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Design procedure for thin three-layer plates made of a depleted material

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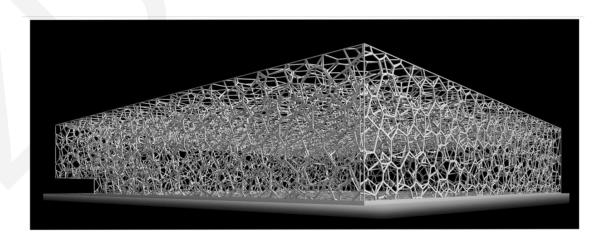
Porous media on a very large scale



Taichung Metropolitan Opera House in Taiwan, Toyo Ito

Water Cube, an example of foam structures at extremely large scale

The void inclusions thought of as part of continuity and not as interruptions [...] where the orthogonal external form is punctured with countless holes, cave-like holes that penetrate the form, giving rise to an interior space made up of continuous convex surfaces (Ito, 2012).



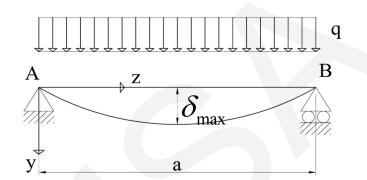
The bubble-like structure of the Water Cube, National Aquatics Center, Beijing

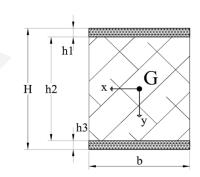


Flexural stiffness of a thin three-layer plate

$$\delta_{\text{max}} = \frac{q}{K_{\chi} / (a^4 \cdot C_f)}$$

Maximum vertical displacement



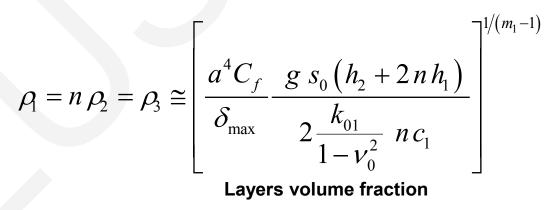


$$K_{\chi} = \sum_{i=1}^{N} \frac{k_{\chi i}}{1 - v_{i}^{2}}$$

Overall flexural stiffness

$$\delta_{\text{max}} = a^4 \cdot C_f \frac{q_a + g \sum_{i=1}^{N} s_i^0 h_i \rho_i}{\sum_{i=1}^{N} \frac{k_{0i}}{1 - v_{0i}^2} c_i \rho_i^{m_i}}$$

Maximum vertical displacement as function of the local properties





Flexural stiffness of a thin three-layer plate

$$\eta_{\chi} = \frac{K_{\chi}}{\overline{K}_{\chi}}$$

Gain of the overall stiffness of the layered plate

$$K_{\chi} \cong 2 c_1 \rho_1^{m_1} \frac{k_{\chi 01}}{1 - v_0^2}$$

Flexural stiffness of the plate

$$\bar{K}_{\chi} = c \rho^{m} \frac{E}{1 - v_{0}^{2}} \frac{b H^{3}}{12}$$

Flexural stiffness of the section

$$\eta_{\Omega} = \frac{\Omega}{\overline{\Omega}}$$

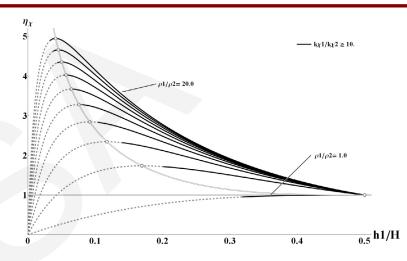
Reduction of the amount of required material

$$\Omega = \rho_1 b \left(2 h_1 + h_2 / n \right)$$

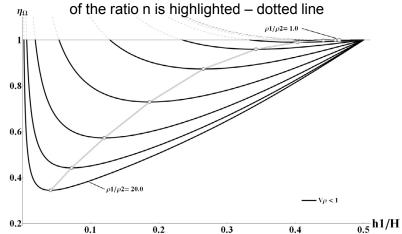
Amount of material per plate unit length

$$\overline{\Omega} = \overline{\rho} b(2h_1 + h_2)$$

Total amount of material



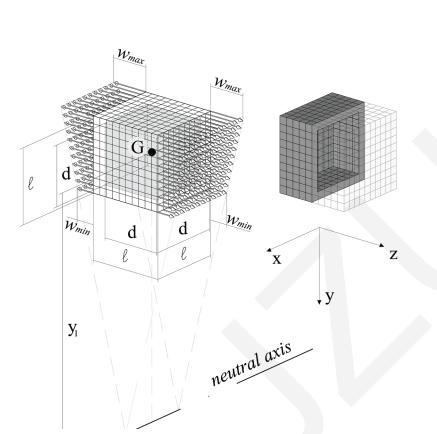
Gain of the overall stiffness of the layered plate in relation to the thickness of the layers, the maximum value for each value



Total amount of material required in the layered plate in relation to the thickness of the layers, the minimum value for each value of the ratio n is highlighted – dotted line

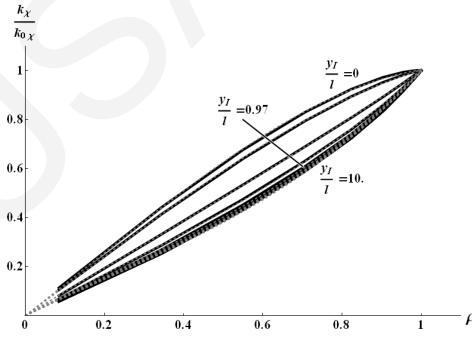


Microstructure of depleted layers



Porous solid structure with cubic depleting voids, setting of the boundary conditions and FE model

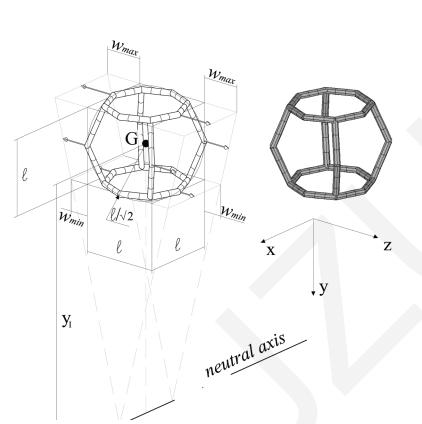
$$\frac{k_{\chi}}{k_{0\chi}} = f_{\chi}\left(\rho, \frac{y_{I}}{\ell}\right)$$



Normalized flexural stiffness as a function of the volume fraction and of the distance of the neutral axis from the centre of mass of the RVE

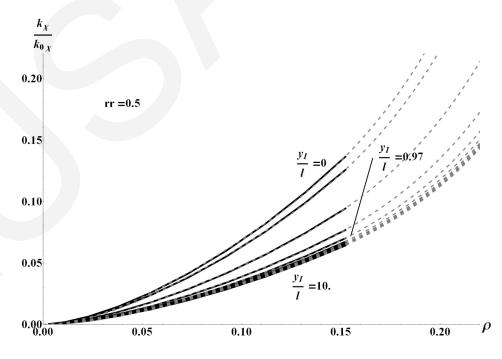


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Normalized flexural stiffness as a function of the volume fraction and of the distance of the neutral axis from the centre of mass of the RVE



Conclusions

A general design procedure has been developed for thin plates made of three layers of depleted material subject to vertical distributed load. The approach allows the locally definition of the optimal amount of material for a specific microstructure with the objective of maximising the overall flexural stiffness/weight ratio of the structure. For each kind of the adopted microstructures, a porous solid structure and a truss arrangement, the flexural stiffness has been successfully correlated to the level of depletion by means of a power law function by setting very few parameters.

In order to test the accuracy of the method, with the aid of the finite element method, each type of microstructure has been employed in a case study of a squared thin plate made of three layers subject to a vertical distributed. The accurate mechanical response has been calculated and compared with good agreement with the results furnished by the homogenization approach proposed in the paper.

undiscovered before me.

