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A Review on the Development of Theory for Hybrid Diagonal Tension Web Panels for Aircraft

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ABSTRACT

With present day aviation industry running on the principle of "A Pound Saved is a Pound Earned" reduction of weight in every possible area of aircraft has become imperative. For continuation of the same; this study aims to gather knowledge, known practices and methods of sizing for shear panels. First the shear resistant webs without taking into account any diagonal tension has been presented to illustrate normal requirement of thickness for a given load. Secondly webs designed for pure diagonal tensions have been compared. Comparative study of both of these follows which underlines their drawbacks and then, the reasons justifying the need for hybrid design which have properties of both shear resistant and diagonal tension webs have been presented. Theory of Hybrid diagonal tension web has been formulated on theories of shear resistance and pure diagonal tension webs. Basis of further research for curved web panels, failure modes of web panels and their FEM analysis is built to be done in follow up research papers.

Keywords

Hybrid Diagonal Tension, Shear Panels, Shear Resistant Panels, Pure Diagonal Tension

1. INTRODUCTION

Weight saving is an important aspect to be considered while designing any structural component of an aircraft. Beam, which forms a large part of the structural components used in any aircraft, have in them the potential for substantial weight reduction. Designing the webs of beams on hybrid diagonal tension principle rather than relying entirely on shear resistance calculations is the key to bring about this weight reduction. This paper aims to reflect upon the necessary theory for pure diagonal tension and hybrid diagonal tension webs so that the transformation from shear resistant webs is possible.

2. METHODOLOGY

2.1 Shear Resistant and Diagonal Tension Webs

Conventional shear resistant webs are designed not to buckle at its design load. They are designed such that the design load is less than buckling load of individual web panels but this criterion has severe weight limitation as this design is heavy.

Designing pure diagonal tension webs gives the ability to develop a web which can take up shear loads even after buckling. It buckles as soon as the load is applied and diagonal tension stresses developed in buckled web carry the shear load. They do not have the weight penalty carried by conventional shear resistant webs.

Since pure diagonal tension webs buckle or deform as soon as the load is applied so they do not meet the requirements for aerodynamic design. So a hybrid between conventional design and pure diagonal tension web can be considered which would not buckle under small loads and would carry the shear load through diagonal stresses by starting to buckle when the load applied is increased.

2.2 Load Distribution

2.2.1 Shear Resistant Web Design

Conventional sizing procedures involve using equation $q = \frac{V}{h_e}$ where 'q' represents shear flow (N/m), 'V' represents vertical shear load applied and 'h_e' represents beam depth between cap centroids as shown in figure 1 below

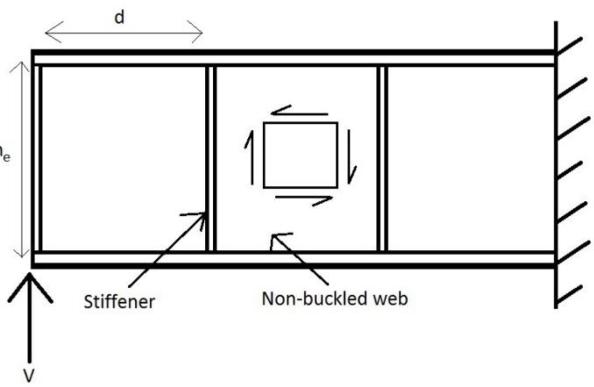

Figure 1. Design of a Shear resistant web panel

So, for a unit element, shear flow and load distribution can be shown as in figure 2 below. Although stiffeners prevent web

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buckling due to compressive stresses induced in web and they should not be too far so that the effective length for buckling is less but installing them too near leads to weight increase and would also cost more.

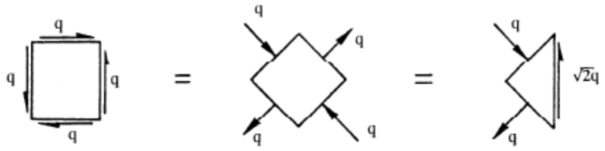


Figure 2. Shear flow and load distribution on a unit element of shear resistant web

Applied shear stress which can be calculated by formula $f_s = \frac{VQ}{It}$ where 'V' is applied load, 'I' is moment of inertia and 'Q' is statical moment of area; when equated to critical buckling stress for web given by

$$F_{s,Cr} = k_s \eta_s E \left(\frac{t}{d_e}\right)^2$$

where 'k_s'is edge restraining constant, 'η_s' is efficiency factor which can be taken as '1' for first trail, 'E' is Young's modules, 't' is thickness of web and 'd_e' is stiffener spacing; gives the boundary condition upon iterative solution.

The only way to increase the allowable stress in conventional shear resistant web panels according to above solution is to either increase web thickness 't' or to decrease panel size by reducing 'd_e'. Both these options would result in large increase in weight if this beam component is designed to be used as principle load carrying members like in wing or fuselage, for example spar, stingers, longerons, etc.

2.2.2 Pure Diagonal Tension Web Design

On other hand Load in Pure diagonal tension webs are equivalent to truss shown in figure 3. Points A and D are pinned supports while Points Band C are fixed supports. AB, AD, CD are rigid members where AB and CD are flanges while AD is where shear load could be applied. AC and BD are cables attached to joints.

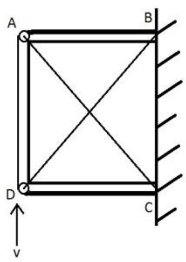


Figure 3. Equivalent truss for pure diagonal tension webs

When load 'V' is applied, cable BD would immediately bend in compression and the whole load would be taken up by AC by being in tension. The web would fold in lines parallel to BD in folds immediately after load 'V' is applied as shown in figure 4 below.

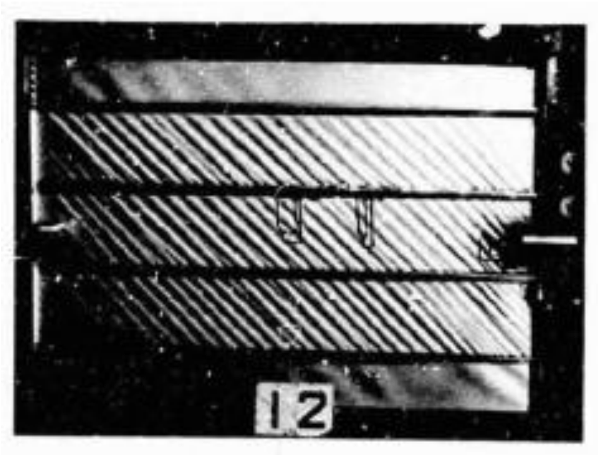


Figure 4. Folds due to diagonal stresses in web panel

Since ideally no compressive load could be carried by the web, so figure 5 below shows the balanced triangular elements.

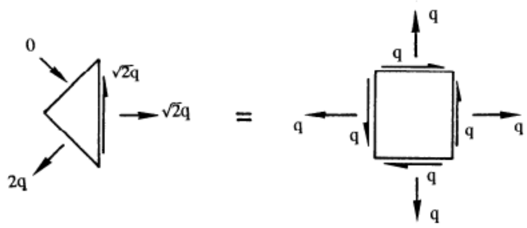
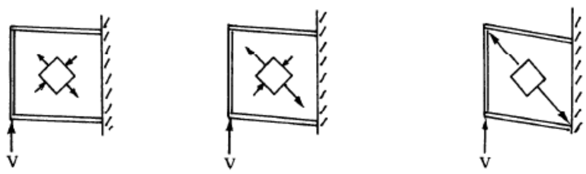


Figure 5. Shear flow and load distribution on a unit element of shear resistant web

Since pure diagonal webs cannot be used in aircrafts widely due to aerodynamic limitations a hybrid design of shear resistant webs and pure diagonal tension webs can be used.

2.2.3 Hybrid Diagonal Tension Web Design

Since a sheet carries its compressive load even if it buckles, and also unbuckled web is subjected to equal tension and compression forces, so by carrying additional shear load after buckling through diagonal tension, hybrid design can have its allowable shear stress value more than that of pure diagonal tension web.



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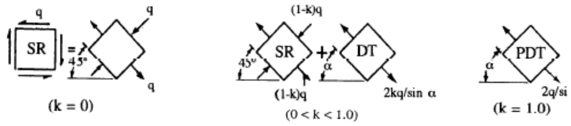

Figure 6. Web stresses for different types of webs

As is clear from the figure 6 that shear load applied on hybrid design would be carried in part by shear and remaining by diagonal tension, so total shear stress on a diagonal tension web can be written as $f_s = f_{SR} + f_{DT}$ where f_{SR} = (1-k) f_s (Shear resistant stress) and f_{DT} = kf_s (Diagonal tension stress) and 'k' is diagonal tension factor..

Diagonal tension that would be carried for a specific load also depends on the distance between stiffeners for a constant height of web. As it is clear from the equivalent truss diagram for pure diagonal tension webs more is the distance between two stiffeners less will be the diagonal tension stress and more stress would be on shear restraint part for hybrid design.

So small distance on one hand is desirable but can on other hand increase both weight and cost of the structure. So, an optimum distance should be maintained between stiffeners depending on the loading conditions and location where the structure is to be used.

3. CONCLUSION

Hybrid diagonal tension designs are a necessity in today's aviation industry where weight saving is correlated with profits. Reducing weight without compromising the safety of the occupants of the aircraft is also essential. So, in follow up research papers, failure modes of diagonal tension webs, hand calculations of ultimate and allowable stress for diagonal tension and shear resistant panels for a specific case, their FEM analysis for the same case, and also developing the theory for curved hybrid designed panels for use as skin Panels in aircraft would be done.

Hybrid shear resistant panel designs can be used in spars, stringers, longerons and in many other places where beams are used. These panels would reduce not only the weight but also cost as additional web panels could be made from same amount of raw material.

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