# Increasing the Stiffness creating Self-Balancing structures

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## 1.Introduction

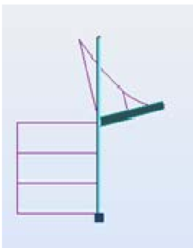
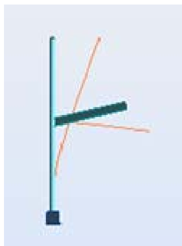
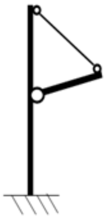
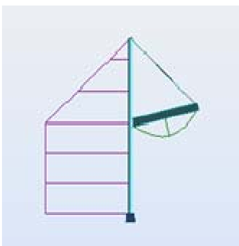
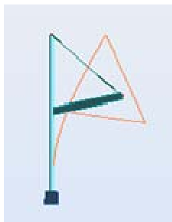
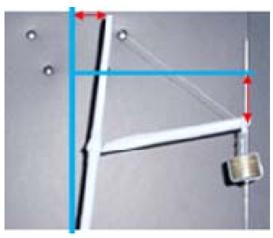
In order to increase the stiffness of a structure without reducing its height or span, different elements that balance the internal forces can be incorporated.

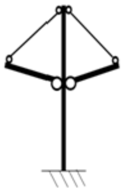
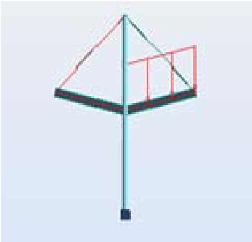
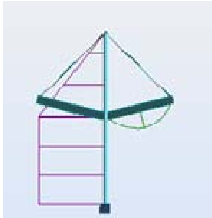
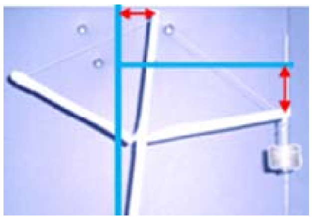
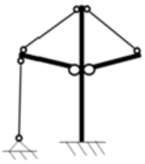
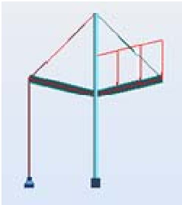
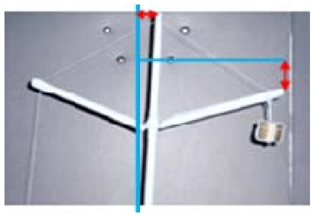
Due to the fact that they work only in tension, cables are among the most efficient elements that achieve this purpose.

## 2.Computer model and physical model

A computer model and a physical model have been developed to prove how the stiffness is gradually increased after incorporating cables and some other additional structural elements.

The following table shows the results obtained after having analysed four similar structures with these models. Self-weight of the structure and an additional load on the beam have been considered.

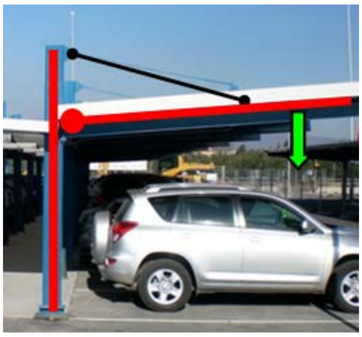
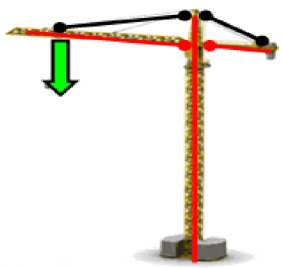
| | COMPUTER MODEL | | | PHYSICAL MODEL |
|---|---|---|---|---|
| | **Geometry and loading** | **Bending moment** | **Deflected shape** | **Deflected shape** |
| **Model 1**  |  |  |  | (*) |
| | - The beam is *rigidly jointed* to the column.<br>- The *second moment of area (I)* of the cross section of the beam has to be *big enough* so as to *resist the bending moment* and *reduce the deflection* at the free end. | | | |
| **Model2**  |  |  |  |  |
| | - The connection between the beam and the column is *nominally pinned*.<br>- The *second moment of area (I)* of the cross section of the beam *can be smaller* that the one in "Model 1" as the design bending moment ($M_{Ed}$) is smaller.<br>- If there were not a cable, the structure would be a mechanism. Therefore, the *cable reduces the deflection at the free end.* | | | |

| | | | | |
|---|---|---|---|---|
| **Model 3**  $\delta_3 < \delta_2$ |  |  |  |  |
| | - The *bending moment of the column is smaller* than in "Model 2" as the effect of the self-weight and the external load applied on the right beam is *partially balanced* by the self-weight of the left beam.<br>- As a result, the *deflection* in"Model3" is *smaller* than the deflection in "Model 2". | | | |
| **Model4**  $\delta_4 < \delta_3 < \delta_2$ |  |  |  |  |
| | - The *bending moment of the column* is almost completely *self-balanced*.<br>- As the internal forces are much smaller than the ones in "Models 1, 2 and 3", the *stiffness is* bigger. | | | |

(*) There is not a physical model due to the difficulty of creating a perfectly rigid joint.

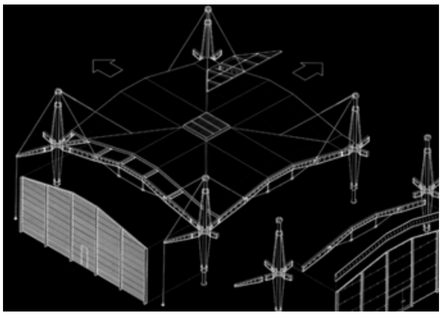
### 3.Practical examples

The models that have been previously described are widely used in very common structures:

| **Model 1:** Car park | **Model 2:** Car park | **Model 3-4:** Crane |
|---|---|---|
|  |  |  |

However, this simple structural concept is also the basis of more complex and famous buildings such as the following ones in which bigger areas or heights are reached:

<u>*Renault Centre Swindon (Norman Foster, 1982):*</u>

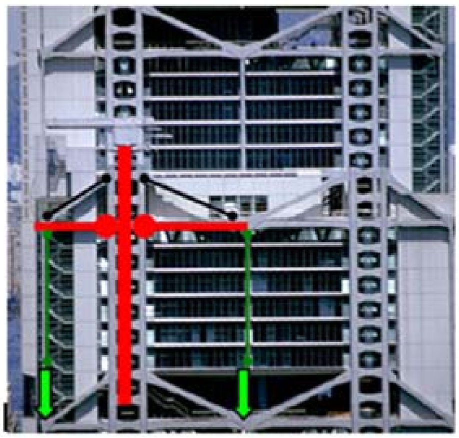


The self-balancing structure is two-directional and creates a 24m$^2$ module.

The whole building is created by attaching several modules, which provides a huge flexibility on its shape and geometry, as well as allowing future expansion.

*Headquarters for the Hongkong Shangai Banking Corporation (Norman Foster, 1986):*

This skyscreeper was conceived as a suspension structure that is based on the same principle of reducing the internal forces in order to provide lateral stability.



**4.References**


- Tianjian, J. and Bell, A.(2008) *Seeing and touching structural concepts*.[e-book].Oxon: Taylor & Francis. Available from: http://www.dawsonera.com/ [accesed 22 October 2011]

- Abel, C. (1991). *Renault Centre Swindon 1982. Architect: Norman Foster.* 1st ed. London:Architecture design and Technology Press.

- http://www.fosterandpartners.com/[accessed 22 October 2011]