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ULTIMATE STRENGTH OF SQUARE PLATE

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1. INTRODUCTION

The behavior of plate under uniform compressive strain is focused and the strain hardening property as observed in high strength steel is also taken into account. In this study, the typical strain hardening portion of high strength steel is assumed in a form convenient to introduce the material properties such as the tensile strength and the strain level at the tensile strength. The influence of strain hardening, initial out-of-plane deflection and aspect ratio on the ultimate strength is discussed.

2. ANALYTICAL METHOD

The present analysis is carried out using assumed-stress hybrid finite element method. The constitutive equation is developed considering kinematic hardening model. The panel is divided into 10 × 10 mesh and only a quarter is analyzed. The initial out-of-plane deflection is assumed in a double-sinusoidal form having its maximum value at the midpoint. It is assigned three different values of $b/150, b/500$, and $b/1000$. The yield stress is taken as 600MPa when it is not stated otherwise. The results of the hardening case are limited to the material whose tensile strength is attained at the strain level of 20 times the yield strain and its yield ratio is 0.8. The non-hardening material is assumed to be elastic-perfectly plastic.

The strain hardening portion is assumed to be defined by

$$\left(\frac{(\sigma-\sigma_o)}{A(\sigma_u-\sigma_y)}\right)^n+\left(\frac{(\epsilon_o-\epsilon)}{B(\epsilon_u-\epsilon_Y)}\right)^n=1 \qquad \epsilon_y\le\epsilon\le\epsilon_u$$

where $\sigma_o,\sigma_u,\sigma_y,n,\epsilon_o,\epsilon_u,A,B$ are constants for a material. σ_y is the yield stress. σ_u and ϵ_u are the ultimate strength and the strain level at that point, respectively.

3. DISCUSSION OF RESULTS

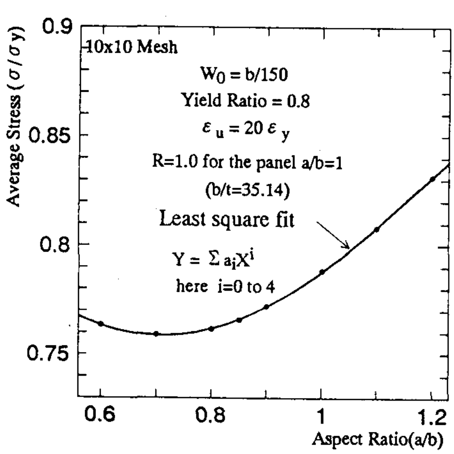

Fig. 1 Variation of ultimate strength

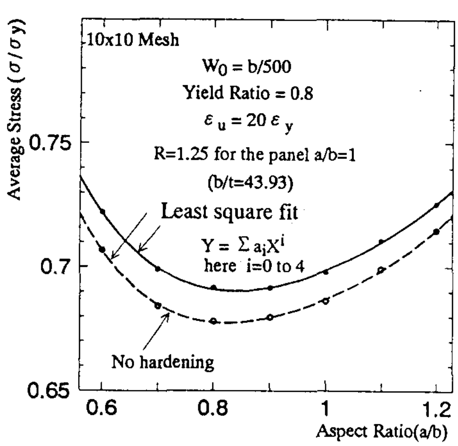

Fig. 2 Ultimate strength with varying aspect ratio

In **Fig.1**, the variation of ultimate strength with the aspect ratio is plotted for the case of out-of-plane deflection $b/150$ which is the allowable value given in JSHB(1980). The generalized width-thickness ratio (R) is given by

$$R=\frac{b}{t}\sqrt{\frac{\sigma_y}{E}\frac{12(1-\nu^2)}{\pi^2k}}$$

and it is taken as 1.0 for a square panel. In the computation of R, the buckling coefficient k is assumed to be 4.0, equivalent to the value of a simply supported elastic plate subjected to uniform axial stress. This figure shows that the ultimate strength reduces when the aspect ratio goes down from 1 to 0.7 and it is minimum for aspect ratio 0.7. However, it is interesting to note that the ultimate strength of a square panel is only about 4% higher than the minimum ultimate strength.

Fig.2 gives some more information. These results are for a different R equal to 1.25 for a square panel and the corresponding b/t becomes 43.93. The difference between the hardening and non-hardening material shrinks a little bit while moving away from the minimum strength points. However, the difference itself is very small as expected for this case, because the governing criterion is elastic buckling. The initial deflection is taken as $b/500$. Because of this, the minimum ultimate strength point shifts to 0.8. Further, the difference between the minimum strength and the strength of a square plate stands at a reduced level(about1%).

The influence of out-of-plane deflection of $b/150$ and $b/1000$ for mild steel type stress-strain curve is explained in **Fig.3** for varying yield stress from 200 to 500MPa. The initial out-of-plane deflection of $b/150$ gives the largest drop-off in strength for the smallest yield stress. This weakening effect is very much in command in the elastic portion of the curves, and the difference diminishes with increasing compressive displacements. For larger yield stress, the difference is getting smaller and smaller for this b/t ratio. This figure shows that the comparison of the results for the different yield stresses under the same value of b/t ratio is meaningless because the results fall apart when the normalized ultimate strength is plotted.

With varying yield stress, the load-shortening curves for $b/t = 60$ are given in **Fig.4**. The initial out-of-plane deflection is set $b/1000$ which is generally used to compare the experimental results, and it gives an idea of the nature of the influence exerted by the small initial deflection. It is evident that the strain hardening material shows higher strength in the portion where the plastic flow occurs. Even though the difference seems to be not changing very much with yield stress but it shows slightly larger difference for smaller yield stress. The possible maximum difference is equivalent to the difference in uniaxial stress-strain curves of those two material, but this can be expected only with smaller b/t or generalized width-thickness ratios.

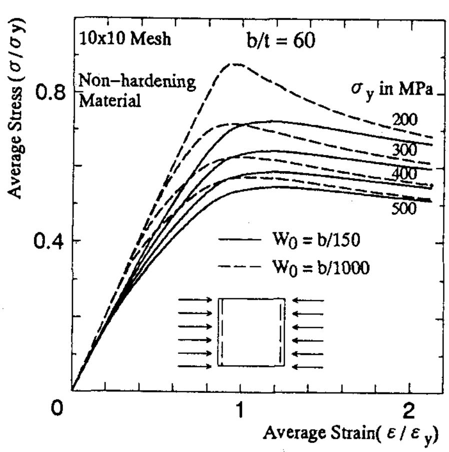

Fig. 3 Influence of initial deflection

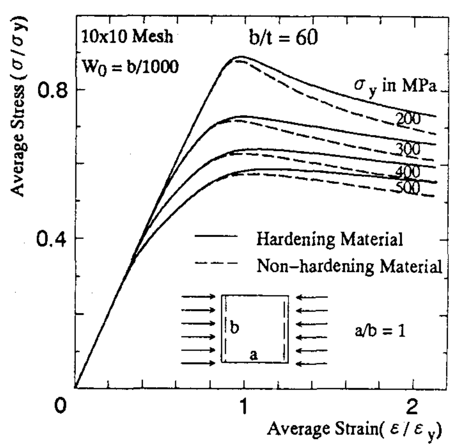

Fig. 4 Influence of strain hardening

4. SUMMARY

The strain hardening portion of high strength steel is assumed in a form which explicitly contains the material properties and that relation is successfully used to study the behavior of high strength steel panel under uniform compressive strength. The influence of initial out-of-plane deflection on the ultimate strength is also described and it may be a good idea to control the initial deflection in order to attain higher strength. The strength of square plate is about 1 to 4 percent higher than the minimum ultimate strength depending on the initial deflection and R value for both hardening and non-hardening cases.