



Introduction to 1.5-Layer Space Frames

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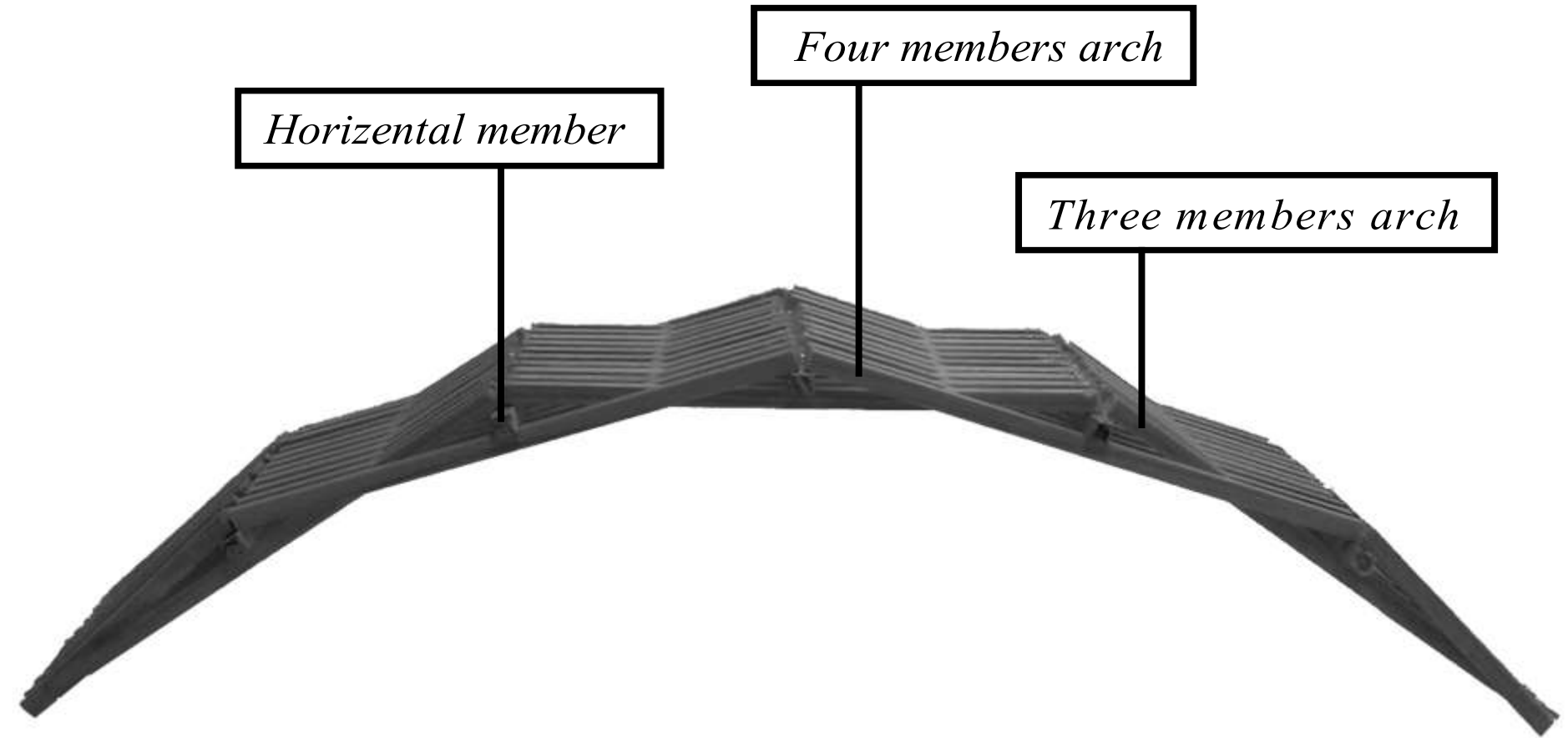
**Hachinohe Institute of
Technology**

Qingming Shanghe Tu

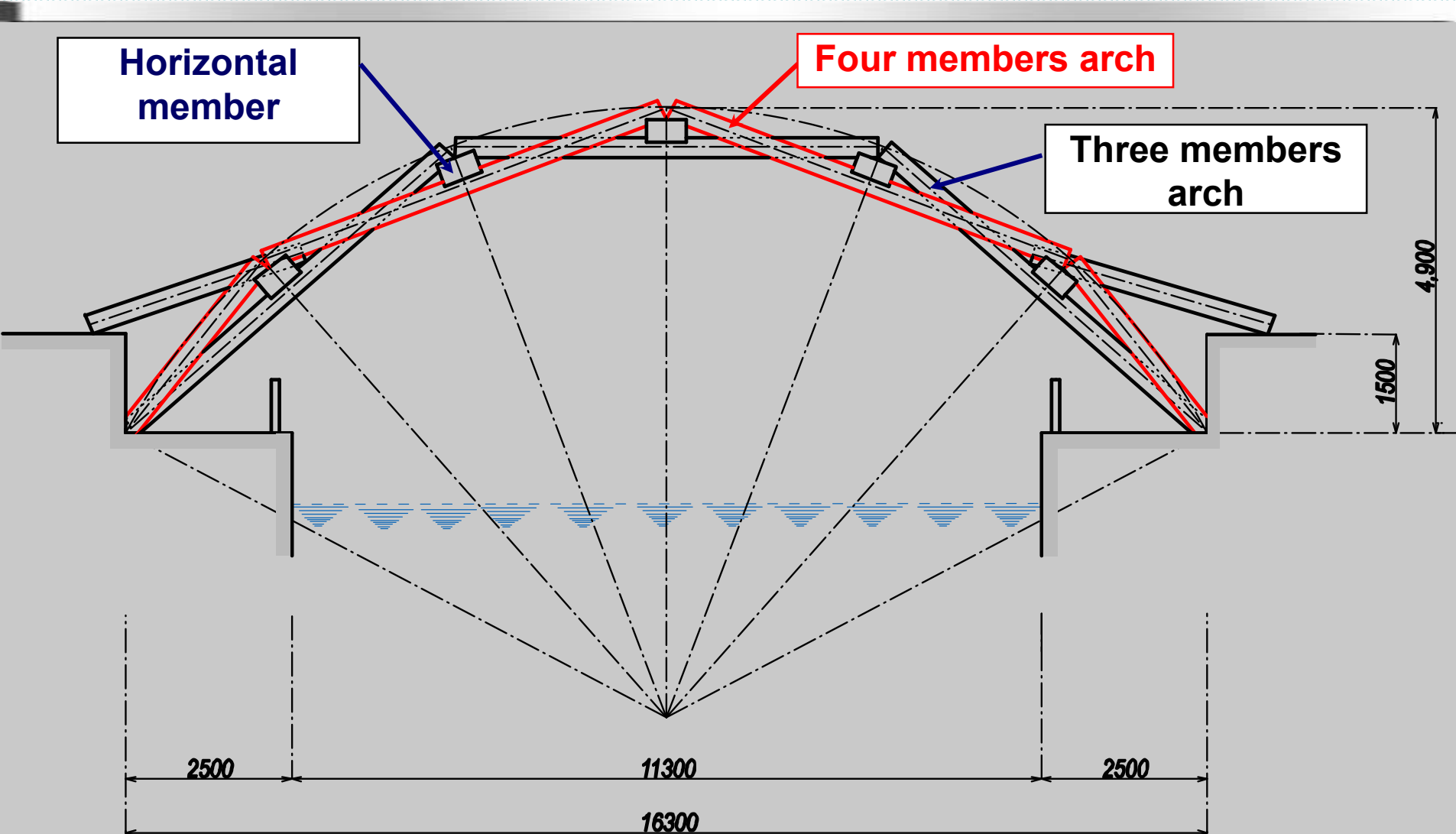


528cm in length , 24.8cm in width
Northern Song Dynasty (A.D. 960-1127)

The Study Model



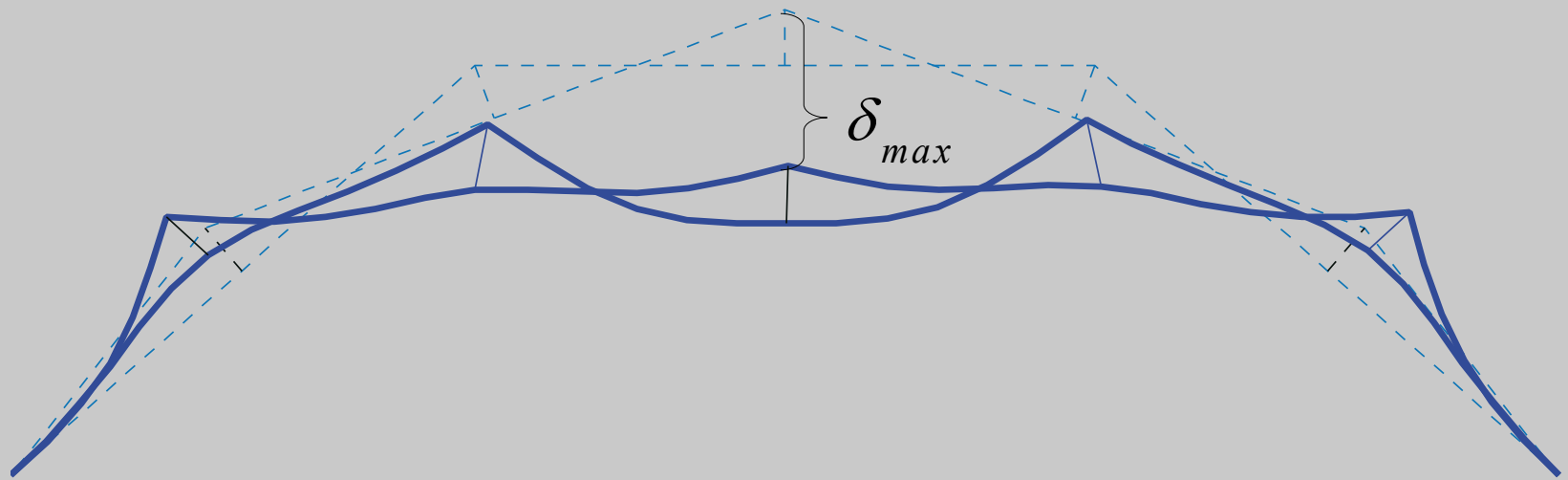
Elevation Section



Model of Hongqiqao

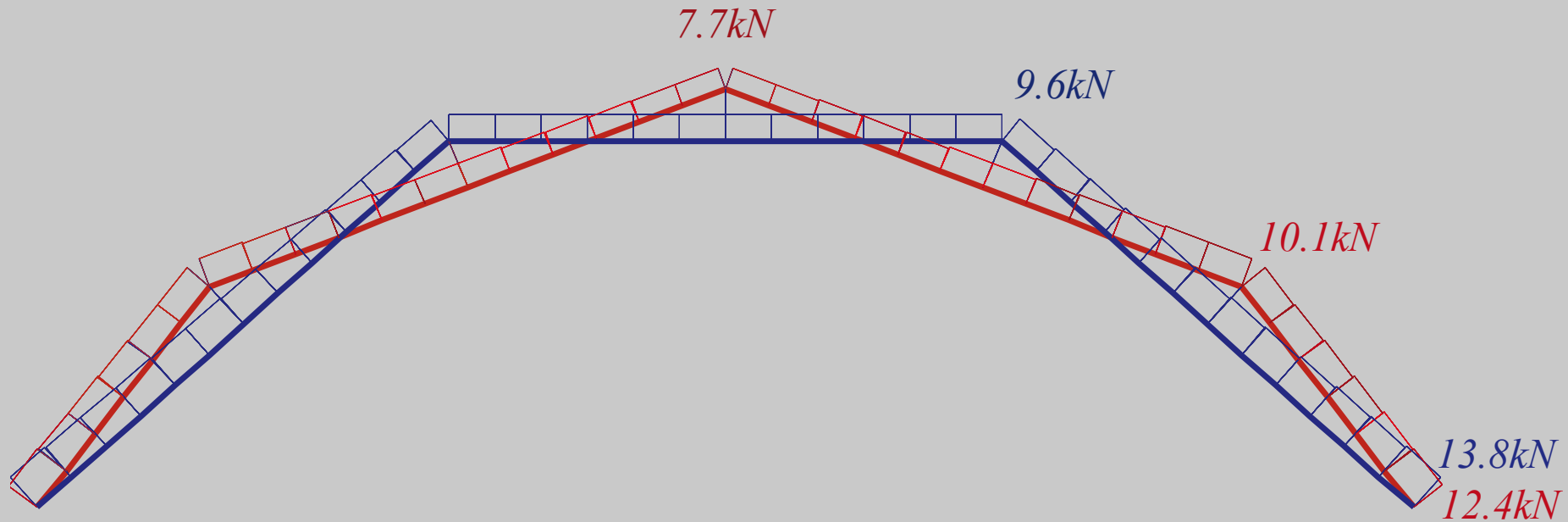


The Deformation

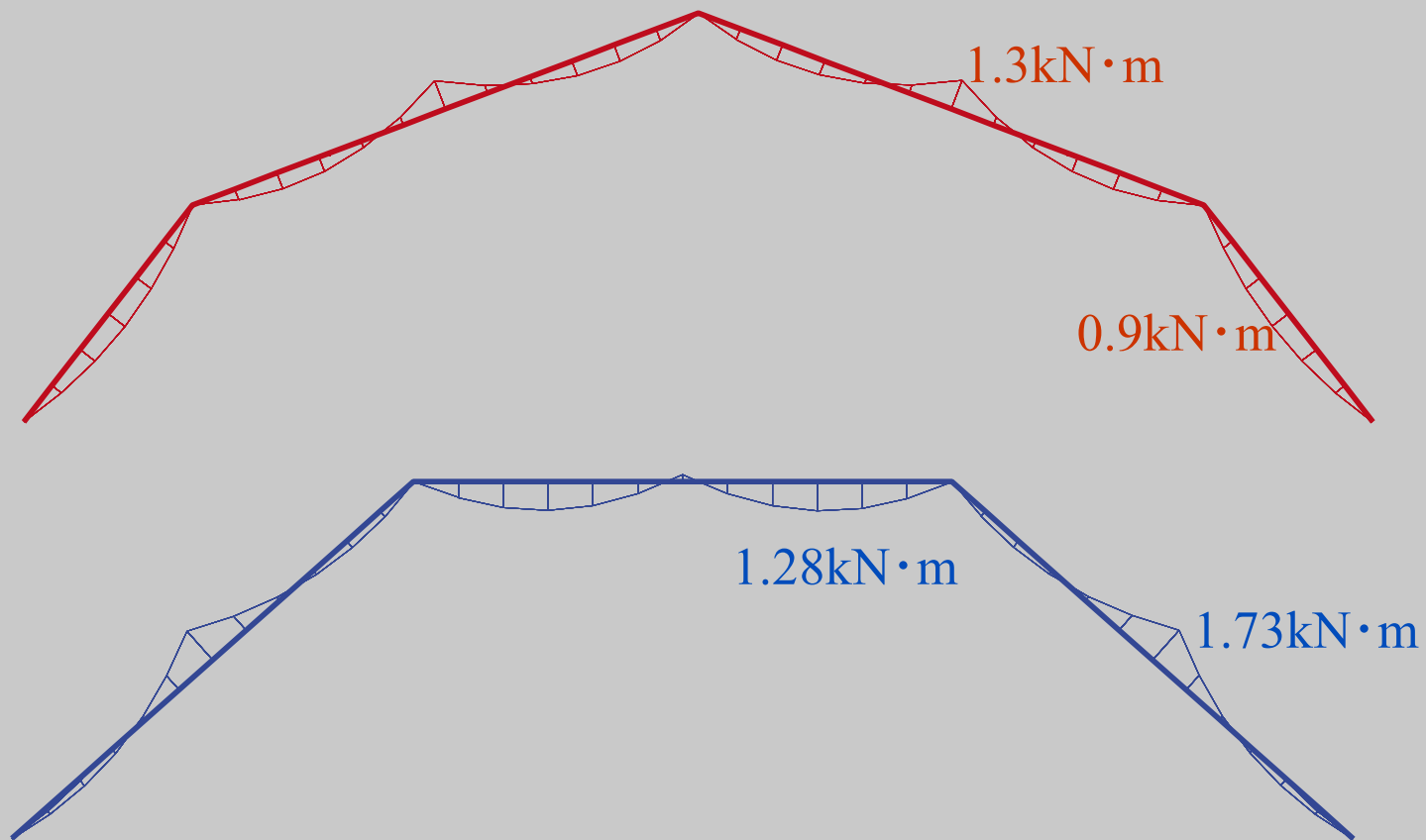


$$\delta_{max} = 0.23mm$$

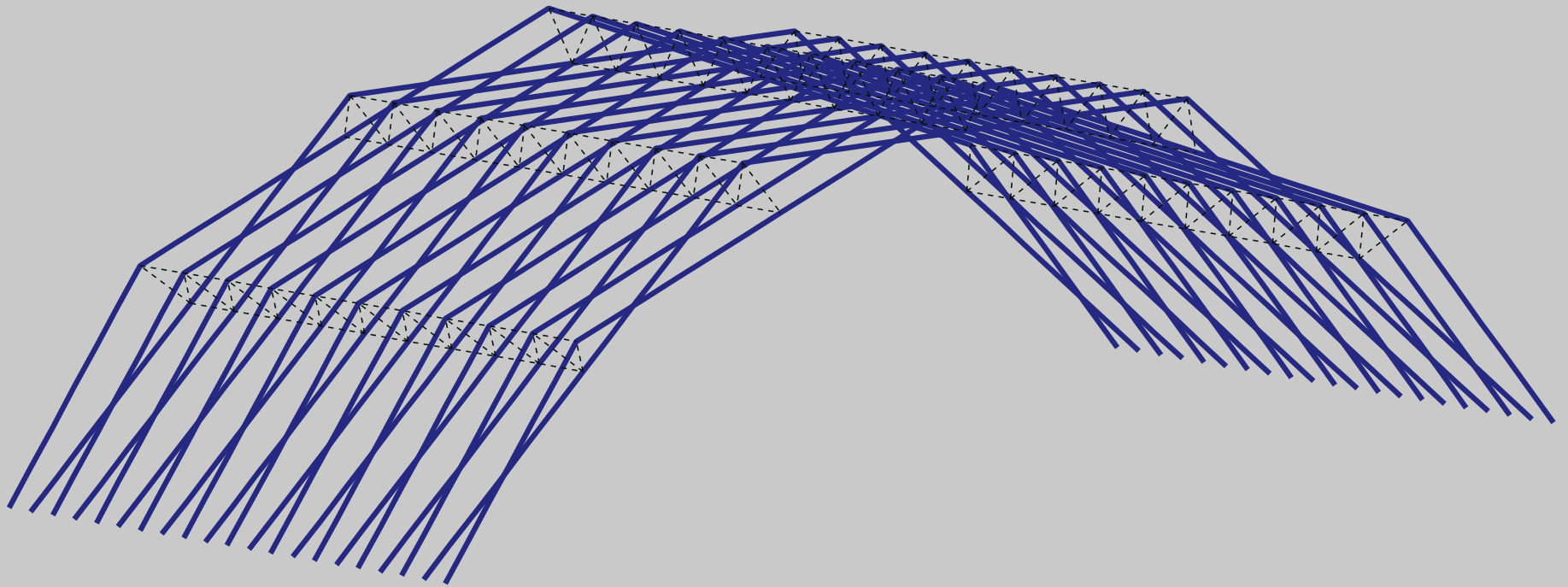
Distribution of Axial Forces



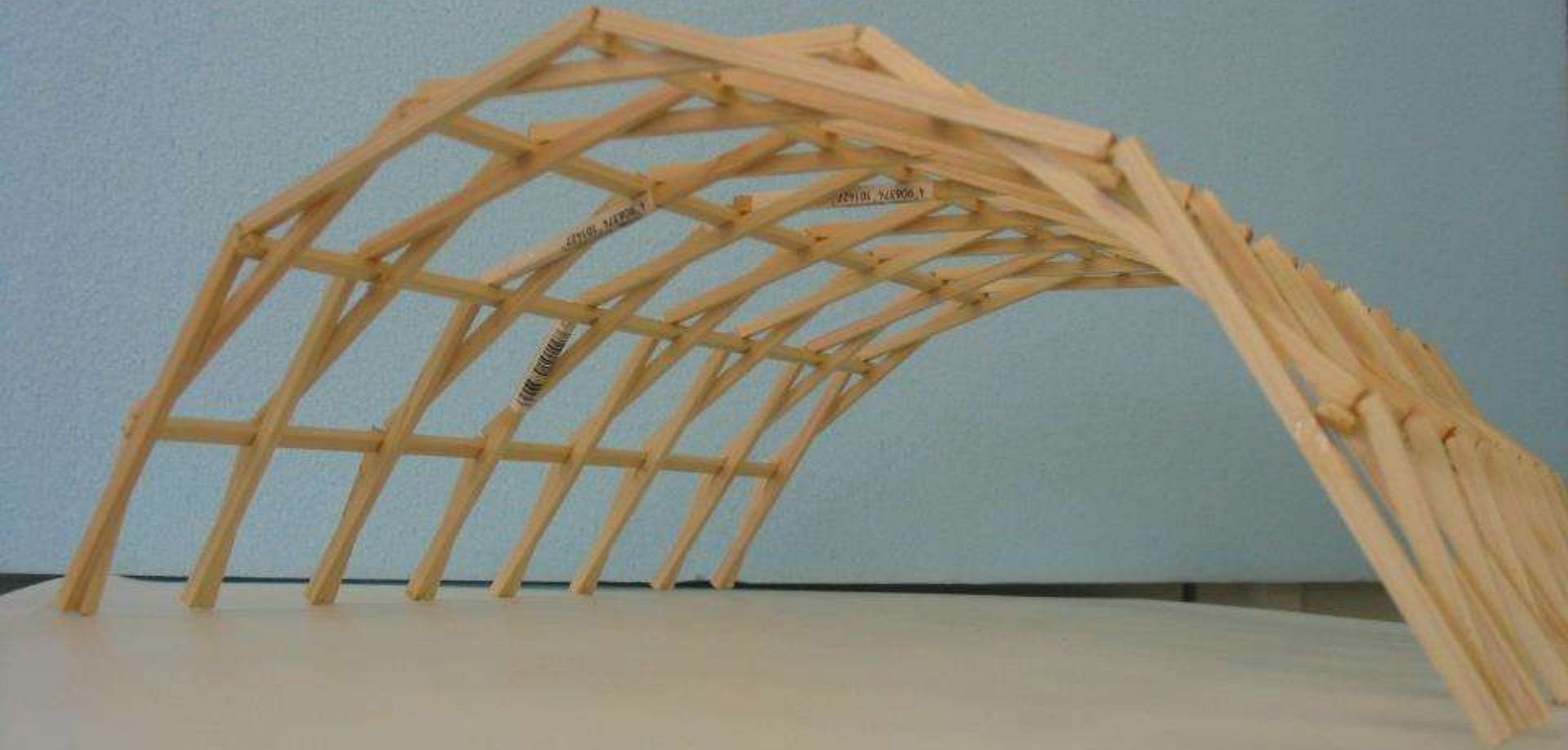
Distribution of Moments



Model for Structural Analysis



Application to Modern Structural Design



A cylindrical frame with Lap-Beams

Cone-Shaped Lap-Beam



Application to Modern Structural Design



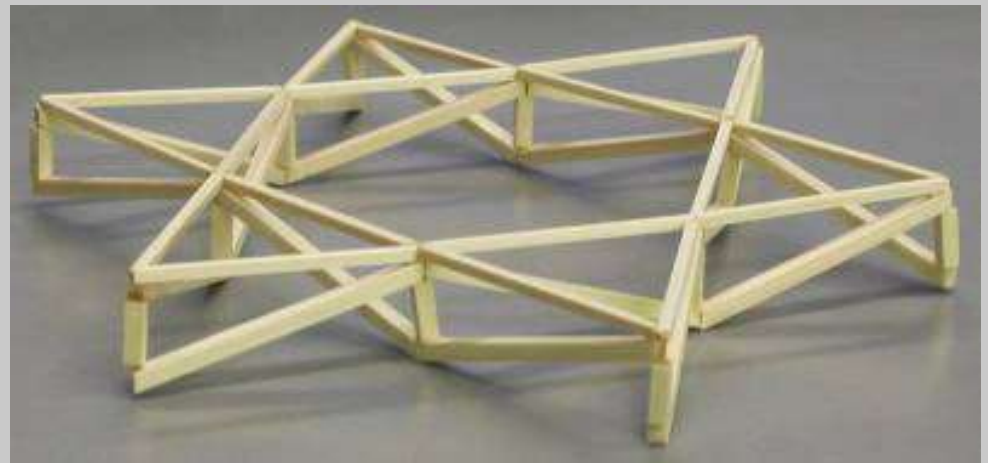
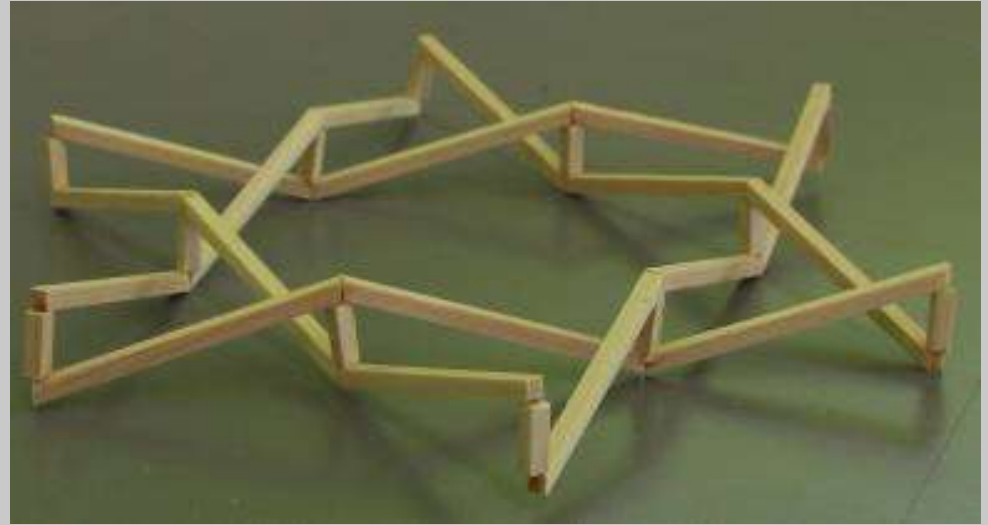
Lap-Beam Dome (Zaru Dome)



A Zaru Dome

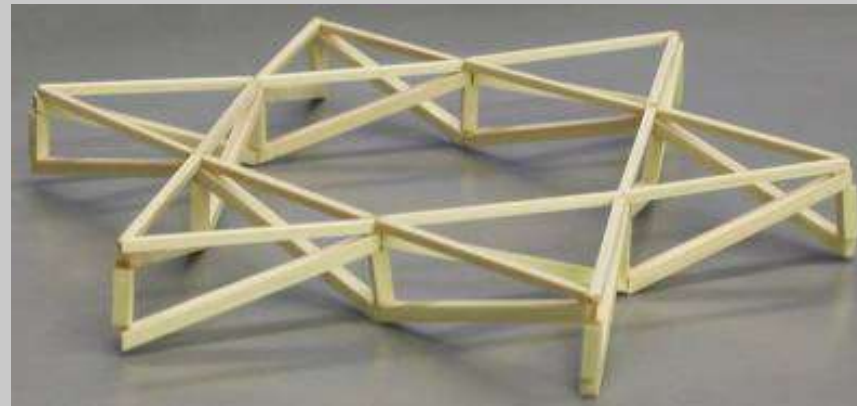


From Basket Meshing to Space Frame

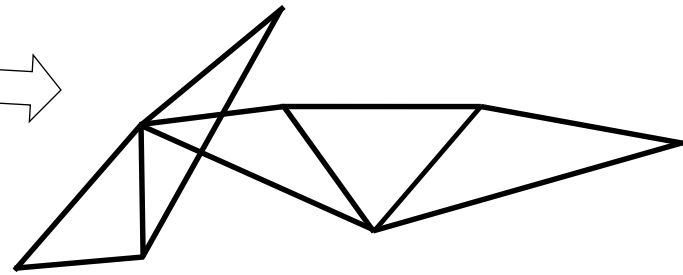
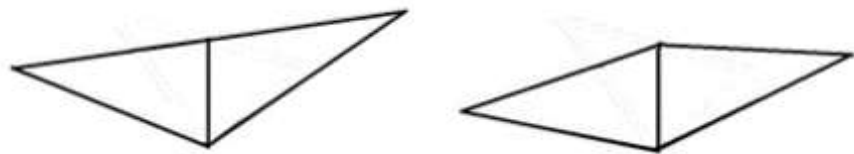


Definition of A 1.5-Layer Space Frame

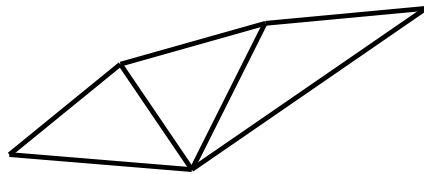
A 1.5-Layer Space Frame is a structure composed by bars pinned with two layers of joints, and there is no member linking two or more joints in one certain layer.



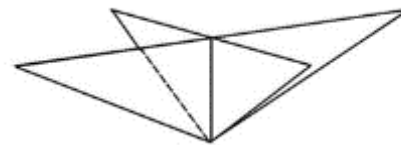
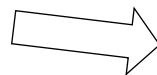
The key parts and basic units



(b) Lap- units

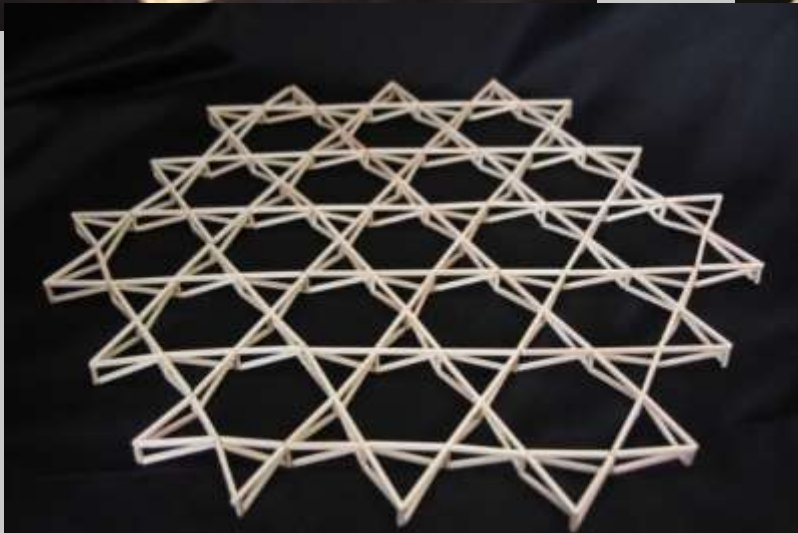
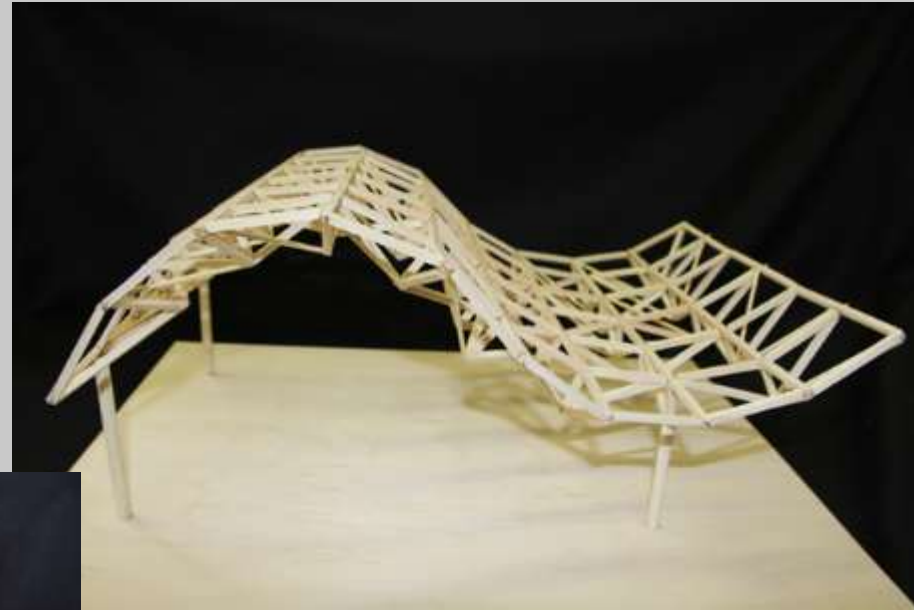
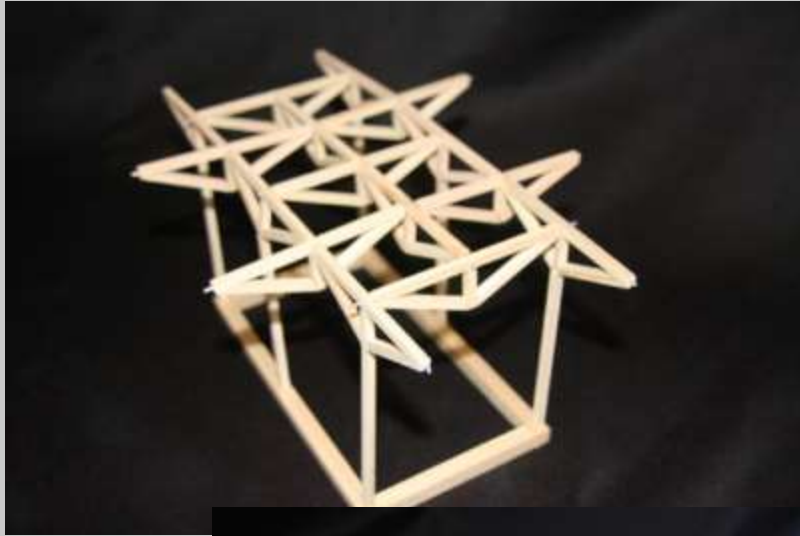


(a) Key parts

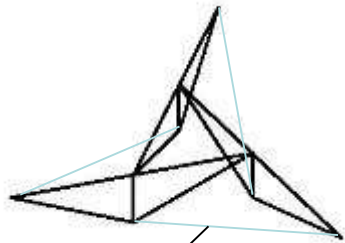


(c) Crossing- units

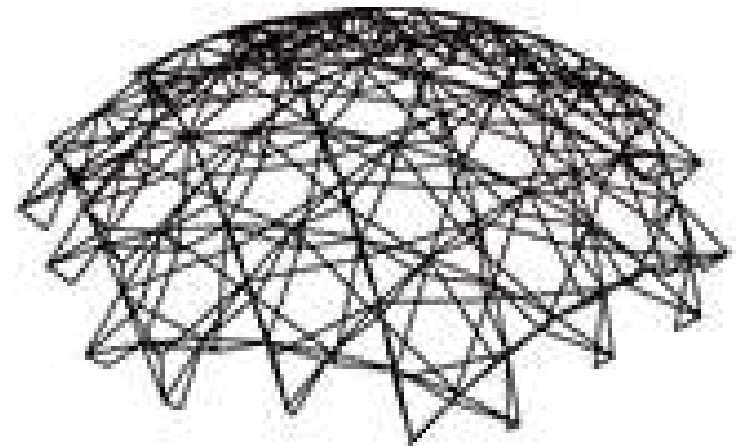
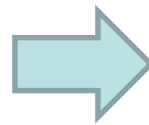
Lap- units



Lap-units in Curved Shape



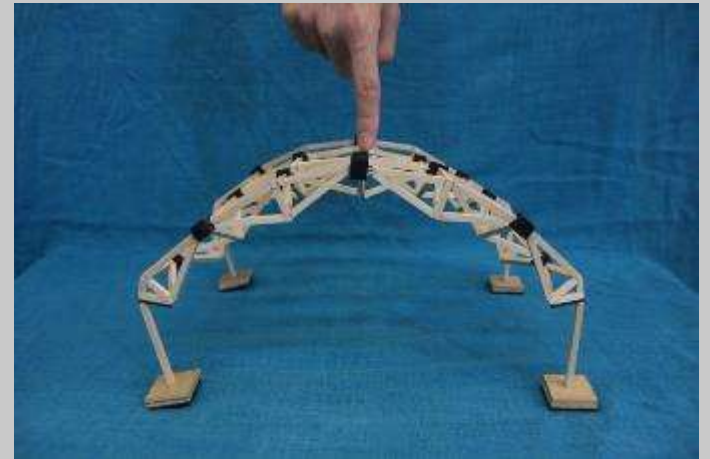
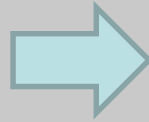
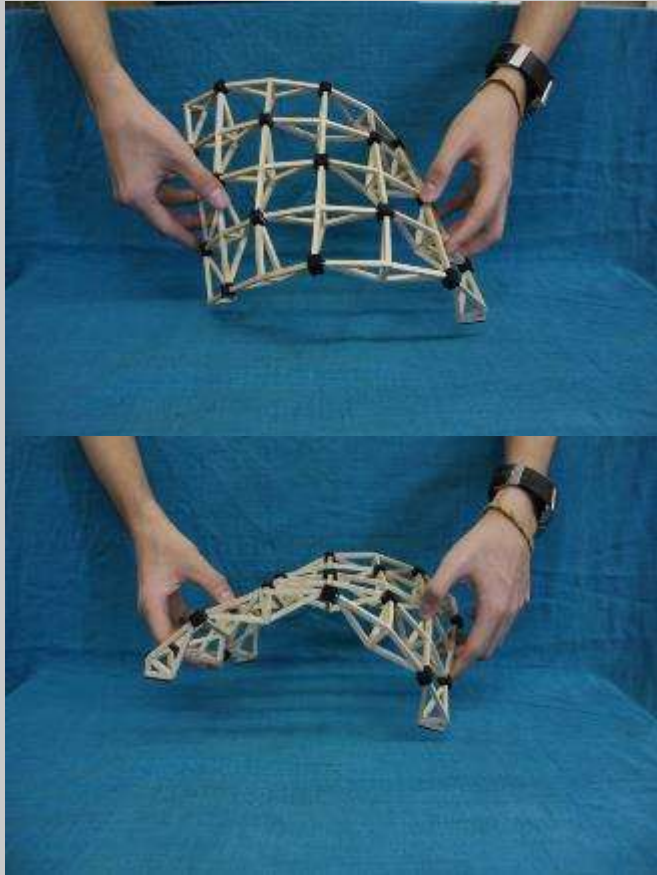
added members



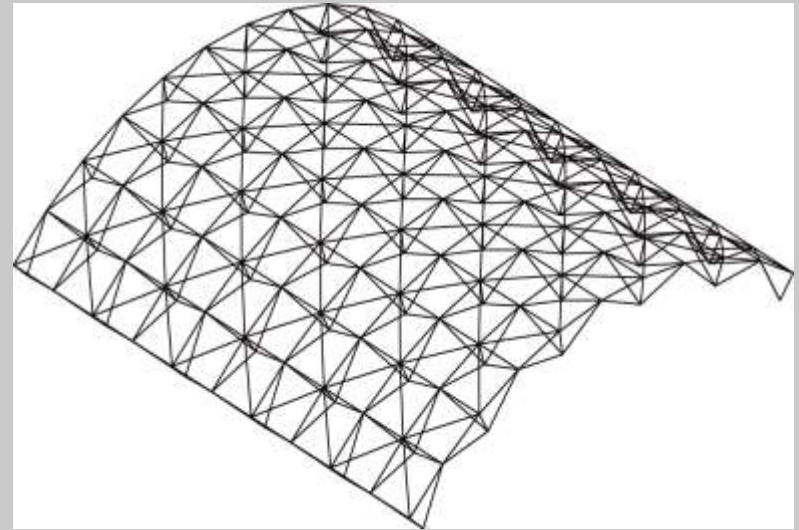
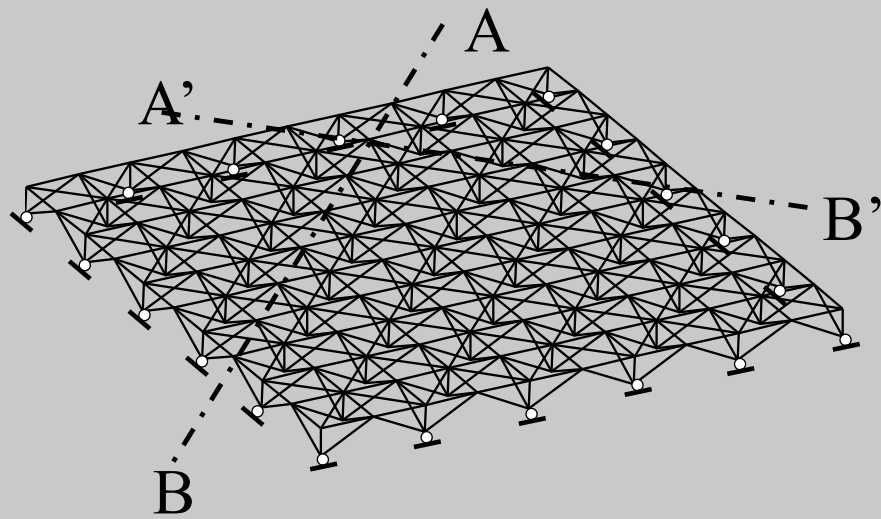
Crossing- units



On the Stability

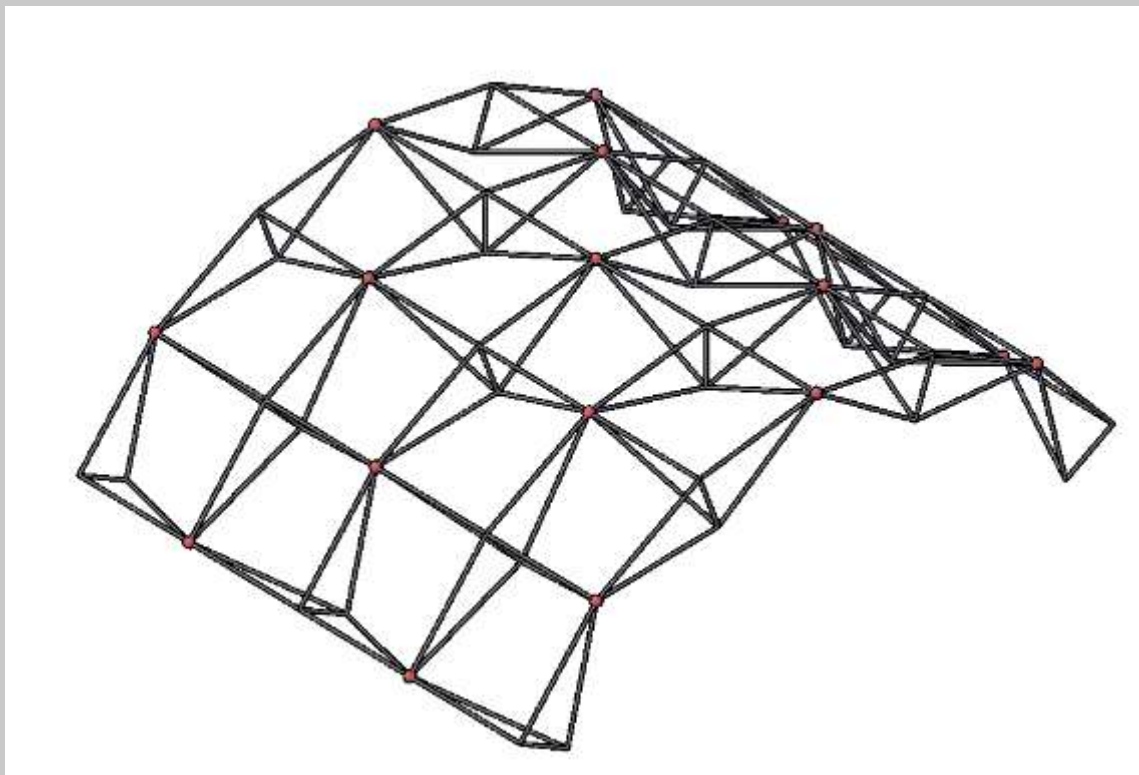


On the Stability



Kutzbach-Gruebler Equation

$$F=6(n-1)-\sum_k(6-k)f_k$$



Demonstrate the stability by linear analysis

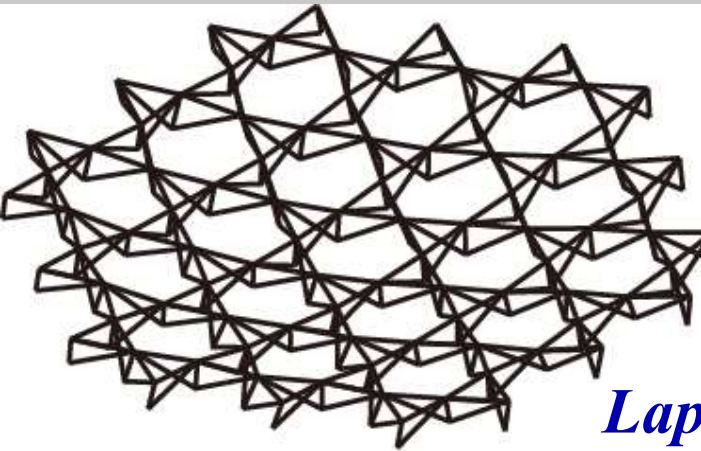
Rank(Stiffness Matrix) $\rightarrow$ *DOF*

Linear static solution $\rightarrow$ Stable structure

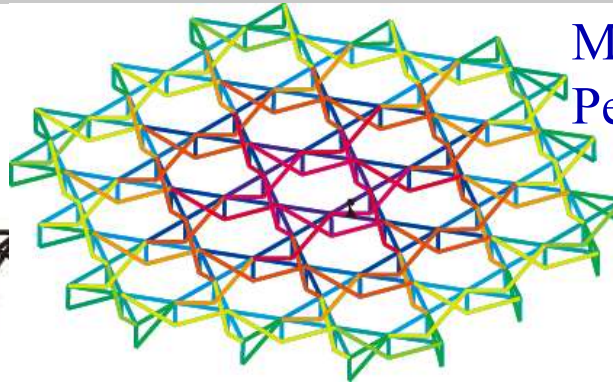
Analytical model $\Rightarrow$ flat/planar frames

Demonstrate the stability by linear analysis

Plane frame, Steel, Span: 33.0m, Vertical members $H=1.5m$, $A = 100cm^2$, $P= 18kN$



Lap- units

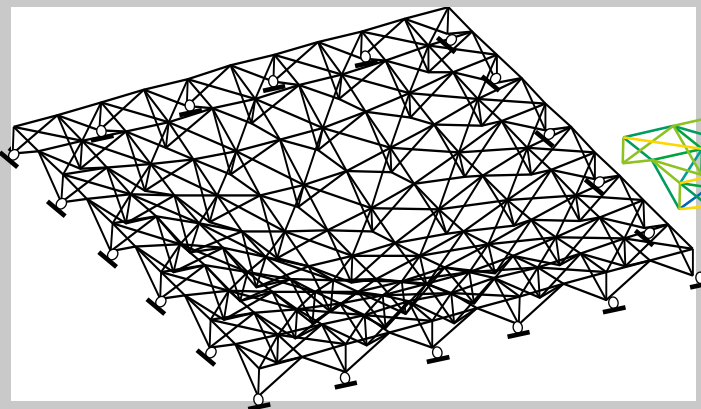


Max. Vertical disp.: 4.70cm

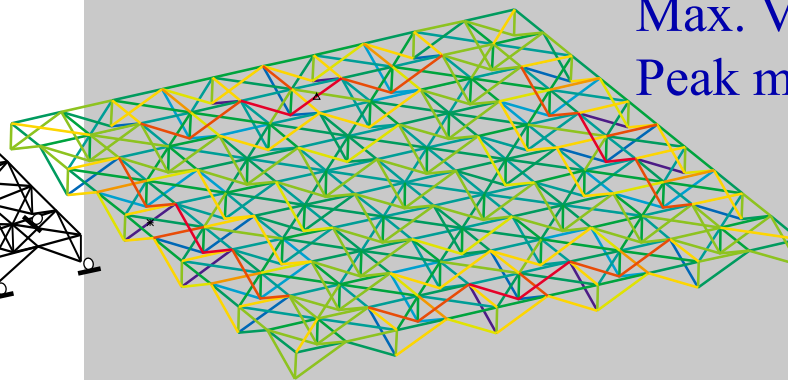
Peak member forces:

+255kN

-558kN



Crossing- units



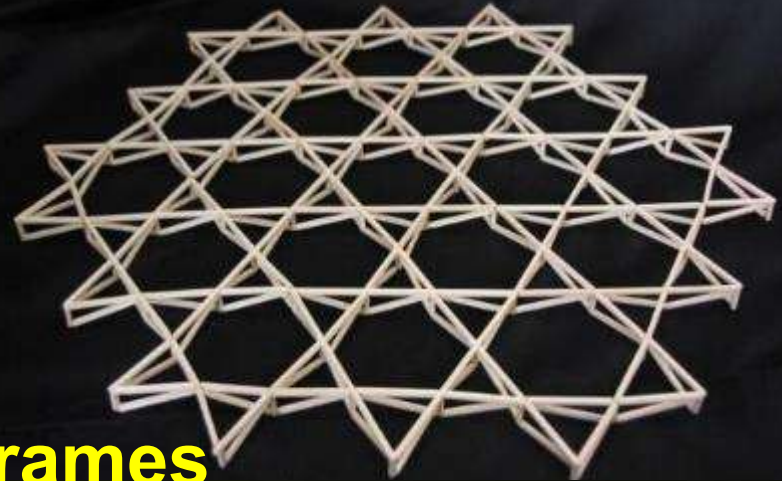
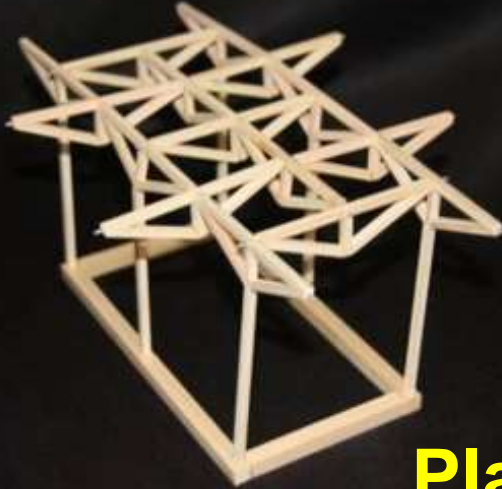
Max. Vertical disp.: 7.45cm

Peak member forces:

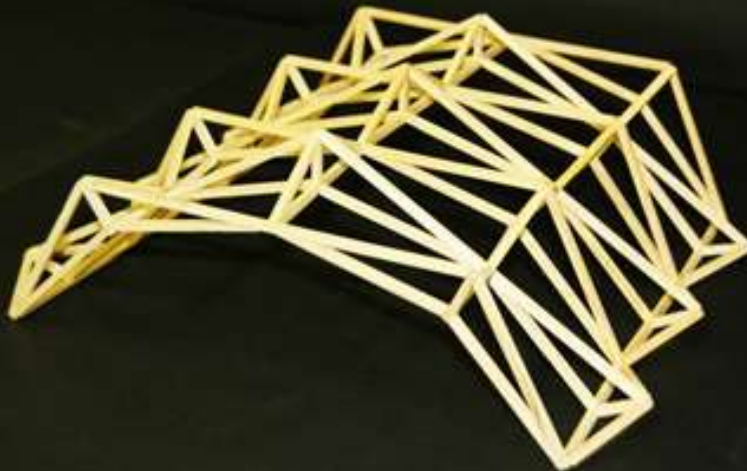
+332kN

-473kN

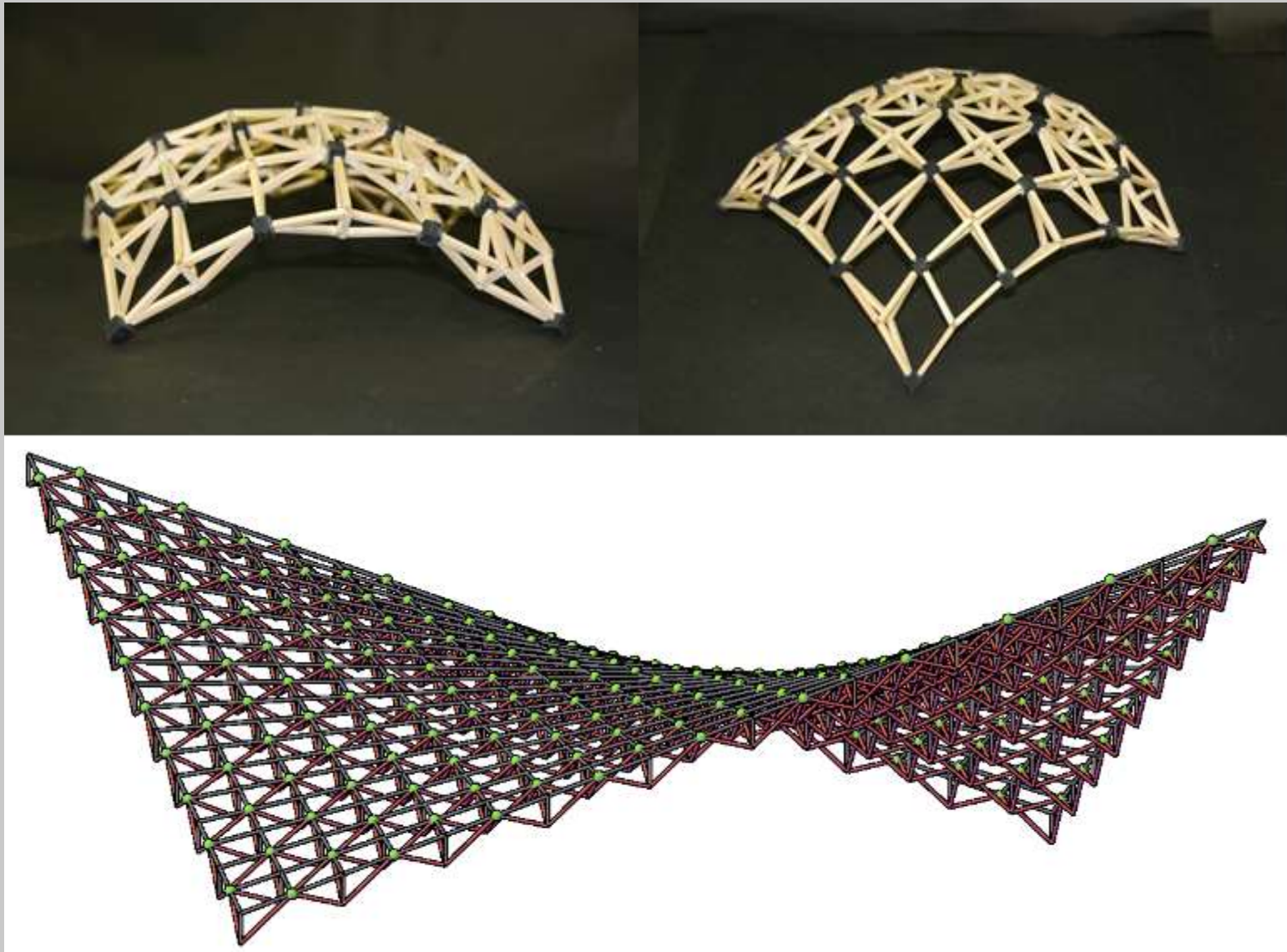
Versatility for Form Design



Planar frames

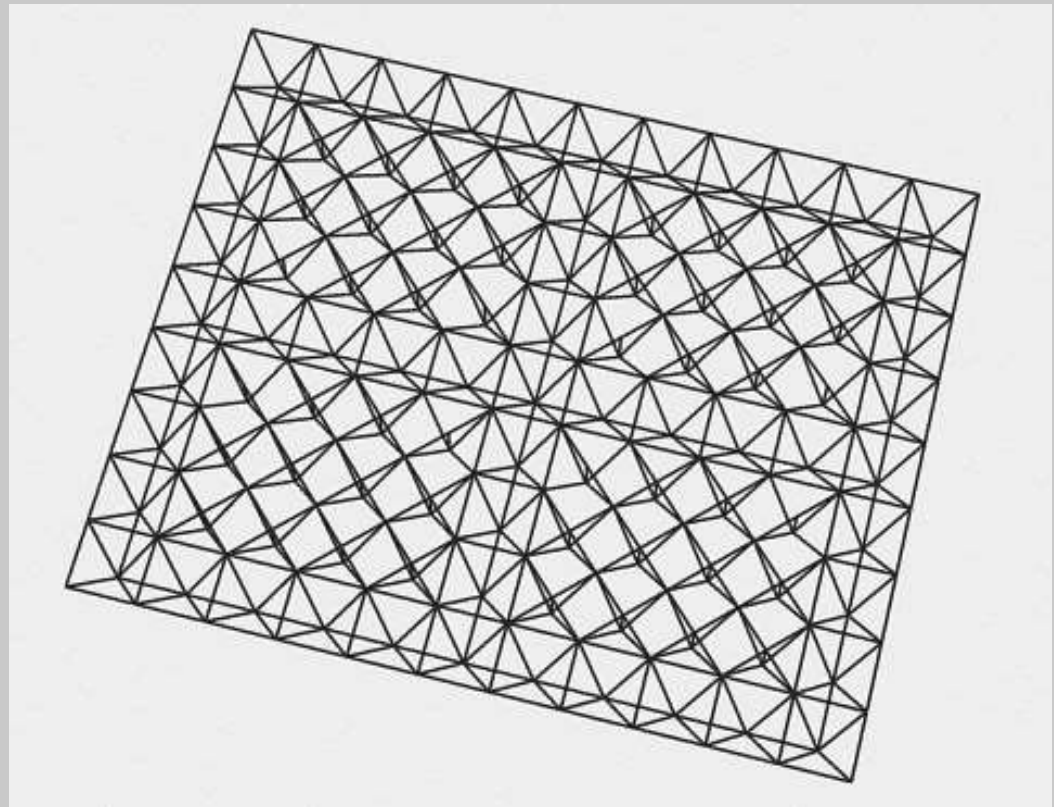
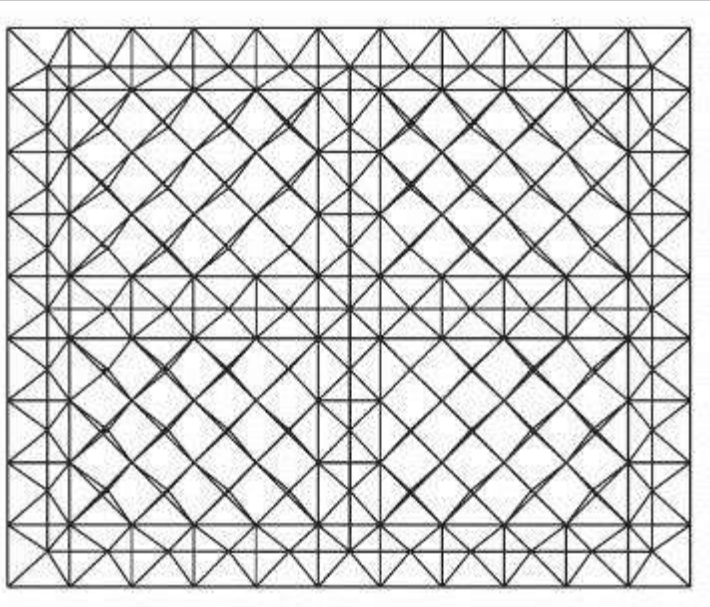


Versatility for Form Design

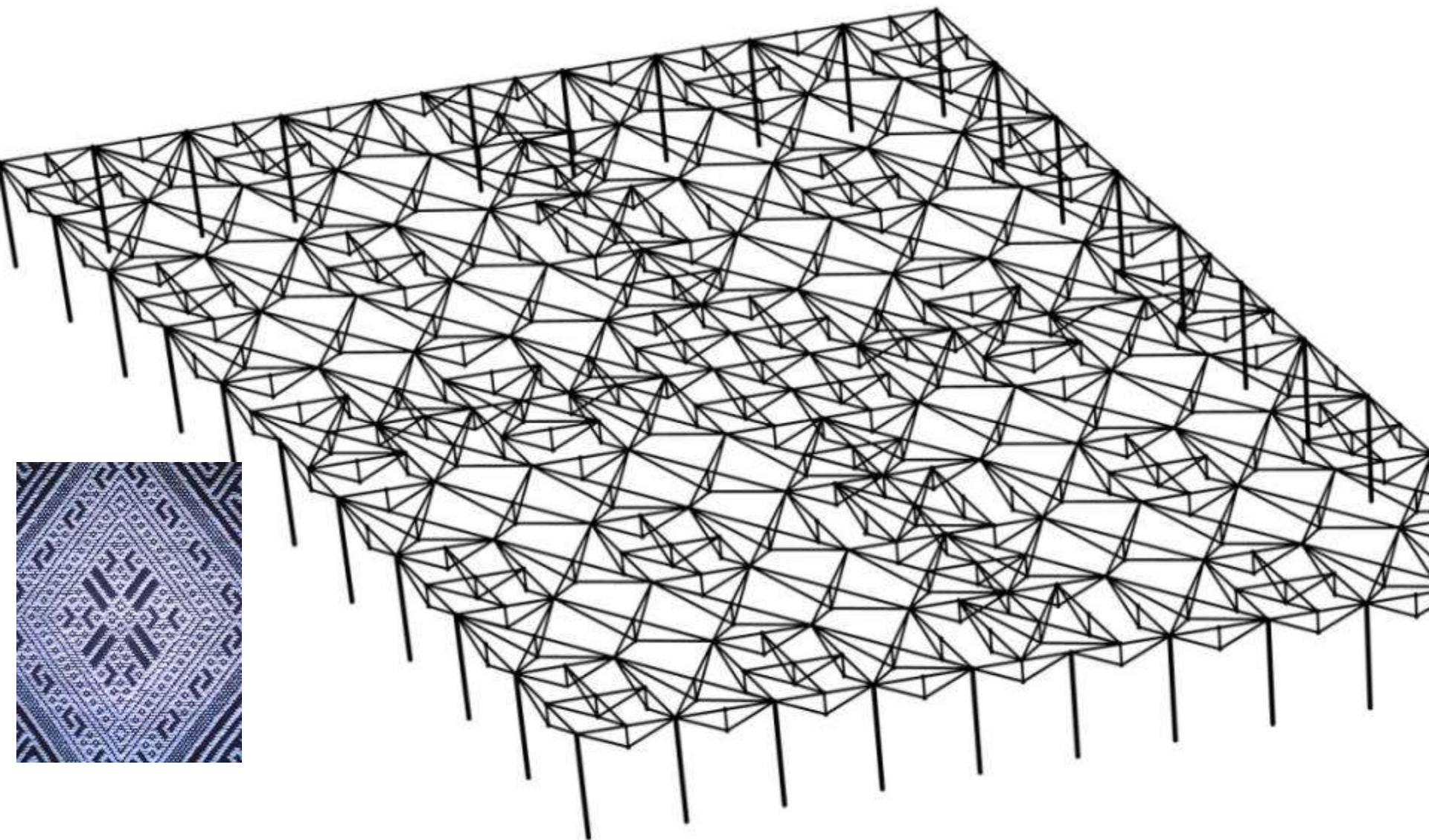


Hybrid Frame System

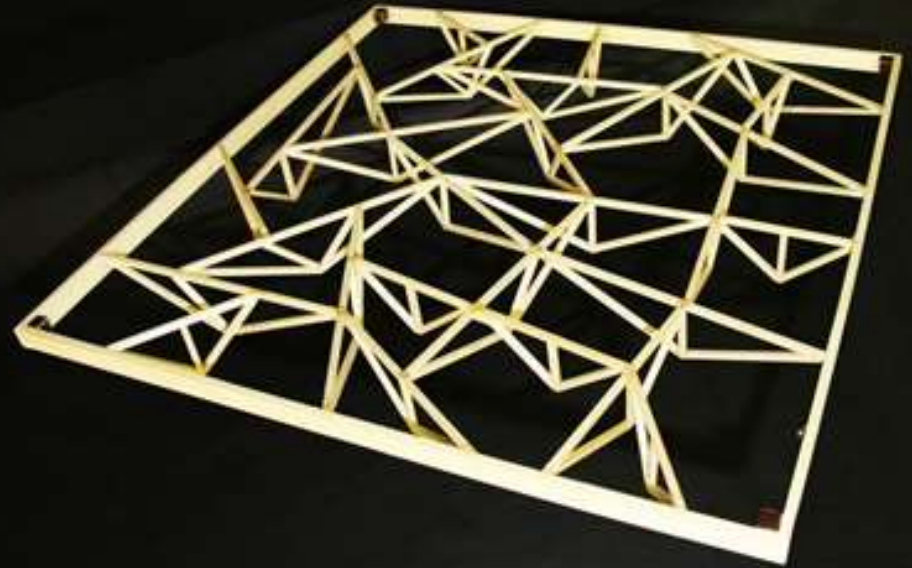
1.5-Layer Space Frames + Double Layer Space Frames



Free Grid

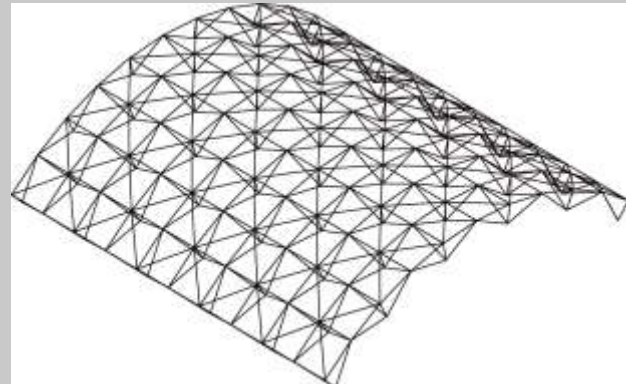
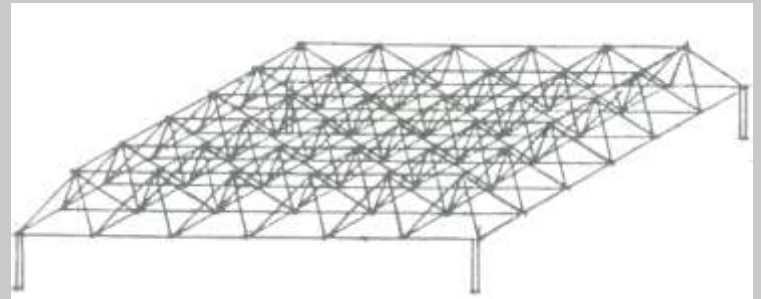
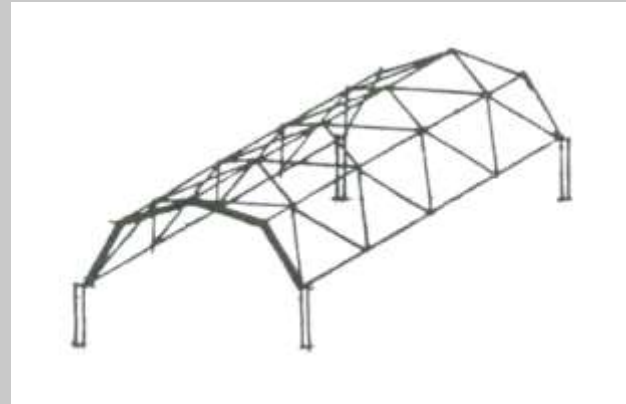


Random grids generated from Chinese window grilles



Classification of Space Frames

- **Single Layer**
- **Double Layers
multi-Layers**
- **1.5-Layer**





Conclusion

- The 1.5-Layer Space Frame is a new structure system inspired from the Hongqiao bridge painted in Qingming Shanghe Tu.
- The system has versatility for form design.
- Further researches are required to demonstrate its mechanical characteristics and develop the structural design methods.
- The author promotes to re-classify the types of space frames into: 1) Double and multi-Layers, 2) 1.5-Layer, and 3) Single Layer Space Frames.

八戸工业大学 S-Art 研究会



Thank you !!