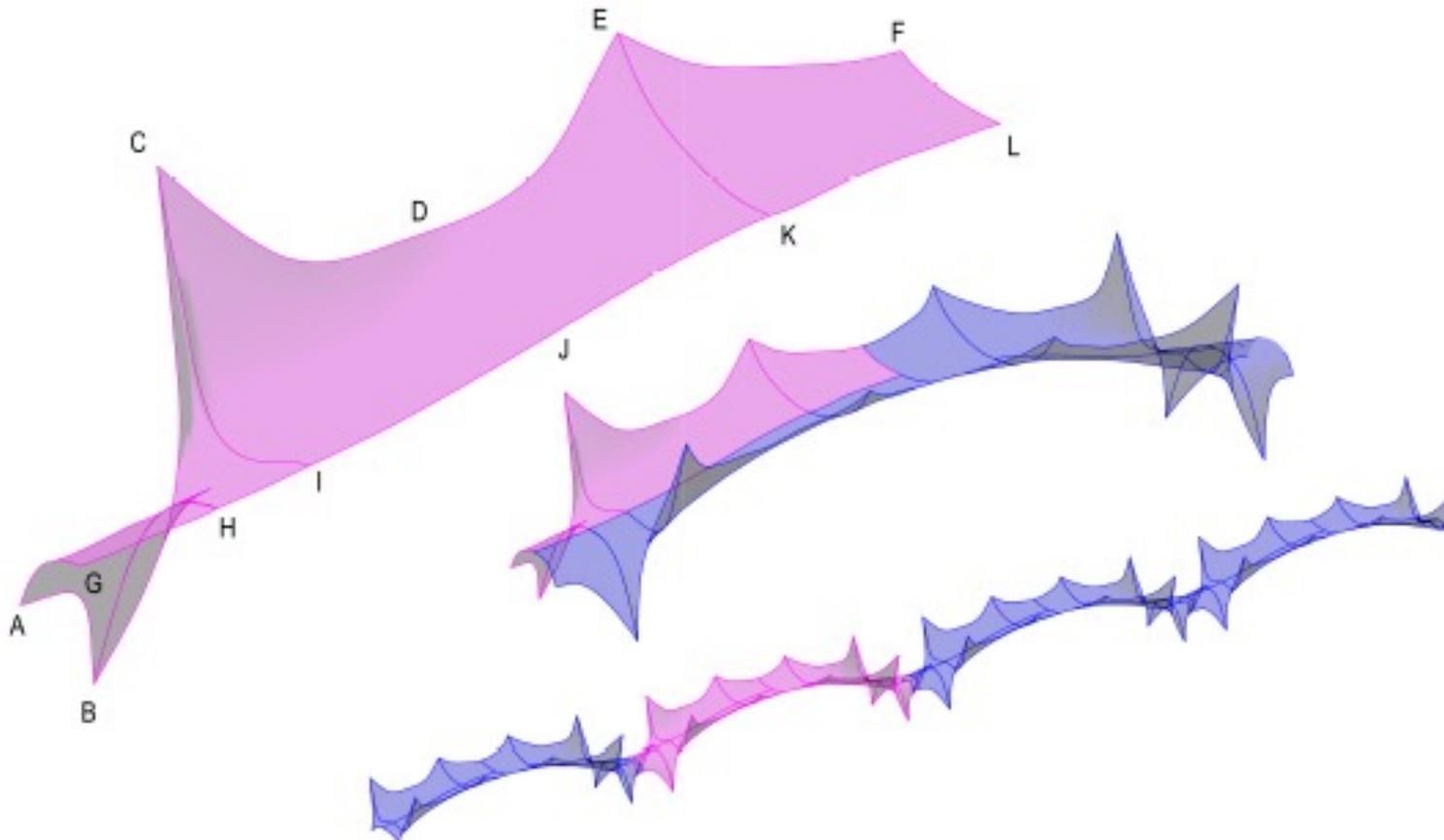
$$\mathbf{D} \mathbf{x} = \mathbf{f} \quad \mathbf{D} = \mathbf{A}_b \begin{bmatrix} D^b & -D^b \\ -D^b & D^b \end{bmatrix} + \mathbf{A}_m \begin{bmatrix} D^{s_b} + D^{s_c} & -D^{s_c} & -D^{s_b} \\ -D^{s_c} & D^{s_a} + D^{s_c} & -D^{s_a} \\ -D^{s_b} & D^{s_a} & D^{s_a} + D^{s_b} \end{bmatrix}$$

$$D(\cdot) = N(\cdot) / \ell(\cdot)$$

ELEMENTI TRIANGOLARI

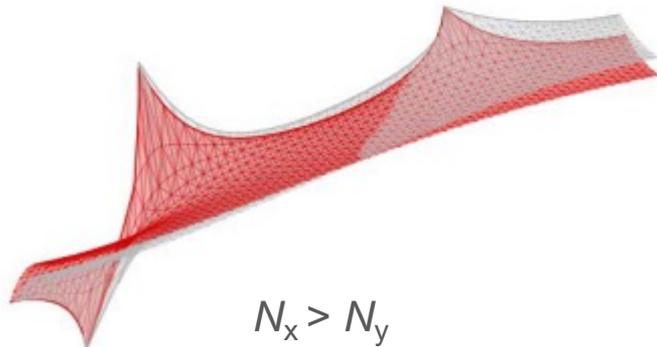
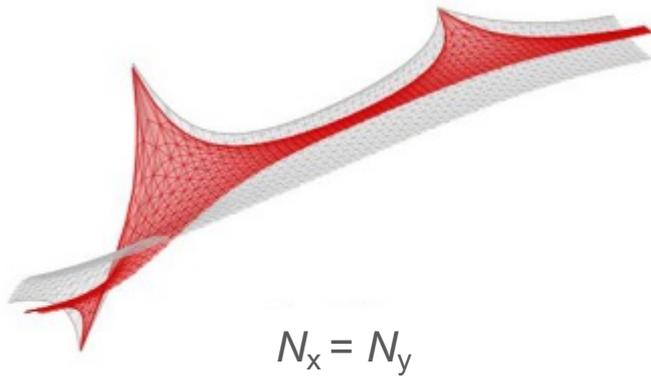


APPLICAZIONE AL PONTE SUL BASENTO



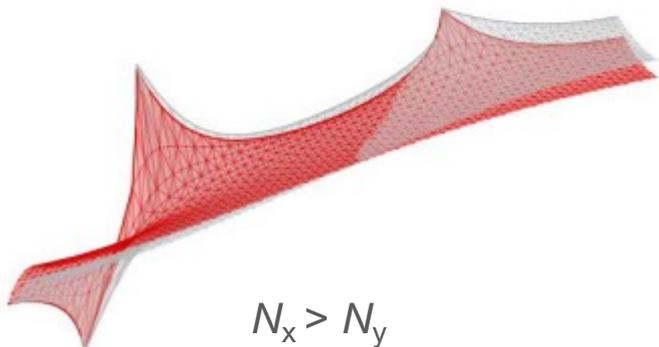
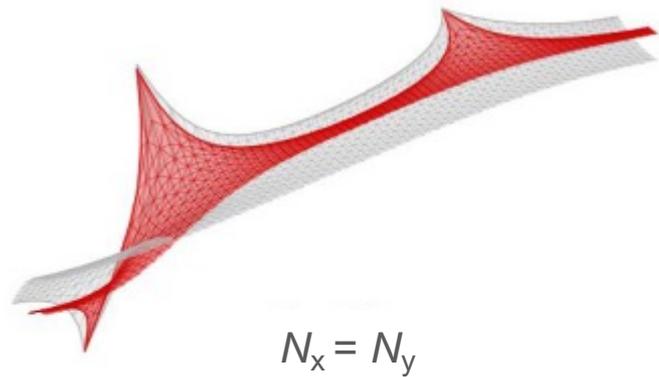
APPLICAZIONE AL PONTE SUL BASENTO

Posizione assegnata ai nodi C ed E (~~F_x~~ ~~F_y~~)

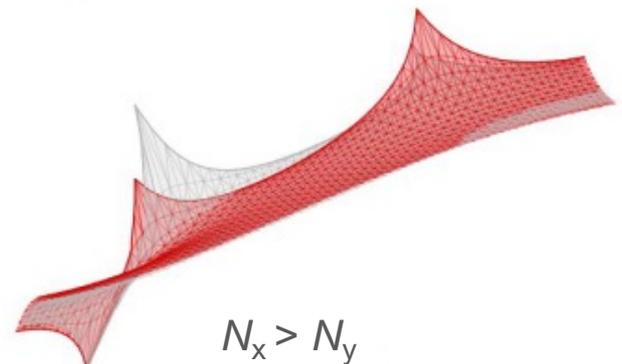
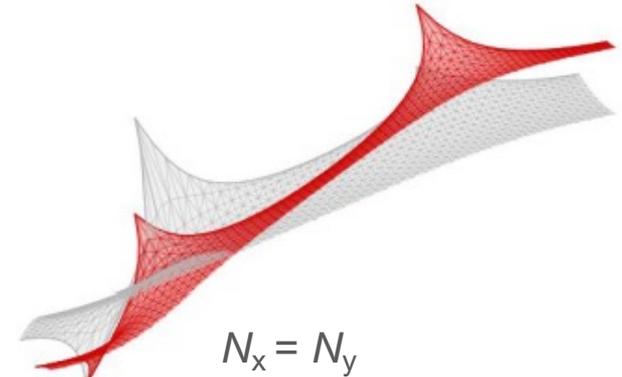


APPLICAZIONE AL PONTE SUL BASENTO

Posizione assegnata ai nodi C ed E (~~F_C~~ ~~F_E~~)



Forza assegnata ai nodi C ed E (~~F_C~~ ~~F_E~~)



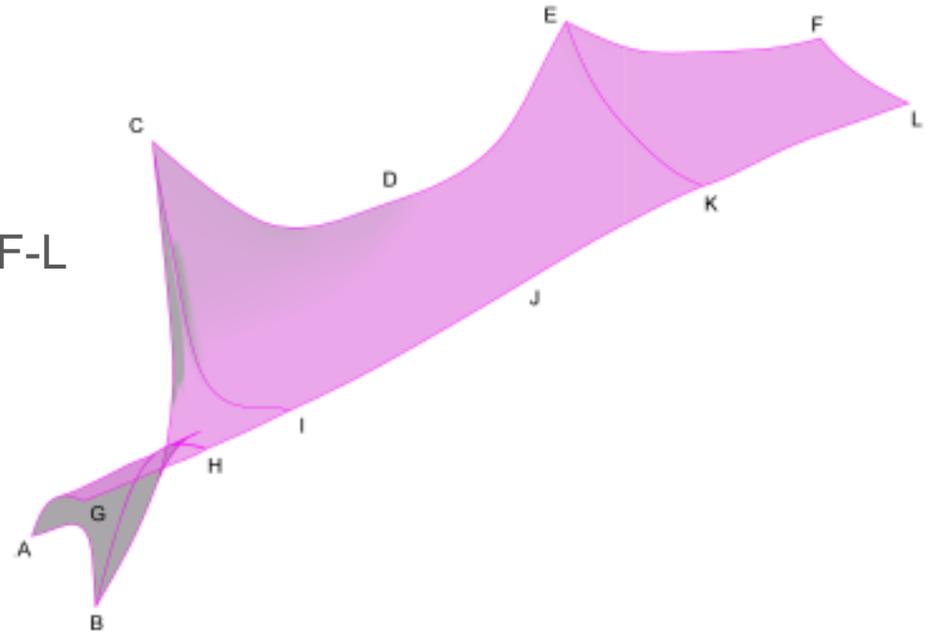
PROCEDURA ITERATIVA

Vincoli:

- Posizione del nodo B
- Posizione orizzontale dei nodi C ed E
- Posizione long. nodi sul bordo A-G e F-L
- Posizione tras. nodi sul bordo G-L
- Carichi:
- Forza verticale sui nodi C ed E
- Peso proprio del guscio in CA

Incognite:

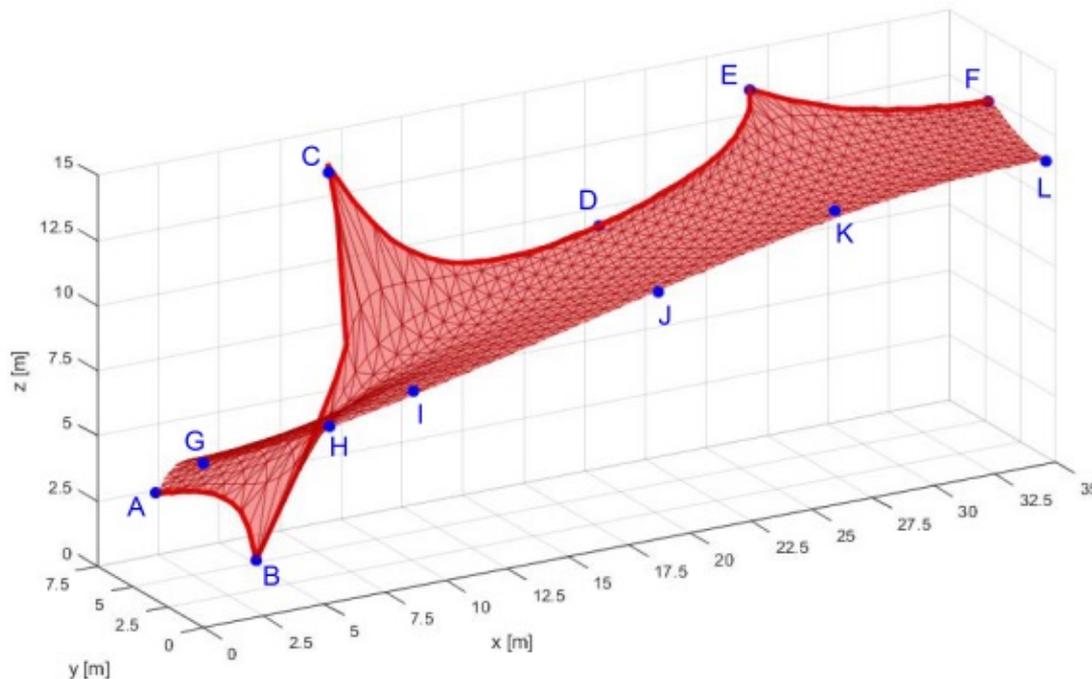
- Densità di tensioni di membrana in 5 regioni del modello
- Densità di forza in 5 regioni del cordolo laterale



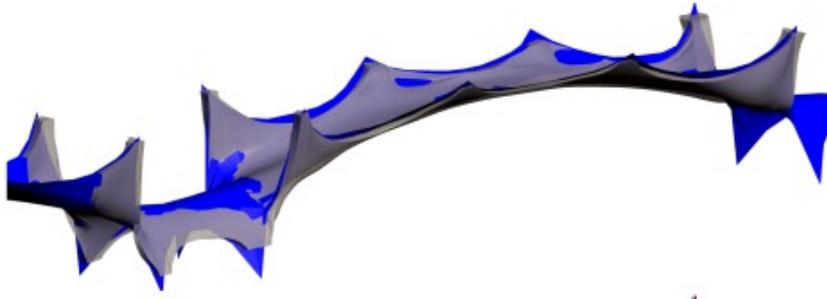
PROCEDURA ITERATIVA

Analisi:

- Algoritmo: Ottimizzazione non lineare (interior point method)
- Iterazioni sul valore delle incognite per minimizzare la distanza tra i nodi A-L e la loro posizione ottenuta dal rilievo fotogrammetrico



VERIFICA DELLA FORMA

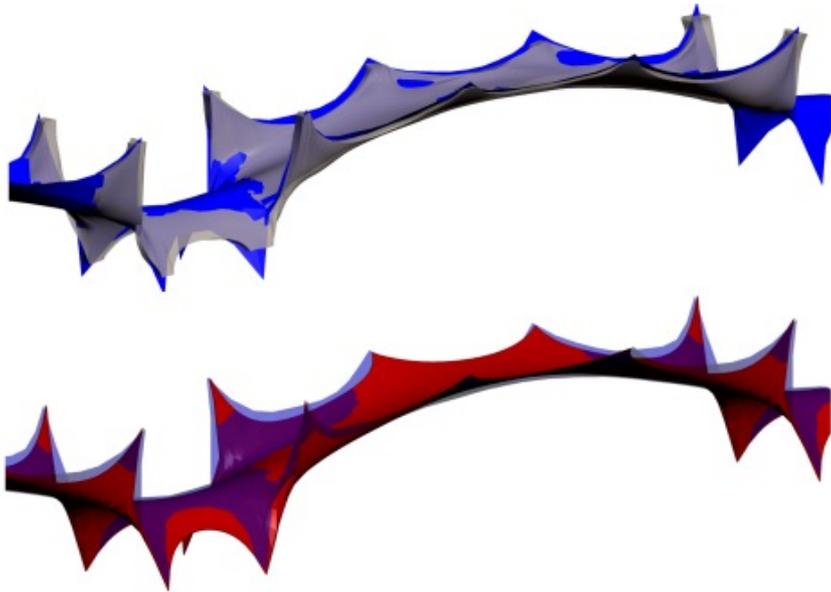


Progetto

Rilievo

FDM

VERIFICA DELLA FORMA

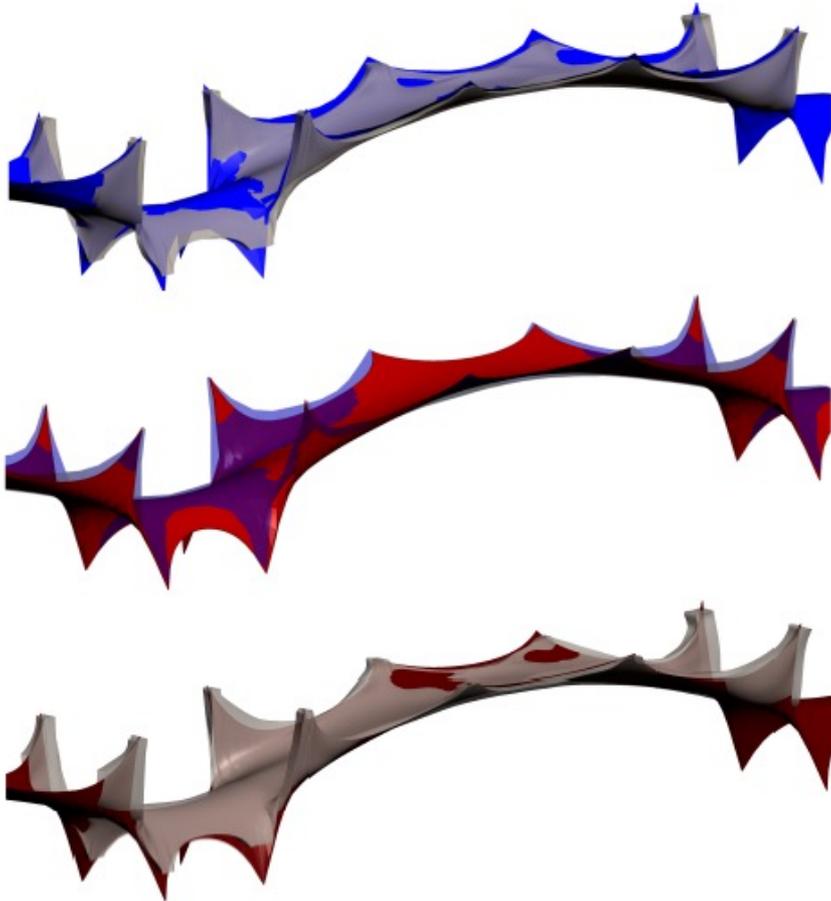


Progetto

Rilievo

FDM

VERIFICA DELLA FORMA

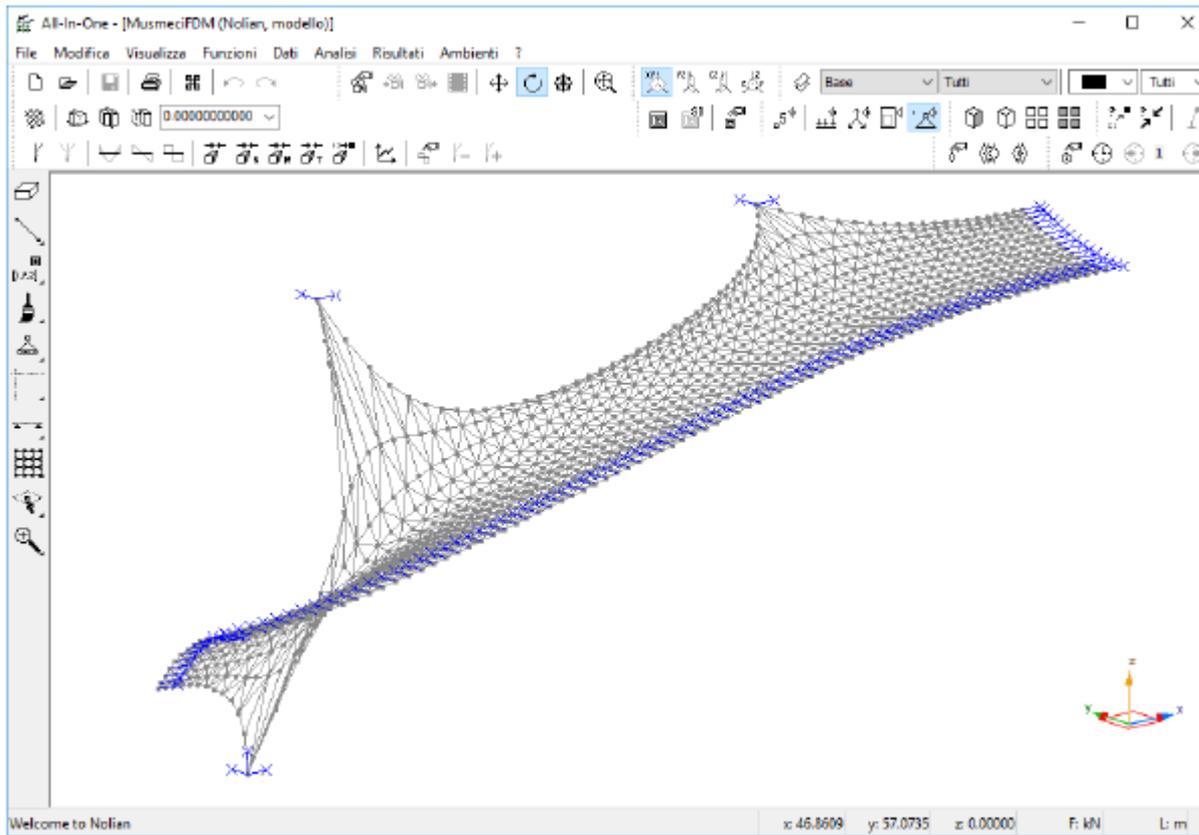


Progetto

Rilievo

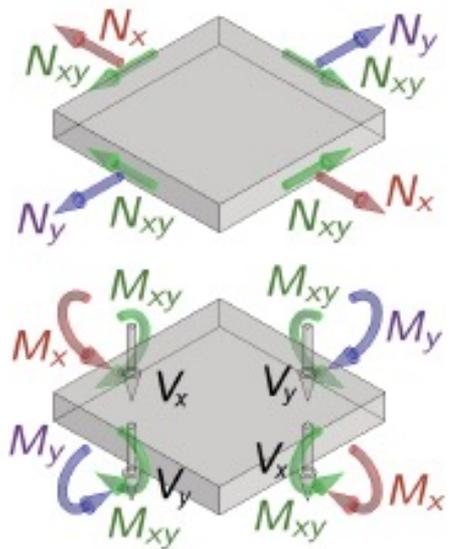
FDM

VALUTAZIONE DELLO STATO TENSIONALE



VALUTAZIONE DELLO STATO TENSIONALE

Componenti di sforzo nei gusci



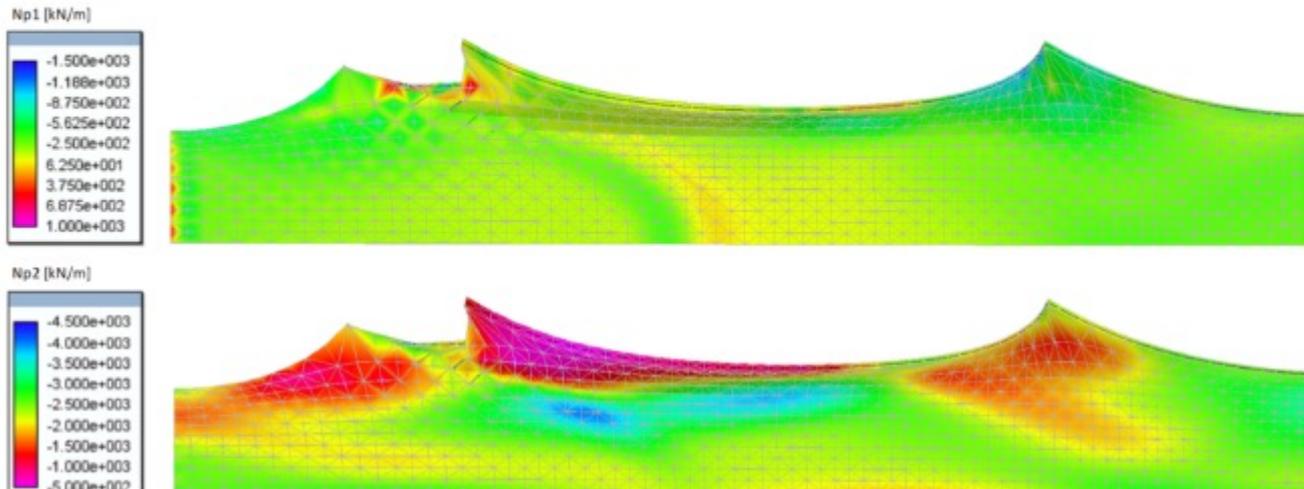
$$\mathbf{N} = \begin{bmatrix} N_x & N_{xy} \\ N_{xy} & N_y \end{bmatrix}$$

$$\mathbf{M} = \begin{bmatrix} M_x & M_{xy} \\ M_{xy} & M_y \end{bmatrix}$$

$$\mathbf{v} = \begin{bmatrix} V_x \\ V_y \end{bmatrix}$$

SFORZI DI MEMBRANA PRINCIPALI

$$N_p = \frac{\text{Tr}N \pm \sqrt{(\text{Tr}N)^2 - 4 \det N}}{2}$$



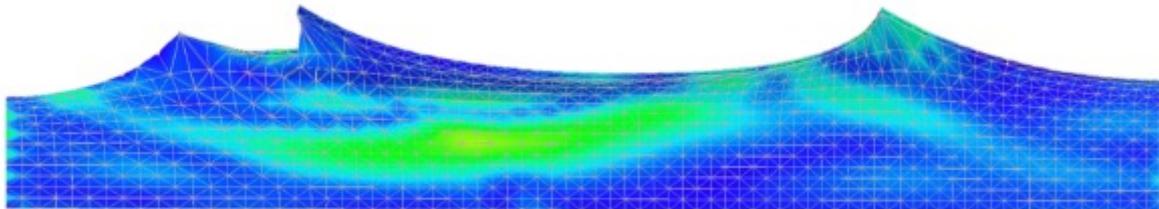
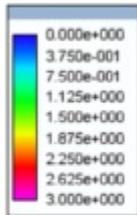
$$N_{p1} = -500 \div -100 \text{ kN/m}$$

$$N_{p2} = -2400 \div -1800 \text{ kN/m}$$

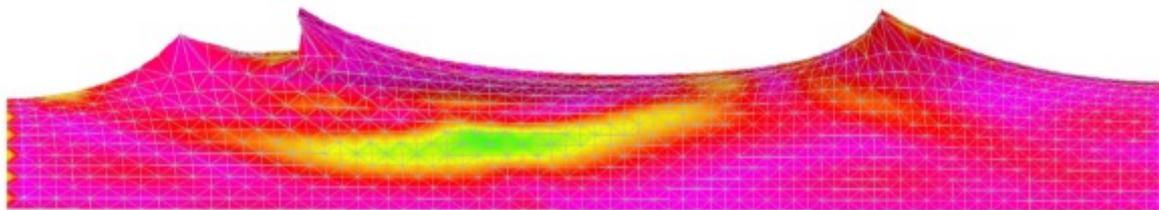
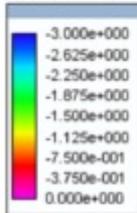
SFORZI FLESSIONALI PRINCIPALI

$$M_p = \frac{\text{Tr}M \pm \sqrt{(\text{Tr}M)^2 - 4 \det M}}{2}$$

Mp1 [kN m/m]



Mp2 [kN m/m]



$$M_{p1} = M_{p2} = \pm 2 \text{ kN m/m}$$

VERIFICA DELLA FUNICOLARITA'

$$\mathbf{n} = \begin{pmatrix} \cos \theta \\ \sin \theta \end{pmatrix} \quad N(\theta) = \mathbf{n}^t \mathbf{N} \mathbf{n} = N_x \cos^2 \theta + 2N_{xy} \sin \theta \cos \theta + N_y \sin^2 \theta$$
$$M(\theta) = \mathbf{n}^t \mathbf{M} \mathbf{n} = M_x \cos^2 \theta + 2M_{xy} \sin \theta \cos \theta + M_y \sin^2 \theta$$
$$e(\theta) = \frac{M(\theta)}{N(\theta)} \quad e_{max} = \max_{\theta} \frac{M(\theta)}{N(\theta)}$$

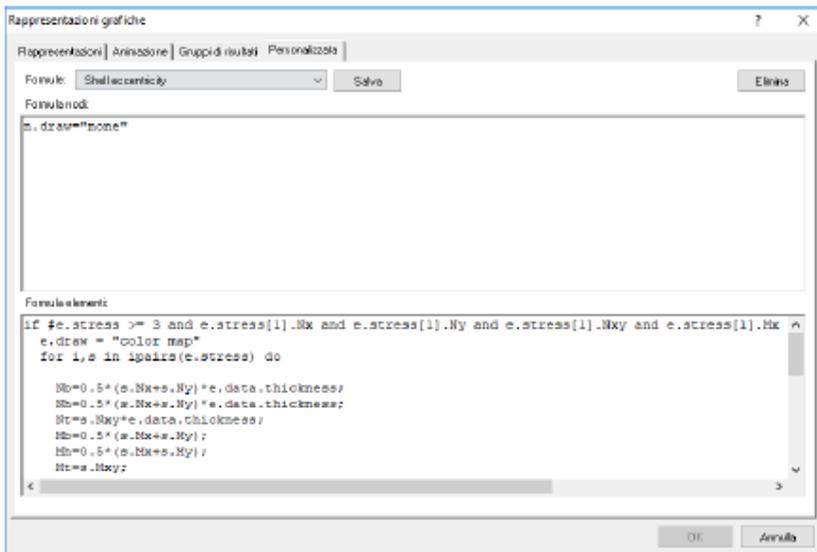
VERIFICA DELLA FUNICULARITA'

$$\mathbf{n} = \begin{pmatrix} \cos \theta \\ \sin \theta \end{pmatrix}$$

$$N(\theta) = \mathbf{n}^t \mathbf{N} \mathbf{n} = N_x \cos^2 \theta + 2N_{xy} \sin \theta \cos \theta + N_y \sin^2 \theta$$

$$M(\theta) = \mathbf{n}^t \mathbf{M} \mathbf{n} = M_x \cos^2 \theta + 2M_{xy} \sin \theta \cos \theta + M_y \sin^2 \theta$$

$$e(\theta) = \frac{M(\theta)}{N(\theta)} \quad e_{max} = \max_{\theta} \frac{M(\theta)}{N(\theta)}$$



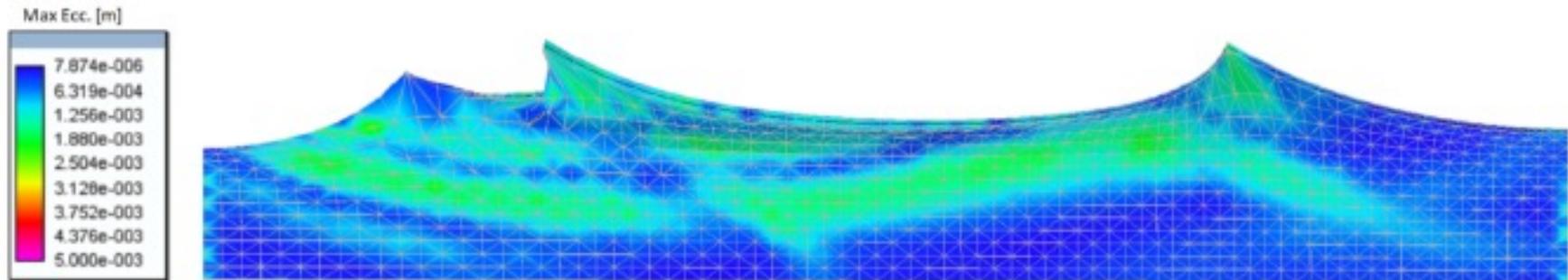
VERIFICA DELLA FUNICULARITA'

$$\mathbf{n} = \begin{pmatrix} \cos \theta \\ \sin \theta \end{pmatrix}$$

$$N(\theta) = \mathbf{n}^t \mathbf{N} \mathbf{n} = N_x \cos^2 \theta + 2N_{xy} \sin \theta \cos \theta + N_y \sin^2 \theta$$

$$M(\theta) = \mathbf{n}^t \mathbf{M} \mathbf{n} = M_x \cos^2 \theta + 2M_{xy} \sin \theta \cos \theta + M_y \sin^2 \theta$$

$$e(\theta) = \frac{M(\theta)}{N(\theta)} \quad e_{max} = \max_{\theta} \frac{M(\theta)}{N(\theta)}$$



CONCLUSIONI

- Il più famoso esempio di form-finding italiano.
- Progettato con approccio numerico-sperimentale.
- Rilievo fotogrammetrico necessario per una forma così complessa.
- Verifica della forma mediante FDM.
- Verifica della funicularità mediante eccentricità generalizzata.

Engineering Structures 191 (2019) 658–673



On the form of the Musmeci's bridge over the Basento river

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Bruno Briseghella^f, Roberto Spagnuolo^g, Yan Xiao^b, Ivo Vanzì^h, Luciano Rosati^h

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ARTICLE INFO

Keywords:
Musmeci
Bridge over the Basento river
Force density method
UAV geometric survey
Form finding
Optimal form
RC shell

ABSTRACT

The bridge over the Basento river in Potenza, Italy, designed by Sergio Musmeci, is supported by a continuous double-curvature RC shell optimized to reduce bending forces. This 300 m long bridge can be considered as a unique representative example of pioneering research on the design and construction of optimized structures.

First, the design process employed for determining the form of the shell and the relevant constructive issues are described. A refined 3D geometric model of the shell is then obtained through an aerial survey carried out by a commercial UAV and a photogrammetric image-based reconstruction. A recent formulation of the Force Density Method allowing for non-isotropic stress state is employed to numerically derive the form of the supporting shell; it is validated versus the surveyed geometry of the shell by employing a nonlinear optimization procedure in order to identify forces and stresses to be used as input parameters. Finally, the derived form of the shell is tested by a Finite Element analysis to verify its funicular efficiency, i.e., whether it is capable to withstand design loads by pure membrane actions.

LA THRUST NETWORK ANALYSIS

Metodo per la ricerca di forma e la verifica di funicularità.



Originally formulated by
O'Dwyer (1999)
Mainly developed by
Block (2007)
Noticeable extensions:
Fraternali (2010)
Fantin & Ciblac (2016)

Block - Armadillo (2016)

LA THRUST NETWORK ANALYSIS

Metodo per la ricerca di forma e la verifica di funicularità.

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Journal homepage: www.elsevier.com/locate/comstruct

Reformulation and extension of the thrust network analysis

Francesco Marmo*, Luciano Rosati

Dipartimento di Strutture per l'Ingegneria e l'Architettura, Università degli Studi di Napoli Federico II, Italy

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Thrust network analysis
Masonry vaults
Isostatic polygons

ABSTRACT

We address the Thrust Network Analysis (TNA), i.e. the methodology for modeling masonry vaults as a discrete network of forces in equilibrium with gravitational loads, first contributed by O'Dwyer and fully developed by Betti and Cosserotti. Reducing the task by the quoted authors in terms of a graphical interpretation of the method, we reformulate the original version of the TNA by discarding the dual grid and leaving only as the primal grid, thus significantly enhancing the computational performances. The proposed reformulation of the TNA is also extended by including horizontal forces in the analysis as well as holes or free edges in the vault. Furthermore, the coefficient matrices relating the solution scheme are obtained by assembling the separate contributions of each branch, thus avoiding the ad hoc node numbering and branch orientation required by alternative implementations. Numerical examples, some of which referred to vaults having a particularly complex geometry, show the effectiveness and robustness of the proposed approach in assessing the safety conditions of existing masonry vaults or in designing new ones.

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INTERNATIONAL JOURNAL OF ARCHITECTURAL HERITAGE
2016, VOL. 12, NO. 6, 799-819
<http://dx.doi.org/10.1080/15483883.2016.1243867>

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Thrust network analysis of masonry helical staircases

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Dipartimento di Strutture per l'Ingegneria e l'Architettura, Università degli Studi di Napoli Federico II, Napoli, Italy

ABSTRACT

We exploit a recent generalization of the Thrust Network Analysis (TNA) to analyse masonry structures of extremely complicated and audacious geometry such as helicoidal staircases. Actually, differently from available methods, based on ad-hoc solutions holding for each particular structure, the TNA allows for studying the equilibrium of structures of arbitrary shape by invoking the principles of limit analysis of masonry structures dictated by Heyman. Four paradigmatic monumental staircases, with increased degree of complexity, have been selected as case studies in order to show the versatility and accuracy of the proposed approach. The results entailed from the generalized TNA are also successfully compared, for the first time in the literature, with those related to the adoption of available analytical methods for the analysis of no-tension membranes.

ARTICLE HISTORY

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KEYWORDS

masonry helical staircase;
no-tension membranes;
thrust network analysis

Historical study and static assessment of an innovative vaulting technique of the 19th century

Francesco Marmo, Nicola Ruggieri, Ferdinando Toraldo, and Luciano Rosati

Dipartimento di Strutture per l'Ingegneria e l'Architettura, Università degli Studi di Napoli Federico II, Napoli, Italy; Parco Archeologico di Pompei Ministero dei Beni e delle Attività Culturali e del Turismo, Pompei, Italy

ABSTRACT

We report on a historical study and on the evaluation of the structural performance of an innovative vaulting system developed in the 17th and 18th centuries. This peculiar construction technique, which employed clay hollow cylinders as construction blocks, was used to reduce erection times and costs as well as to guarantee several static and functional benefits connected to the reduced weight and high bolting performance of these elements. The static performance of the structure is assessed by employing the Thrust Network Analysis technique, a recently formulated methodology used to study the equilibrium of masonry shells. It is shown by numerical computations that the actual geometry of these structures sensibly influences their equilibrium. For this reason, the combination of several innovative surveying techniques has been employed to increase the accuracy of the geometrical model.

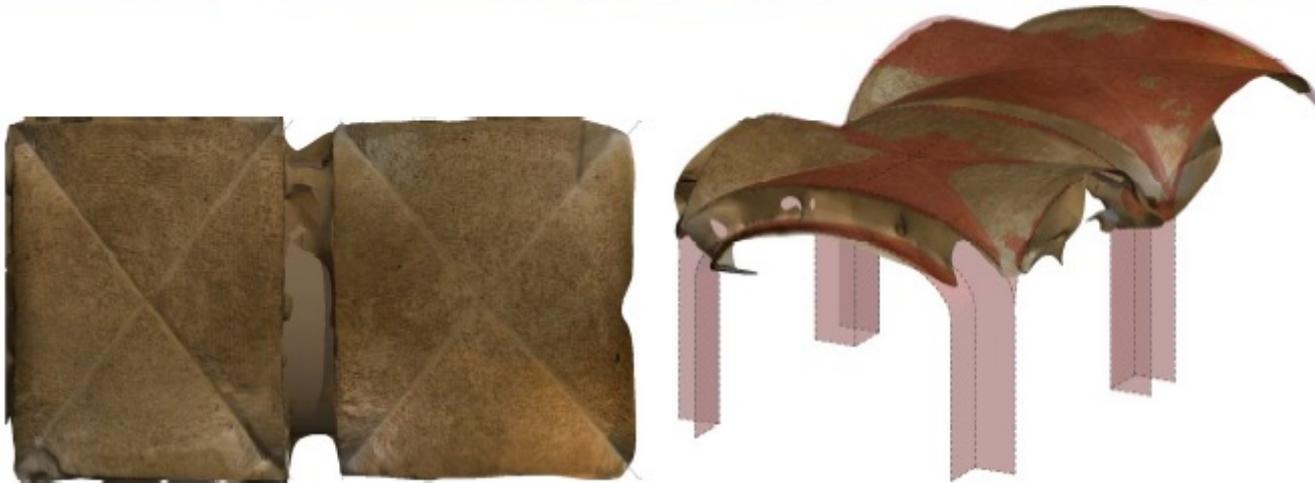
ARTICLE HISTORY

Received 28 February 2016
Revised 9 May 2016
Accepted 11 May 2016

KEYWORDS

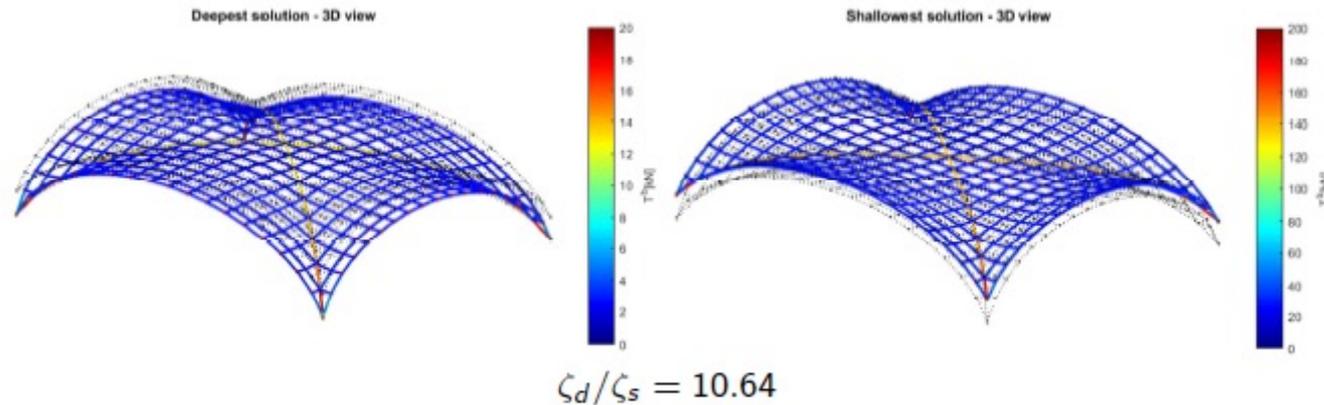
Rittle vaults; history of constructions; limit analysis; masonry structures; no-tension material; thrust network analysis

Analisi di una volta a crociera: Palazzo Marincola (Catanzaro)

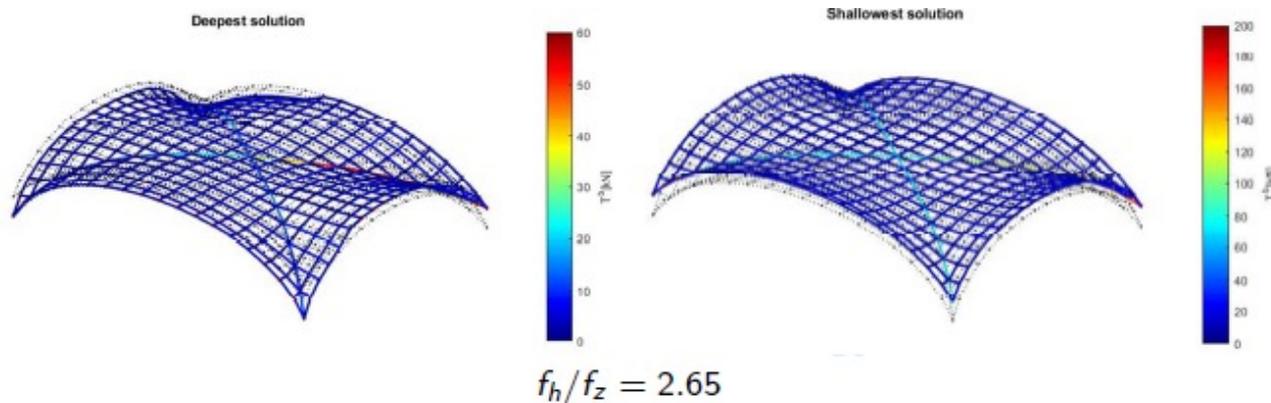


Analisi di una volta a crociera: Palazzo Marincola (Catanzaro)

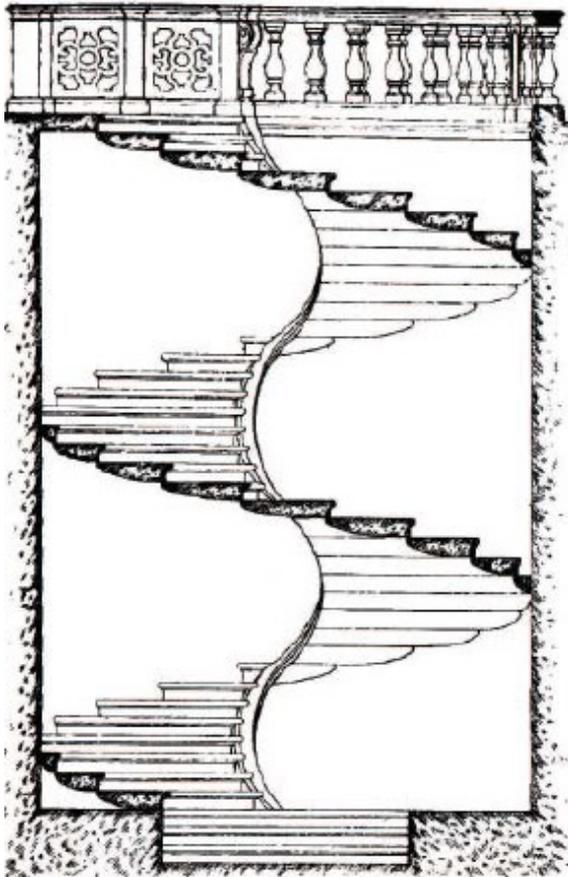
Volta soggetta a carichi gravitazionali



Volta soggetta a carichi gravitazionali e sismici



Analisi della scala elicoidale che conduce alla Biblioteca della Certosa di Padula



Sacco, La Certosa di Padula disegnata, descritta e narrata su documenti inediti, 1916

Analisi della scala elicoidale che conduce alla Biblioteca della Certosa di Padula

