

Tensegrity bridges

2000



Bridge of Masts
J. den Hollander



2009



Kurilpa Bridge
Cox Architecture and Arup

Optimal design of Tensegrity bridges

Influence of random loads



doctiris
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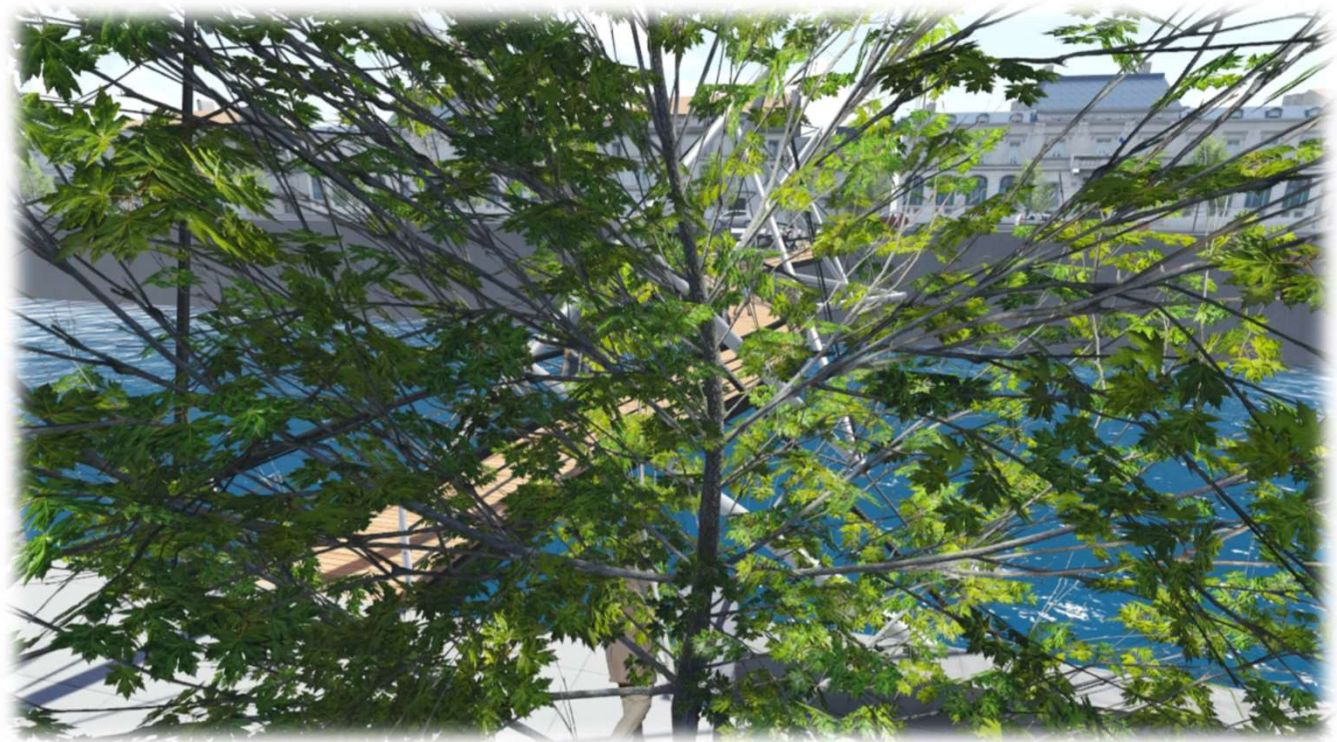
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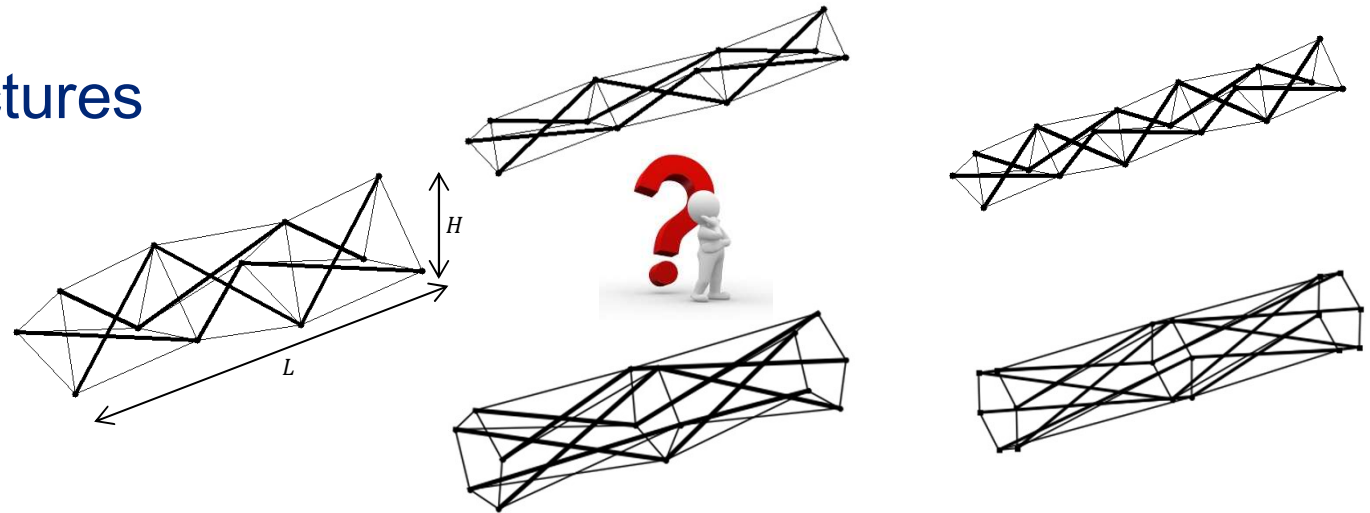
P. Mangeot



Thursday, October 10, 2019



Infinity of structures



Non Linear Solver

Parameters

Performances

Span L	Load F	Geometry S, H	Area A_1, \dots, A_n	Inertia I_1, \dots, I_n	Material E, σ, ρ	Prestress P_1, \dots, P_n

Static δ, V



Original article

Latteur P., Feron J., Denoël V. 2017.
A design methodology for lattice and tensegrity structures based on a stiffness and volume optimization algorithm using morphological indicators, *International Journal of Space Structures*; 32 (3-4): 226-243.

Abstract
This article presents a design methodology based on a stiffness and volume optimization algorithm for three-dimensional nonlinear hyperstatic and pre-stressed structures composed of elements only subjected to axial forces, with a special emphasis on tensegrity structures. The algorithm is based on dimensionless numbers called morphological indicators that allow finding, within a given family of structures, the geometry related to a maximum stiffness or a minimum volume of materials or the best ratio between stiffness and volume. The algorithm takes into account the buckling of the struts and different materials for cables and struts. This article first demonstrates the optimization algorithm and then gives numerical confirmations and examples.

Keywords
design methodology, lattice, mass, morphological indicators, optimization, stiffness, tensegrity, volume

Introduction and historic of morphological indicators

Tensegrity structures are part of a fascinating field of structural engineering and architecture. Indeed, Skelton and De Oliveira¹ point out that they could bring innovative solutions by taking inspiration from behaviors observed in the nature (deployment, control, etc.). But the fact that very few tensegrity-based civil structures have been built around the world illustrates that they are largely unknown, or at least a source of mistrust, to most practitioners, architects, and engineers. There are several reasons that can explain this fact, but among them, certainly the design and construction complexity and the nonlinear behavior which implies pre-stressing to reach the desired stiffness (Figure 1) and which can lead to an adverse effect on the volume of materials used for the structure. For tensegrity structures, the optimization of stiffness and volume is a key aspect, and the optimization of stiffness and volume is often, more than for any other kind of structure, a great challenge for the designers, a great challenge due to the great amount of parameters that characterize a structure: the span, the width, the height, the shape, the characteristics of the cross

sections, the buckling lengths, the pre-stress, and so on. However, materials, the loads, the pre-stress, and so on. However, optimization and form-finding algorithms can lead the designers to select the feasible ranges of tensegrity-based civil structures. Skelton and De Oliveira¹ already multi-optimization and form-finding algorithms can lead the designers to select the feasible ranges of tensegrity-based civil structures. Skelton and De Oliveira¹ already multi-efficient behavior in compression and bending. Tibert and Pellegrino² summarize the form-finding methods for tensegrity structures and classify them into two categories: the first one contains kinematical methods which determine the configuration of either maximal length of the struts or minimal length of the cables, while the second

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Feron J., Boucher L., Denoël V., Latteur P., 2019.
Optimization of footbridges composed of prismatic
Tensegrity modules, *ASCE's Journal of Bridge
Engineering*; 24 (12): 1-28.

Abstract: The architectural potential of tensegrity structures is proven. Yet, paradoxically, very few real construction projects have been built around the world. The main reasons are complex construction processes, lack of design and optimization guidelines, and excessive self-weight due to the prestress needed to guarantee stiffness and dynamic behavior. Hence, optimizing the stiffness and self-weight is a key aspect when designing a tensegrity footbridge. Previous research has demonstrated the validity of a design and optimization methodology based on morphological indicators, that identifies geometry with a maximum stiffness and/or a minimum self-weight for a family of structures. In this paper, that methodology is applied to footbridges composed of tensegrity modules comprising simplex, quadruplex, pentaplex, and hexaplex types. A comparison of the stiffest and lightest structures is provided, a practical case study is developed, and the relevance and feasibility of such tensegrity footbridges are discussed. As a result, the study provides advice on optimum footbridge topologies with the following characteristics: excellent stiffness and dynamic behavior; efficient structures composed of simplex modules; and self-weight that is still rather high but similar to that of bent structures, although with potential to be reduced thanks to optimization of the prestress scenario.
DOI: 10.1061/(ASCE)JB.1943-5592.0001438. © 2019 American Society of Civil Engineers.

Author keywords: Tensegrity; Footbridge; Optimization; Feasibility; Stiffness; Volume; Mass; Self-weight; Morphological indicators.

State of the Art and Objectives

Tensegrity is a word with controversial definitions (Hansen 2012). The term tensegrity system often refers to a system in a stable self-equilibrated state comprising a discontinuous set of compressed components inside a continuous set of tensioned components (Moussier 2005). In order to widen the potential of tensegrity to engineering applications, it is also often considered that a tensegrity structure may have a compressive component in contact on a single node. In this case, Skelton and de Oliveira (2009, pp. 1-7) wrote about a structure "of class K." Extended tensegrity refers, in this article, to other definitions of tensegrity. This includes, among others, structures with some members subjected to bending moments or structures that are prestressable only if supports exist.

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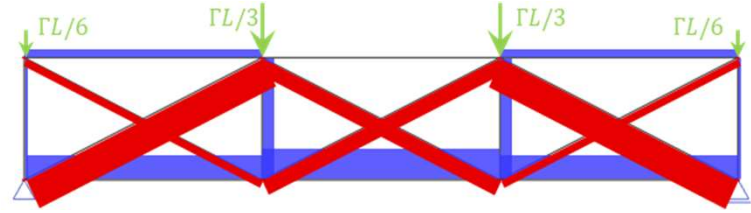
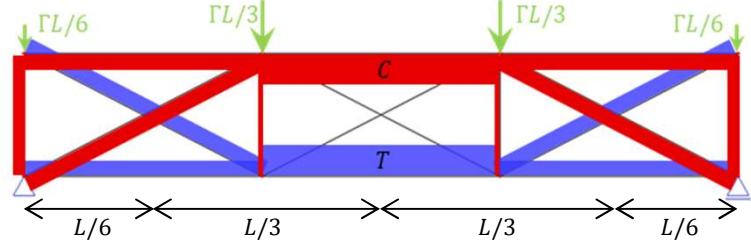
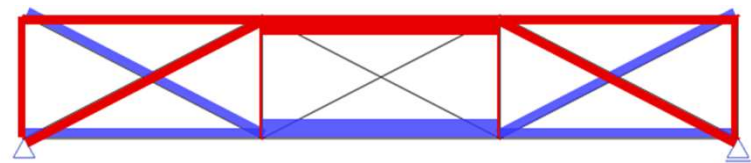
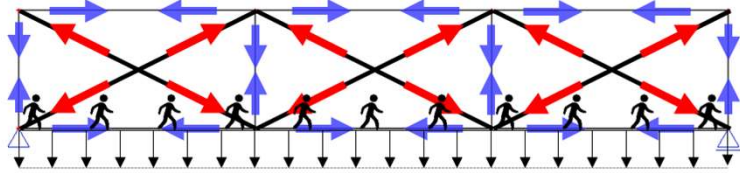
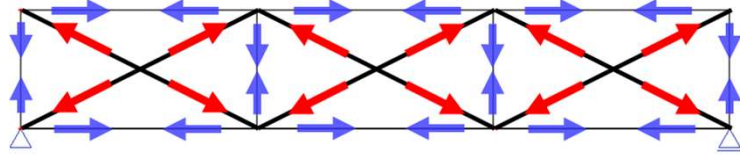
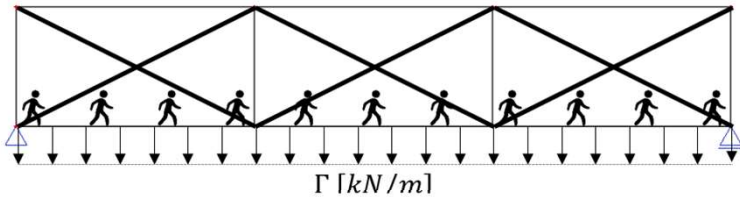
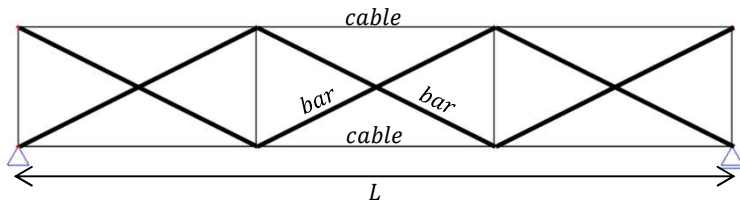
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Although tensegrity and extended tensegrity structures have found a significant place in scientific papers these last decades, the topic of tensegrity applied to footbridges is relatively absent in the literature. Gómez-Járegui (2010) established a large state of the art about tensegrity structures and their application to architecture. He cited some authors suggesting the use of tensegrity for bridge applications, but his investigations did not reveal any existence of tensegrity-based bridge proposals before 2004. He also cited some authors describing structures having, according to them, a high stiffness and economical design. Other cited authors, on the contrary, were more skeptical about the performances of tensegrity structures in comparison with more classical structures. Yet nowadays there is still a lack of rigorous and quantitative proofs about the structural efficiency or inefficiency of tensegrity structures for engineering applications, in particular bridges and footbridges.

Fig. 1 shows a few creative prototypes with high architectural potential, which, however, never reached the construction stage. In his 2004 master's thesis, Gómez-Járegui (2010) proposed a concept based on a succession of simplex modules (Fig. 1(a)). Architect from the firm WilkinsonEyre (2004) and the structural engineer C. Balmond from Arup developed a prototype of a 35-m-long tensegrity bridge composed of a mesh of tetrahedral cells (Fig. 1(b)). The footbridge was designed to span the Great Hall of the National Building Museum in Washington, DC, and to react to palestinian by lighting the glass struts as they were subjected to changing stresses (Dawey and Foster 2007). Michdemi et al. (2005) presented the Tor Vergata footbridge (Fig. 1(c)), a 32-m-long Class 2 tensegrity footbridge composed of expanded octahedron modules. The height (3.6 m), the number of modules (five), and the sections of the struts (193 mm diameter, 12 mm thick) and of the cables (72 mm) (193 mm deflection of 8 cm under the maximum load) were chosen in order to find a compromise between (deflection) and cost etc.

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Uniform load distribution



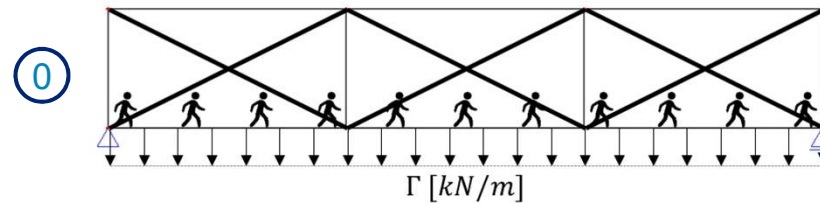
What is the worst distribution ?

Uniform or Random

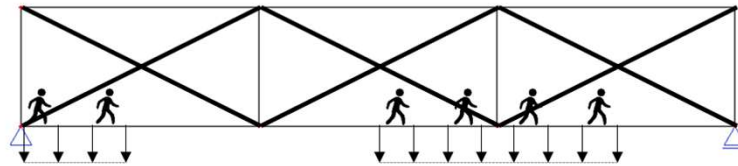
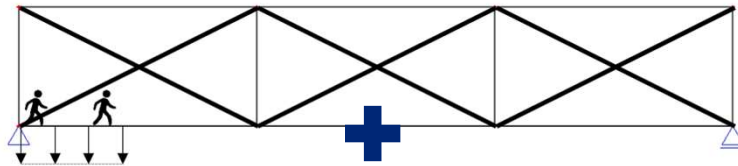
Required Prestress ?

Dimensions A_c, A_b ?

Deflection δ ?

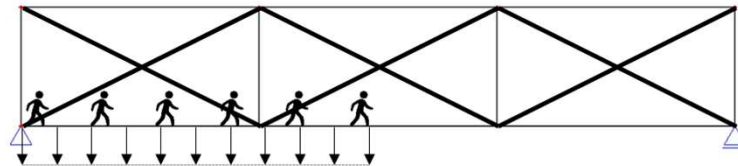
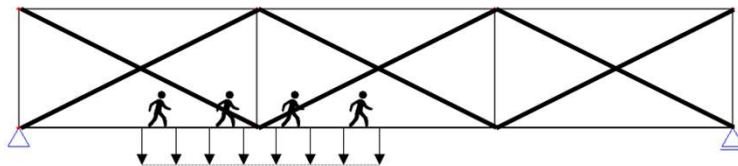


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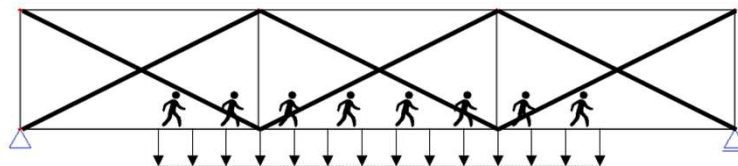
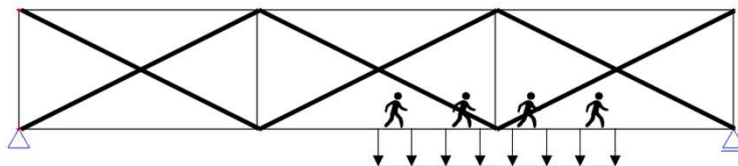
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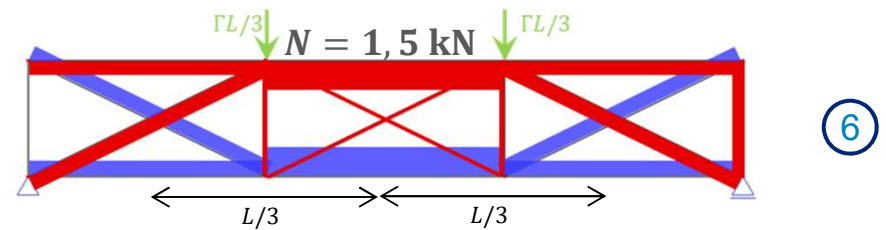
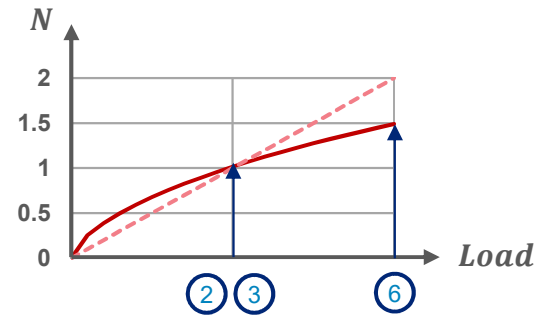
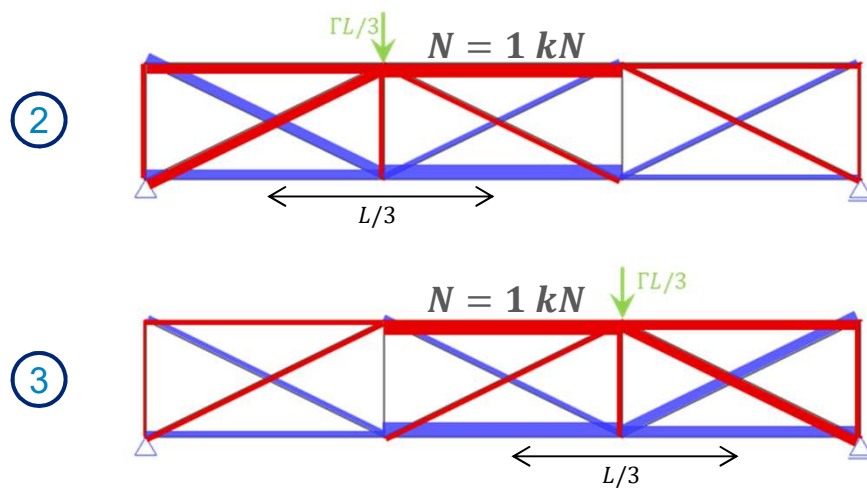
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Superposition principle

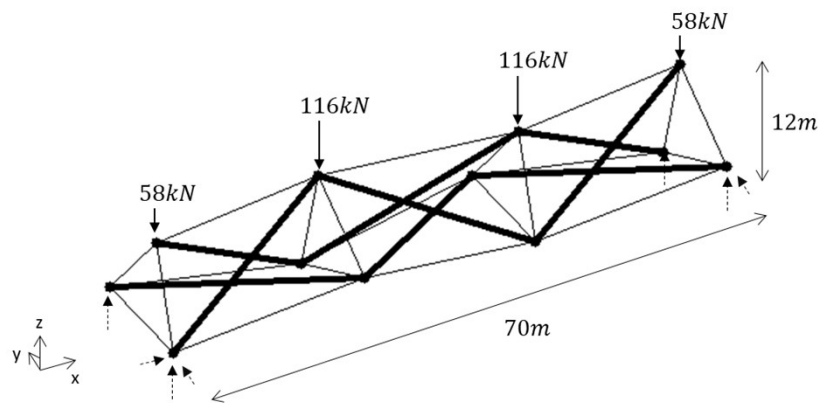
Non Linear behavior



- Calculate every load combination
- Keep the worst results :
 - Highest Prestress
 - Biggest Dimensions $A_c, A_b \rightarrow$ Volume V
 - Largest Deflection δ

Influence on optimal design

Uniform distribution

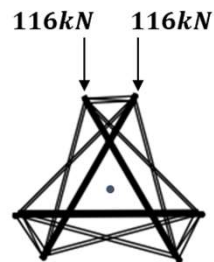


Distributed load
 $\Gamma = 5kN/m$



Steel

$\sigma = 200MPa$
 $E = 200GPa$
 $\rho = 77kN/m^3$

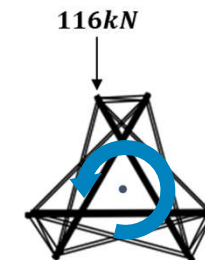
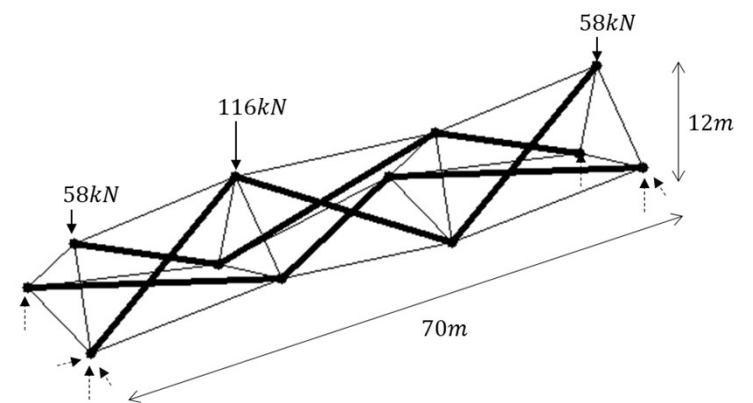


$\delta = 83\text{ mm}$

43 tons

Worst Random distribution

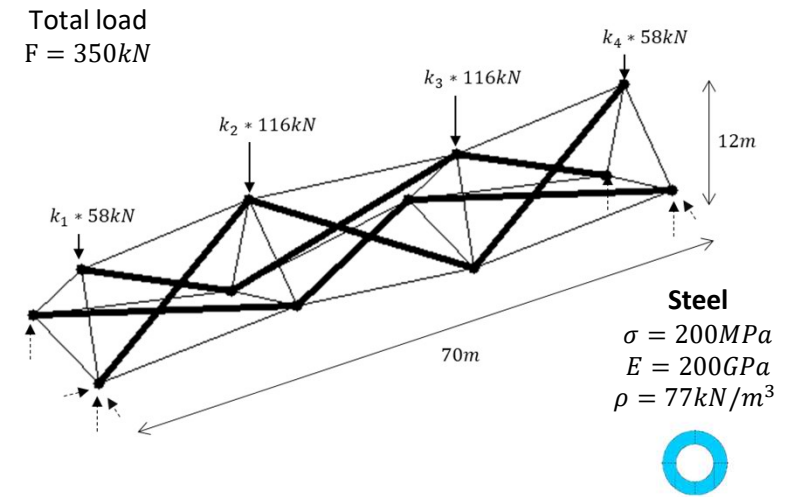
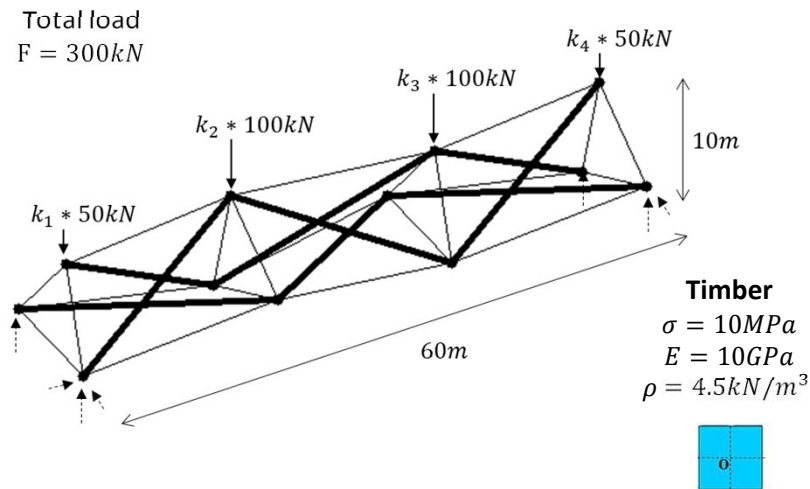
$(k_1 = 1, k_2 = 1, k_3 = 0, k_4 = 1)$



$\delta = 127\text{ mm}$

Morphological Indicators

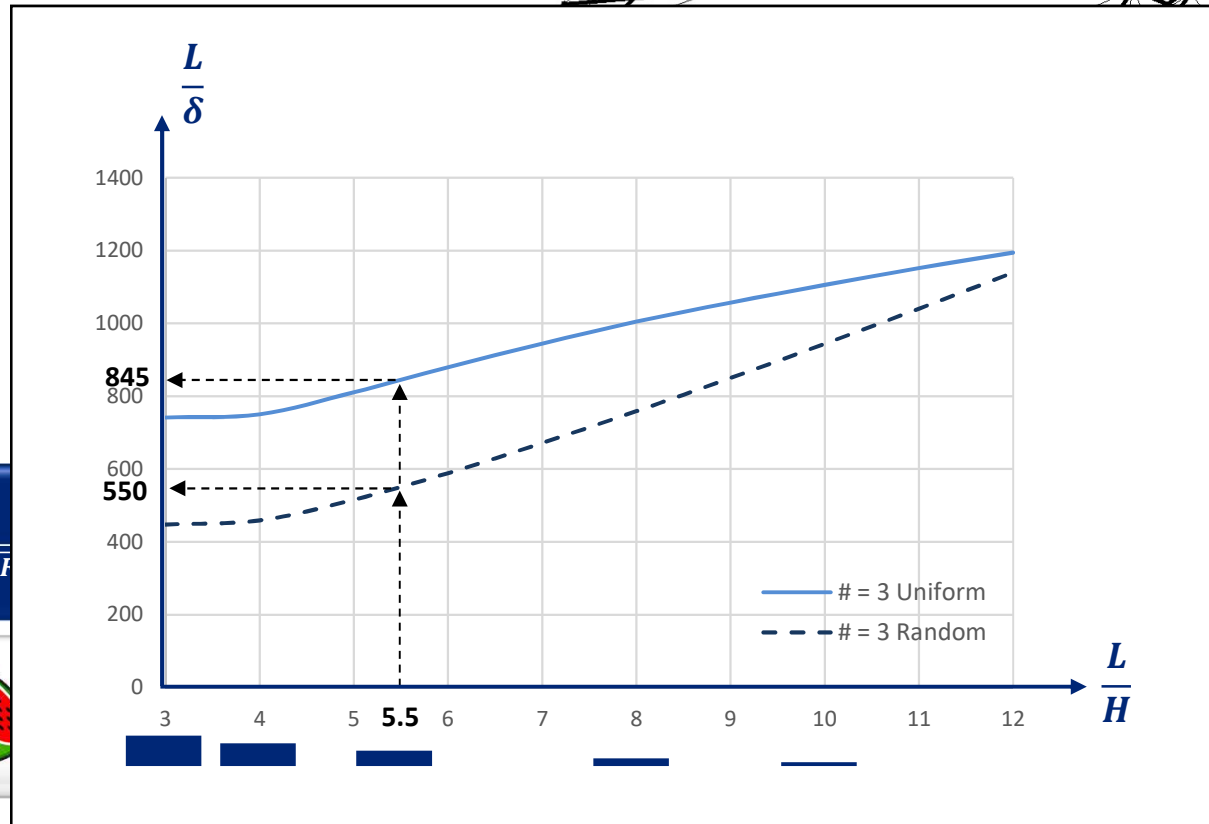
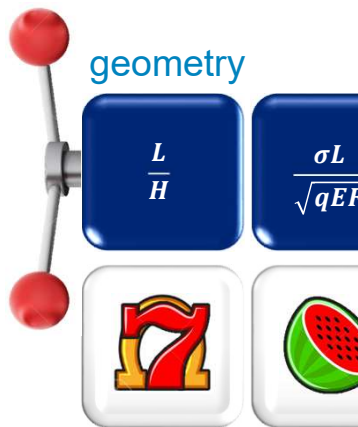
$$\frac{L}{H} = 6 \quad \frac{\sigma L}{\sqrt{qEF}} = 38 \quad \frac{\rho L}{\sigma} = 0.027 \quad \frac{E}{\sigma} = 1000 \quad \frac{P}{F} = 2$$



$$\frac{\sigma V}{FL} = f\left(\frac{L}{H}, \frac{\sigma L}{\sqrt{qEF}}, \frac{\rho L}{\sigma}, \frac{E}{\sigma}, \frac{P}{F}\right)$$

$$\frac{L}{\delta} = f\left(\frac{L}{H}, \frac{\sigma L}{\sqrt{qEF}}, \frac{\rho L}{\sigma}, \frac{E}{\sigma}, \frac{P}{F}\right)$$

Optimization



Conclusion

- Uniform IS the worst distribution governing the design of prestress and dimensions
- Tensegrity forms are highly sensitive to live loads distribution
 - Random distribution MUST be considered for serviceability checks
 - Uncomfortable vibrations might be induced by moving pedestrians
- Morphological indicators
 - Allow rigorous and quantitative comparison of efficiency
 - Reduce the amount of optimization's parameters
 - Are dimensionless numbers linking small scale and full scale structures

Thank you for
your attention !

