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Limit collapse load analysis of perforated plates

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ABSTRACT: Elastic-plastic analysis of perforated plates with triangular perforation pattern, of different ligament efficiencies (15% to 50%), was done in order to evaluate its collapse load. These plates were also analysed using, computationally inexpensive, equivalent solid plate concept. Comparision between their results has been made.

1 INTRODUCTION

The components of Nuclear Reactor Systems are designed for broad range of loads, which varies from normal service loads to extreme loads e.g. major earthquake and postulated accident loads, ASME, 1986. Unlike normal service loads, the probability of occurrance of extreme loads is very low (may be once in the design life) but can induce high stresses and components may have to be replaced. Elastic-plastic analysis is necessary to evaluate their collapse loads.

Perforated plates are part of many nuclear components viz., steam generator tube sheets, flow distribution plate, end-shield & calandria tube sheets of Pressurized Heavy Water Reactor. Their elastic-plastic analysis was done using two different structural models. In first approach, perforated plate was modelled with all the holes. In another approach it was modelled as equivalent solid plate with modified elastic constants and reduced yield strength.

2 STRUCTURAL DETAILS & MATERIAL PROPERTIES

The perforated plate analysed was simply-supported, having 19 holes in triangular pattern (Fig.1). Transverse load (P) acts along the circumference of central hole. The diameter (D) of plate is 60 cm, thickness (t) is 3 cm & hole pitch (p) is 10 cm. Hole diameter (d) was varied such that ligament efficiency (η) lies between 15% to 50% (Fig.1).

The material of plate is AISI Type SS 304L. Its Young's modulus (E)=2.1E06 Kg(f)/sqcm, Poisson's ratio (ν)=0.3 and yield strength (Sy)=1758 Kg(f)/sqcm, ASME,1986. It was assumed that material is elastic-perfectly plastic, (Fig.2).

3 THEORETICAL BACKGROUND

The modelling and elastic analysis of perforated plate as equivalent solid plate is well accepted, ASME,1986, O'Donnell & Langer,1962, Meijers,1970 & 1986 and Slot & O'Donnell, 1971. The equivalent soild plate concept is preferred due to ease in modelling and inexpensive analysis. The perforated plate is modelled as solid plate of same geometrical dimensions and thickness but with modified Young's modulus & Poisson's ratio such that their flexural rigidity and hence the displacement field is same. The nominal stresses obtained from equivalent solid plate analysis are multiplied by appropriate multipliers in order to estimate actual stresses in perforated plate. Modified elastic constants for thin plates (t/p <2) were suggested by Meijers, 1970 & 1986.

The elastic-plastic analysis of equivalent solid plate requires modified yield surface in addition to modified elastic constants. The modified yield surface of perforated plates with triangular perforation pattern was suggested by O'Donnell & Porowski,1973,1974 & 1981 and is based on Tresca's yield criteria. This yield surface is illustrated in Fig.3, where S1 and S2 are nominal stresses. The maximum value of S1 & S2 in solid plate are given by yield-surface shown by outer most hexagon in Fig.3, where as for perforated plate it is defined by middle curve. From Fig.3 it is clear that effective reduced yield strength (Sym) of perforated plate varies with biaxiality ratio of stresses and the maximum value of Sym is $Sy.\eta$ for equibiaxial stresses. To avoid complexity of Sym varying with biaxiality ratio a general cut-out factor (Co) is used in the analysis. Co is defined by the largest size of yield-hexagon inscribed in the yield surface of perforated plate as shown by inner most curve (eq. isotropic yield surface) in Fig.3. Then

$$Sym = Sy.\eta.Co \qquad (1)$$

For all the ligament efficiencies Co < 1.0, O'Donnell & Porowski, 1973, 1974 & 1981, and Table 1. The Sym given by eq(1) will lead to very conservative assessment for equi-biaxial stresses whereas, if we assume Co is 1.0 then resulting Sym may lead to overprediction of collapse load.

Limit collapse load of a structure, with elastic-perfectly plastic material, is the load at which rate of change of deflection (w) with respect to load (P) tends to infinity or dP/dw =0. ASME,1986, has adopted Twice-Elastic-Slope method to estimate collapse load. It states that collapse load (Po) is the load at the intercept of a line drawn from origin of a load-deflection (P-w) curve at a slope of twice the value of the slope of the elastic portion of the curve. This method is illustrated in Fig.4.

4 FINITE ELEMENT ANALYSIS

Plate-Shell elements were used to model the plate. Quarter symmetric finite element mesh of perforated plate is shown in Fig.5. Finite element model of equivalent solid plate consisted of two zones, the inner one, which simulates perforated zone, was with modified elastic constants and reduced yield strength (Sym), while the outer rim zone was with material properties same as those of actual plate.

Elastic-plastic analysis was done for ligament efficiencis of 15%, 20%, 30%, 40% & 50%. For each ligament efficiency equivalent solid plate analysis was done twice. Once with Sym=Sy.η (i.e. Co=1.0), and another with Sym=Sy.η.Co. The former may over-estimate and later under-estimate the collpase load.

In analysis Von-Mises criteria was used whereas, Co values are based on in-plane load and Tresca's criteria.

5 RESULTS & CONCLUSIONS

Total load (P) has been plotted against average deflection (w) of nodes at which load acts. The P-w curves for perforated plate analysis are given in Fig.6 and for η =50% calculation of collapse load (Po) based on Twice-Elastic-Slope method has been shown. Fig.7 & Fig.8 show the comparison between P-w curves of perforated plate and equivalent solid plate. The Po of both the models is given in Table 1.

For the case when Sym=Sy.η .Co, then as expected, the Po of equivalent solid plate is less than that of perforated plate and the difference is maximum for η =15% while minimum for η =50%. Similar trend is observed in P-w curves also.

For the case when Sym=Sy.η , then for η = 40% & 50% the Po of equivalent solid plate is over-estimated where as for η = 15%, 20% & 30% it is lower but the difference is insignificant. P-w curves are quite close to each other.

It can be concluded that equivalent solid plate analysis, which is fairly inexpensive, can reasonably predict the load-deflection behaviour and hence the collapse load. Porowski & O'Donnell,1977, have pointed out that equivalent plate will not capture the plastic-strain concentration, near the hole. If plate is being designed for extreme loads whose probability of occurrance is once in life time of a structure then this draw back can be omitted.

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Table 1. Collapse load of perforated & eq. solid plate model

	Co	Collapse load (in Kg) (based on Twice-Elastic-Slope Method) Perf. Plate	Equivalent Solid Plate $S_{ym}=S_y.\eta$	 $S_{ym}=S_y.\eta\,C_o$
15%	0.70	8860	8020	5648
20%	0.75	10008	9608	7088
30%	0.80	12044	11836	9664
40%	0.82	13880	14432	12148
50%	0.87	15528	15788	13436

Note : Co values from O'Donnell & Porowski, 1981.

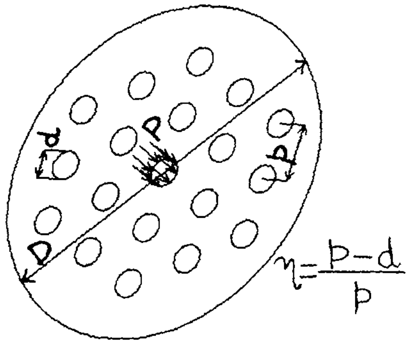

FIG.1 SIMPLY-SUPPORTED PERFORATED PLATE WITH TRIANGULAR PATTERN

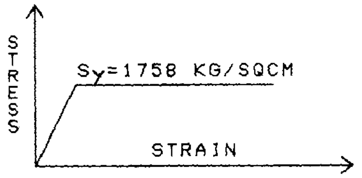

FIG.2 STRESS-STARIN CURVE OF PLATE MATERIAL

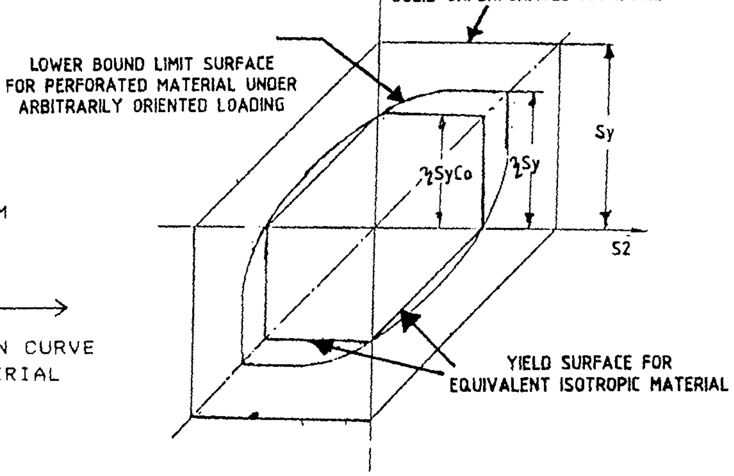

FIG. 3 : LOWER BOUND YIELD SURFACE FOR PERFORATED MATERIALS AND EQUIVALENT TRESCA

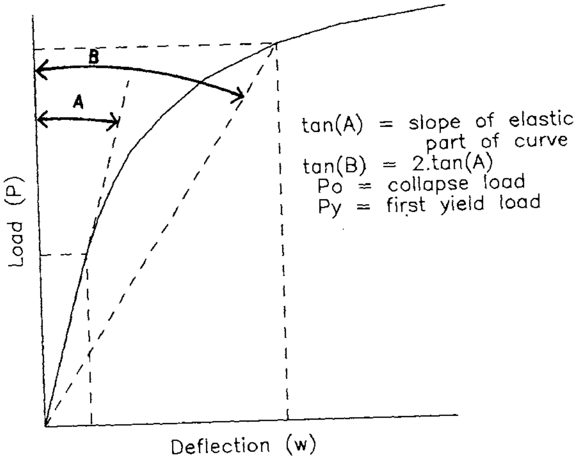

Fig. 4 Twice–Elastic–Slope Method

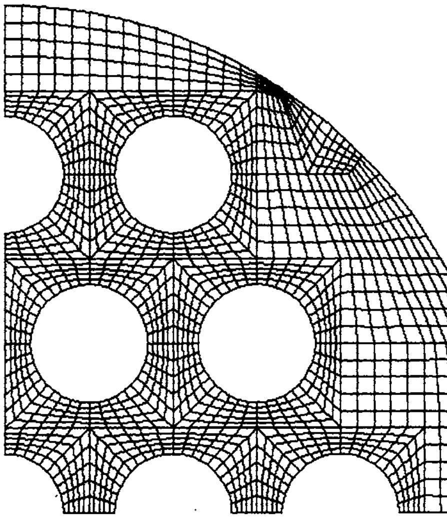

FIG.5 TYPICAL MESH FOR PERFORATED PLATE ANALYSIS

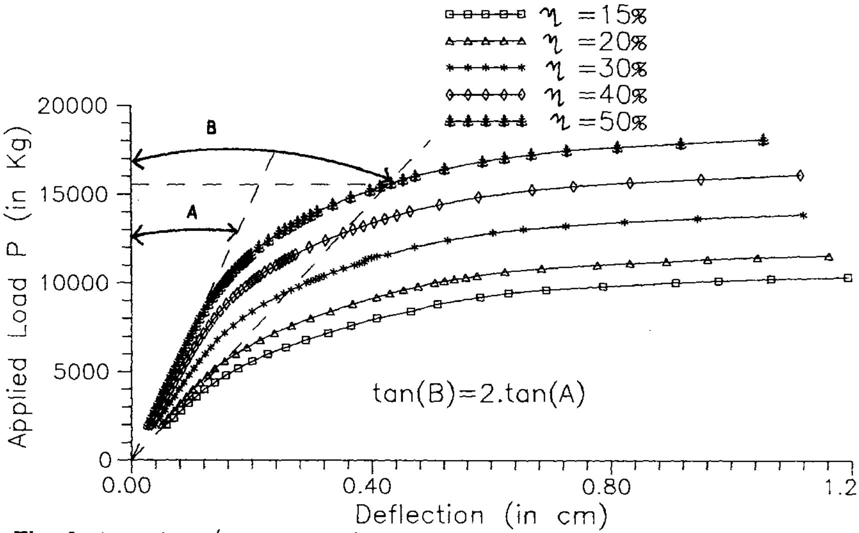

Fig.6 Load v/s deflection curves for perforated plate with different ligament efficiencies. For ligament eff. of 50% collapse load as calculated by Twice–Elastic–Slope method has been shown

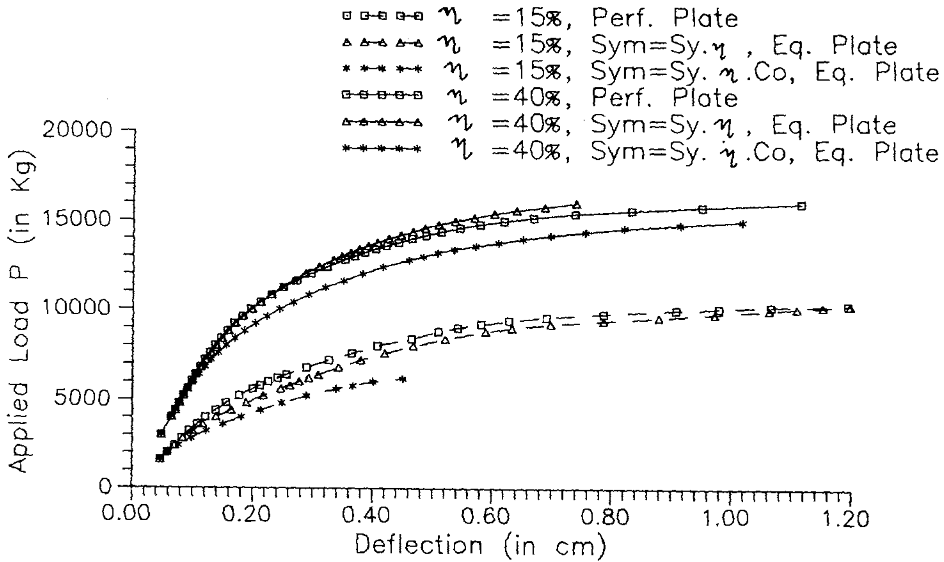

Fig.7 Load v/s deflection curves for perforated plate (15% & 40% ligament efficiency) and corresponding eq. solid plate with reduced yield stress, Sym.

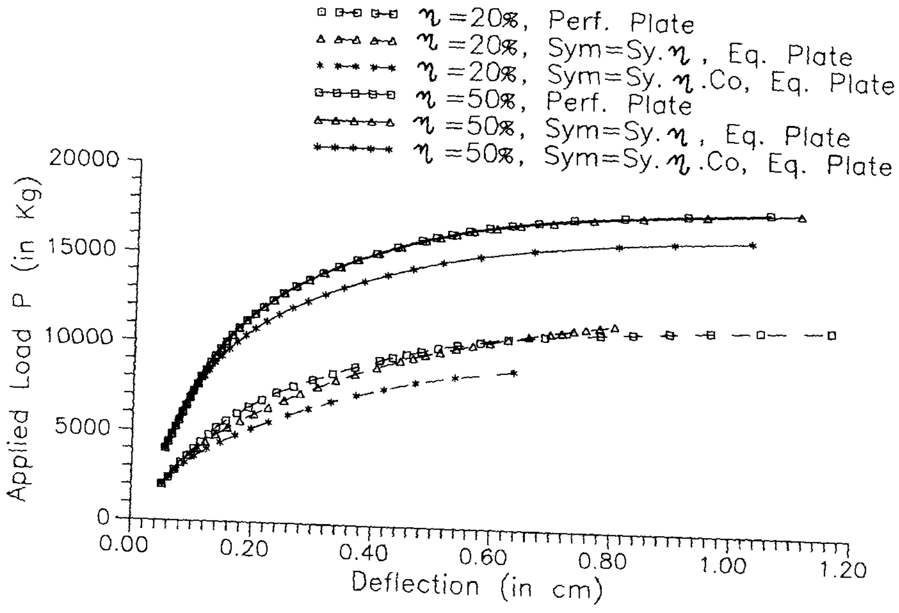

Fig.8 Load v/s deflection curves for perforated plate (20% & 50% ligament efficiency) and corresponding eq. solid plate with reduced yield stress, Sym.