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Mini Review

Evolution of Stiffened Panels in Engineering

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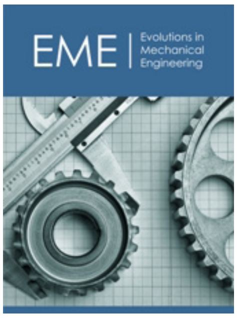

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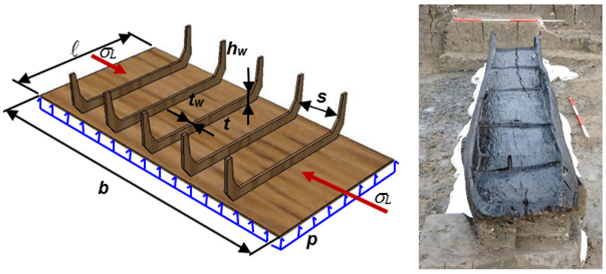
Mini Review

The evolution of stiffened panels from ancient times to nowadays and also in the future may be described as a long hard way from carved-out log boats to complex thin-walled structures, large ships, supersonic airplanes and space crafts. In parallel with human experience evolve common knowledge, methods, experimental and calculational facilities in lasting interaction with the progress of technology [1,2]. This review calls to mind the potential of evolutionary optimization methods for back tracing the evolution of stiffened panels in engineering using the NSGA-II Evolutionary Algorithm (EA) [3] providing a generic multi-objective solver [4,5]. Finally, the review reinterprets the results of evolutionary optimization regarding the evolution of stiffened panels.

The Design Model of Transversely Stiffened Panels

The selected example is the simple bottom of boats and ships considered as transversely framed shells of isotropic material under lateral pressure p and longitudinal in-plane stress σ_L [6], (Figure 1). The archeological discovery of the bronze age log boat 5000 years old in the ancient River Nene (see The History Blog) shows the ingenuity in building lighter and stronger boats by primitive wooden stiffening. The design model (Figure 1) applies the relevant rules and verified practical regulations of classification societies (e.g. CRS; DNV) based on lasting developments of shipbuilding experience, practice and theory [7].



b panel widths; ℓ panel length;
t plating thickness;
t_w| stiffener thickness and height h_w;
s stiffener spacing;
p lateral pressure;
σ_L in plane stress;
τ_f shear stress at supports;
E material elastic modulus;
ν Poisson ratio;
σ_y material yield strength;
ρ material density

Figure 1: Stiffened panel and a carved-out boat.

A. The small deflection elastic plate bending theory defines the maximal local stress σ_p under lateral pressure p in the middle of the longer edge ℓ in the direction of the shorter edge s in the plating of thickness t.

B. The simple elastic beam bending theory defines the normal stresses σ_f in frames.

C. The elastic section modulus $W_{f,e}$ of a single frame accounts for the width of the effective plate flange.

D. The shear stress is σ_f at supporting ends of the frame web for cross sectional area A_f of a flat bar.

E. The orthotropic plate elastic bending theory defines the stresses in the edges of the longer side σ_s in the direction of the shorter of the interframe plating using the Shade's diagrams. I_f is the frame moment of inertia.

F. The critical buckling stress $\sigma_{p,c}$ in-plane compression of plates between frames.

G. The torsional buckling of flat stiffeners prevents the ratio of height to thickness, that is normally <20.

H. The ultimate bending strength with respect to multimodal plastic failure modes of plates at the mid of the longer edge of unit plate plastic section between frames under bending moment acting due to lateral pressures p combined with in-plane load σ_L, follows from appropriate interaction formula.

I. The ultimate lateral pressure on plating $p_{u,p,\sigma}$ accounting for the yield stress σ_y under the in-plane stress σ_L.

J. The ultimate bending strength of frames under lateral pressure and axial stress is the capability to prevent the plastic failure defined as a three-hinged mechanism. $W_{f,p}$ is plastic section modulus of frames.

K. For frames including the effective plate flange under bending moment due to lateral pressure p and for small axial stresses σ_x (the shear is usually small) the ultimate lateral pressure is $p_{f,p,\sigma}$.

L. The ultimate lateral pressure on the whole panel $p_{b,p,\sigma}$ viewed as the orthotropic plate is as shown:

M. The transverse in-plane compression of bottom plating is normally small so that buckling of plating isn't likely.

The stiffened panel safety model applies three safety criteria:

The ultimate lateral pressure on plating $p_{u,p,\sigma}$ inter frame plate bending

The ultimate lateral pressure on frames $p_{f,p,\sigma}$ frame bending

The ultimate lateral pressure on the whole panel $p_{b,p,\sigma}$ overall panel yield

The mathematical model incorporates robustness criterion. The robustness is considered as the minimal variation among safety measures of different failure modes [8,9]. This model considers the inter frame plate bending $p_{u,p,\sigma}$, the frame bending $p_{f,p,\sigma}$ and the overall panel yield $p_{b,p,\sigma}$. The robustness criterion levels out the integral system safety that leads to avoidance of week-links in the structure.

The Evolutionary Design

The example next employs genetic algorithm to investigate the evolution of stiffened panels. Therefore, the stiffened panel design optimization model is defined as a multi-dimensional general non-linear mathematical programming model based on following parameters and variables:

- parameters: $p, \ell, b, k, \rho, \sigma_y, \sigma_f, \sigma_s, \tau_s$

- variables: n, t, t_w, h_w

The multidimensional optimization task is formulated by three attributes with respect to model efficiency expressed by total mass m, workmanship and production efforts related to the number of stiffeners n and to safety level with respect to three failure modes and their robustness.

A1: $m(n, k, t, t_w, h_w, \ell, \rho)$ total mass of the stiffened panel (favorable minimal)

A2: n number of stiffeners (depending on material and workmanship)

A3: st.dev $(p_{u,p,\sigma}, p_{f,p,\sigma}, p_{b,p,\sigma})$ robustness: variability of ultimate loads (favourable minimal)

The design model of the stiffened plate is subjected to following constraints:

C1: $W>W_{min}(p,n,\ell, b, \sigma_{f,a})$

C2: $t>t_{min}(p, \ell , b, p_{u,p,\sigma}, \sigma_{p,a})>2mm$

C3 $10<t_w/h_w<20$

C4: $t_w.h_w>A_f (p, \sigma_y, \tau_{f,a})$

C5: $\min(p_{u,p,\sigma}, p_{f,p,\sigma}, p_{b,p,\sigma})>p$

The Evolutionary Optimization

The optimization model uses the encoding of chromosomes binary strings. At the beginning, the plate thickness t was the only chromosome. The evolution from flat plates to stiffened plates starts with discovery of the importance of stiffening [10]. Therefore, the optimization model includes another two genes describing a flat bar stiffener (web) of thickness tw and height h_w (Table 1). The number of stiffeners n is the most influential chromosome in the evolution of stiffened panels decisively depending on the evolution of material sciences and technology. In this optimization model, every chromosome consists of four genes which comprise four design variables of the stiffened panel (Table 1). The emergence of new genes 2,3 and 4, Table 1, for the number of stiffeners, thickness, and height of the frame web opens the potential for the evolution of plates stiffened by flat bars. These four characteristics and the problem parameters define all the other panel properties. Since the evolution was carried through fix length chromosomes, then the length of the individual genes is also a limitation-a constraint put upon the search space, that guides evolution towards reasonable solutions and hopefully speeds up the search process. The computation results of one out of many iterative trials with repeatable outcomes on standard personal computers are presented as the 3-D Pareto frontier plot n-m-st.dev., (Figure 2). After the full gene potential of chromosome, Table 1, is being unleashed more up to date solutions evolved. The results after 8000 iterations are plotted on Figure 2.

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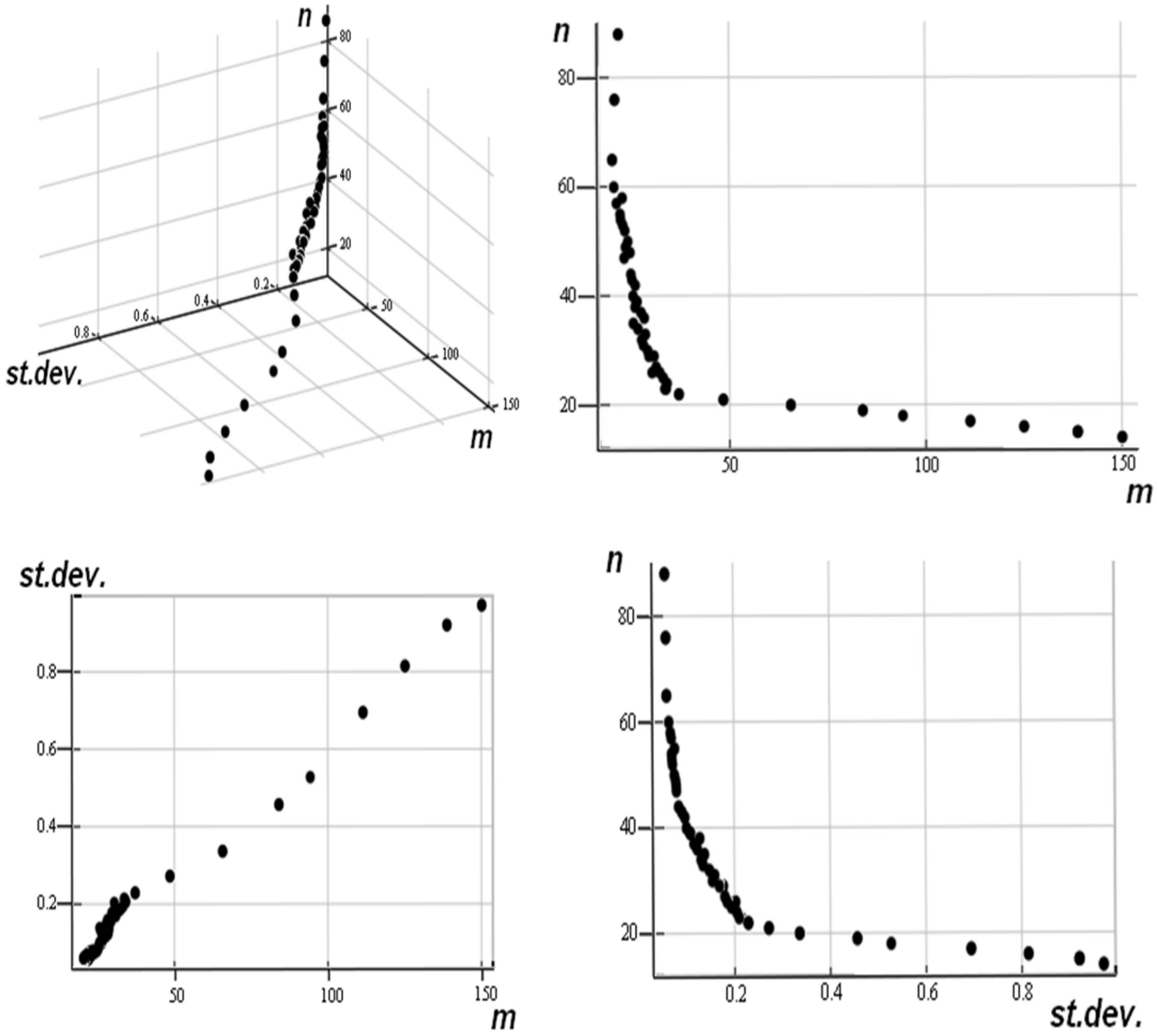

Figure 2: a) 3-D Pareto frontier; b) n-m plot; c) st.dev. -m plot, d) st.dev. -n plot.

Table 1: The chromosome structure.

Design Variable	t	n	h_w	t_w
The gene number	1	2	3	4
Available strings per gene	10	10	10	10
Maximum value attainable after mapping [mm]	130	200	430	20

Conclusion

It is comprehensible (Figure 2b) how ancient condition's lack of knowledge, experience, appropriate materials, and tools yield solutions of thicker wooden structures with smaller numbers or even without stiffeners, also leading to an inefficient increase of the mass of the panel (like carved-out boats). On the other hand (Figure 2b), the evolution of general knowledge, productional methods, material properties experimental and calculational facilities over centuries of engineering experience incited the evolution of more sophisticated lighter stiffened panels with thinner plates and a greater number of stiffeners of stronger and lighter materials (like ships, airplanes, space rockets and shuttles). Also, the number of stiffeners increases robustness and diminishes the mass (Figure 2(c & d)). The engineering design model of stiffened panels in this review implies four genes (Table 1). In the last run, the model degenerates to one single primitive gene number 1, having the plate thickness as the only property. The design model is used in its most degenerative form appropriate to the early days of shipbuilding and lack of engineering knowledge and experience. As a final consequence, the mathematical model points to un-stiffened thick plating, as the least workmanship-demanding solution although inappropriate for nowadays practice. The only affordable outcome of one primitive gene is the simple unstiffened plate of a minimal thickness appropriate to ancient conditions for carved-out logs that satisfy the past and modern safety requirements. The evolution of ancient flat plates to future more efficient stiffened panels is an example of human engineering ingenuity and spirit. possible only by discovering new genes based on the evolution of experience,

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knowledge, methods, experimental and calculational facilities in interaction with the evolution of engineering development under human control.

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