Journal of Engineering and Applied Sciences 2 (2): 456-461, 2007

Blast Loaded Stiffened Plates

A. Kadid, N. Lahbari and A. Fourar
Laboratoire de Recherche en Hydraulique Appliquée (LARHYA) Université de Batna, Algeria

Abstract: This study is concerned with the numerical study of fully fixed stiffened plates. The aim of this research is to determine the dynamic response of the plates with different stiffener configurations and considering the effect of mesh density, time duration and strain rate sensitivity. Numerical solutions are obtained by using the finite element method and the central difference method for the time integration of the non linear equations of motion. Special emphasis is focused on the evolution of mid-point displacements and plastic strain energy. The results obtained allow getting an insight into the effect of stiffeners configurations and of the above parameters on the response of the plates under uniform blast loading and indicate that stiffener configurations and time duration can affect their overall behaviour.

Key words: Blast loading, plates, stiffeners, mesh density, strain rate sensitivity

INTRODUCTION

The dynamic response of structures to air blast has for many years been the subject of numerous studies. Most of them are related to the dynamic response of isotropic plates and shells. Difficulties that arise from the complexity of the problem, which involves time dependent finite deformations, high strain rates and nonlinear inelastic material behaviour, have motivated various assumptions and approximations to simplify the models. These models span the full range of sophistication from simple single degree of freedom system to general purpose finite element programs such as ABAQUS, ANSYS and ADINA etc. Schuback *et al.* (1989) presented a simplified rigid plastic method for modelling beams. This study was extended to asymmetric beam sections and subsequently to one-way and two-way orthogonally stiffened plates (Schuback *et al.*, 1989; Schuback 1991). In this research, the response of a one way stiffened plate under intense loads and the stiffened plated was treated as a single symmetric beam with the plate acting as a large flange. The two stiffened plates are then modelled as a grillage of beams with asymmetric section. The rigid plastic and finite element methods were combined for the modelling of orthogonally stiffened plates Olson (1991). The rigid-plastic modelling used a beam grillage representation of the stiffened plate wherein the beam sections were asymmetric. In connection with structural dynamics analysis, there are several simple degree of freedom methods in the classical books of structural dynamics (Biggs 1964; Clough and Penzien 1975). For more rigorous analysis, the structure must be modelled as a system of multiple degrees of freedom Louca *et al.* (1996). Yuen *et al.* (2003) presented the results of numerical work of built-in quadrangular plates with different stiffener configurations under blast loading. Both temperature-dependant material properties and strain rate sensitivity were included in the numerical modelling. Jacinto *et al.* (2001) conducted numerical modelling on metallic plates subjected to explosive loads. A linear dynamic analysis of the plate models with ABAQUS was carried out. Suggestions were made to computational modelling of structures under explosive loading. Louca *et al.* (1996) presented results of the response of a typical wall and a tee-stiffened panel subjected to hydrocarbon explosions with geometries typical of those used in off shore structures. Non linear finite element analyses were performed, accounting for the effect of plasticity, strain rate and buckling. Comparisons were made between the numerical results and experimental data and the approximate solutions obtained with a single degree of freedom model. Numerical studies of stiffened plates subjected to hydrocarbon explosions and a parametric study of the simplified model of the stiffened plate considering different response aspects including the contribution of stiffeners under different stress state and loading conditions were presented by Pan *et al.* (1999). The main conclusions from this are: the boundary conditions have a significant influence on the response and the contribution of stiffeners is influenced by many factors especially the second moment of inertia of the section. Other investigators have performed similar analyses (Nurick *et al.*, 1995; Pan *et al.*, 1997; Rudraptana *et al.*, 1999). In addition, extensive experimental studies

Corresponding Author: A. Kadid, Laboratoire de Recherche en Hydraulique Appliquée (LARHYA) Université de Batna (Algeria)

have also been conducted to assess numerical simulations (Yuen *et al*., 2003; Jacinto *et al*., 2001; Pan *et al*., 1999; Jacob *et al*., 2004; Turkmen and Mecitoglu, 1999). The numerical results presented in this paper can help to obtain design guidelines of offshore topsides and steel bridge plated structures since explosive tests are costly and dangerous, their reproducibility is not always ensured and the results of the tests always show some degree of uncertainty. This paper presents numerical studies of stiffened plates considering the contribution of stiffeners and taking into account different parameters.

Description of the plates: All the plates are 16 mm thick and 1200×1200 mm^2 with rectangular stiffeners 30 mm thick and 70 mm height. In Fig. 1, are shown the different stiffener configurations used in the numerical studies.

Finite element modelling: Finite element analysis is performed using the general purpose finite element code ABAQUS/EXPLICIT (1998) which can incorporate non linear geometry, strain rate sensitivity and thermal effects.

Model geometry: ABAQUS offers an element library for a wide range of geometric models. In the present study, the fourth nodded shell element S4R with reduced integration and hourglass control was used to model the geometry of the plates and the stiffeners.

Three different models consisting of grids of shell elements of size 0.03, 0.06 and 0.12 representing fine, medium and coarse meshes respectively, were used to verify the accuracy of the finite element models of the plates.

Fig. 1: Stiffener configurations

Idealisation of blast loading: The pressure time-history of a blast wave can be illustrated with a general shape as shown in Fig. 2a. The illustration is an idealization for an explosion in free air.

The pressure time-history is divided into a positive and a negative phase. In the positive phase, maximum overpressure, p_{s+}, rises instantaneously and decays to atmospheric pressure, P_0, in the time T^+. For the negative phase, the maximum negative pressure, p_s^-, has much lower amplitude than the positive overpressure. The duration of the negative phase, $T-$, is much longer compared to the positive duration. The positive phase is more interesting in studies of blast wave effects on structures because of its high amplitude of the overpressure and the concentrated impulse. The pressure time-history in Fig. 2a can be approximated by the following exponential form Eq. 1, Bulson (1997).

$$P(t) = P_0 + P_s + \left[1 - \frac{t}{T_+}\right] e^{-bt/T^+} \quad (1)$$

Where p(t) is the overpressure at time t and T^+ (the positive duration) is the time required for the pressure to return to atmospheric pressure, P_0,. Depending on the value of b, various pressure time-histories can be described. The peak pressure, is dependent on the distance from the charge and the weight of the explosives. In addition, if the peak pressure, the positive impulse and the positive time duration are known, the constant b can be determined and then the pressure time-history is known.

Table 1: Fundamental frequencies and periods

Model	1	2	3	4	5	6
fn (cycles/s)	99.84	143.76	152.50	161.97	163.82	177.63
Tn (s)	0.01	0.007	0.0066	0.0062	0.006	0.0056
Tn/2 (s)	0.005	0.035	0.0033	0.0031	0.003	0.0028

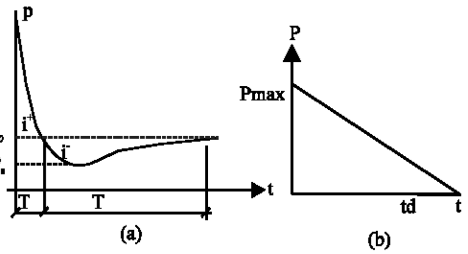

Fig. 2: Pressure time-history from a blast a) exponential form b) simplified triangular form

The Eq. 1 is often simplified with a triangular pressure-time curve Eq. 2, Fig. 2b; Bulson (1997):

$$P(t) = P_{max}\left[1 - \frac{t}{T^+}\right] \quad (2)$$

Conventional high explosives tend to produce different magnitudes of peak pressure. As a result, the environments produced by these chemicals will be different from each other. In order to have a basis for comparison, various explosives are compared to equivalent TNT values. With a scaling parameter Eq. 3, it is possible to calculate the effect of an explosion as long as the equivalent weight of charge in TNT is known.

$$Z = \frac{R}{W^{1/3}} \quad (3)$$

where R is the distance from the detonation and W is the equivalent weight TNT.

Material properties: The adopted material properties were Young Modulus E = 210 GPA, Poisson coefficient $V = 0.3$ and densityρ = 7800 kg m^{-3}. The static yield stress was 300 MPa and the average rupture strain was 35%. The stress-strain curves were converted into true stress and logarithmic plastic strain according to ABAQUS/EXPLICIT code manual.

Dynamic analysis: The dynamic equilibrium equations have been integrated with the central difference scheme with automatic time stepping. The loading function shown in Fig. 1.b is scaled such that Pmax = 1.3 MPa. In order to study the effect of time duration, four time duration t_d have been used in this study 1 ms, 2 ms, 10 ms and 20 ms.

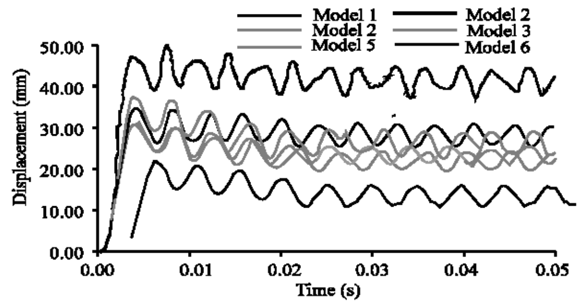

Fig. 3: Influence of stiffener configurations t_d = 20 ms

A modal analysis has been conducted to obtain the natural frequencies of the plates in order to determine the ratio of the duration of the loading over the natural period of the structure. The fist frequency of each structure is shown in Table 1 and is for mesh 1.

The time integration is carried long enough to capture both the forced vibration as well as the free vibration afterwards.

RESULTS AND DISCUSSION

Effect of stiffeners configurations: For the time duration t_d = 20 ms (Fig. 3), the introduction of stiffeners decreases significantly the mid-point displacement; the mid-point displacement for the model 1 is 52.98 mm while for models 2, 3, 4 and 5 it is 39.48 mm, 36.6 mm, 32.36 mm and 32.70 mm, respectively. For model 6, the mid-point displacement is 25.30 mm. Thus, the configurations of stiffeners can have important influence on the response of the stiffened plates. The same conclusions apply for t_d = 1 ms, (Fig. 4).The results obtained are in good agreement with the numerical and experimental results of Yuen *et al.* (2003) where it is stated that as the plates become stiffer (with the addition of more stiffener), the maximum displacement decreases ant that the stiffener location can also influence the response, of Pan *et al.* (1997) where it was found that stiffeners can have a significant effect on global displacement and of Turkmen, H.S. and Mecitoglu, Z (1999) who concluded that stiffeners reduce the peak strains by 11% to 42 %..

Effect of time duration: Increasing the time duration by factors of 2, 10 and 20 results in an increase in the mid-point displacement of 1.73, 3.06 and 3.4 respectively for model 1 (unstiffened plate), Fig. 5. For model 2 (plate with

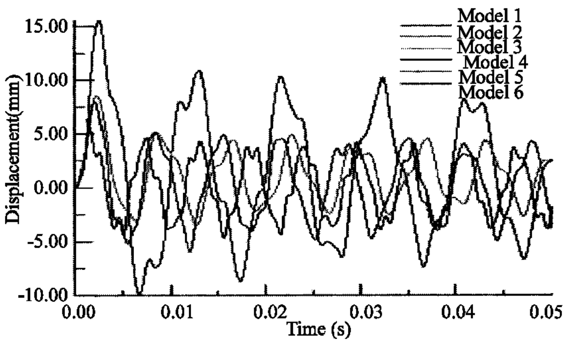

Fig. 4: Influence of stiffener configurations td = 1 ms

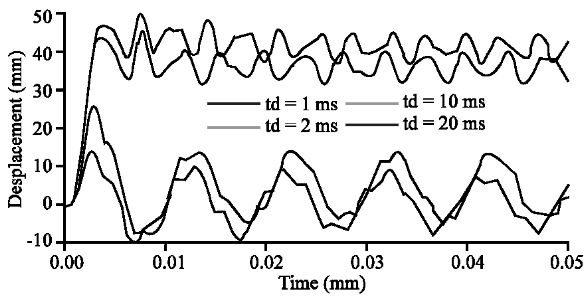

Fig. 5: Influence of loading duration model 1

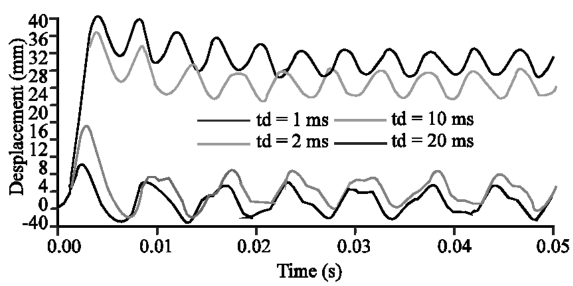

Fig. 6: Influence of loading duration model 2

a central stiffener) Fig. 6, increasing the time duration by factors of 2, 10 and 20 results in an increase in the mid-point displacement of 1.94, 4.19 and 4.60. One important point should be noted, if the time duration t_d is longer than Tn/2, then the maximum deformation occurs during the pulse phase, while on the other hand if t_d is lees than Tn/2, the maximum deformation occurs during the free vibration phase and is mainly controlled by the time integral of the pulse and this is in agreement with Chopra (2001).

Mesh density: For model 1, the three meshes yield the same time history for the mid-point displacement, suggesting that the results are not sensible to the mesh size, Fig. 7 However, for model 2 Fig. 8 and 9, it can be seen that the influence of meshing can be very important for loading duration greater than Tn/2 (t_d = 20 ms)

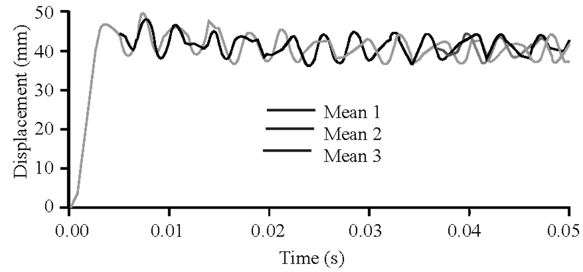

Fig. 7: Influence of meshing Model 1 t_d = 20 ms

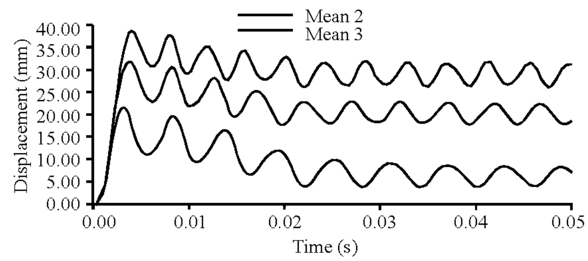

Fig. 8: Influence of meshing Model 2 t_d = 20 ms

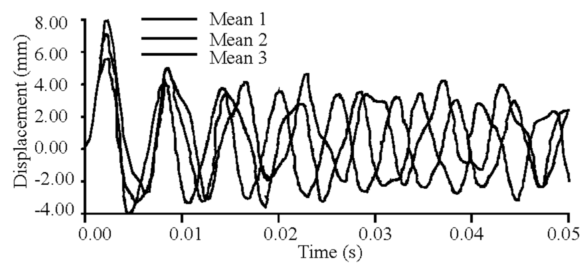

Fig. 9: Influence of meshing Model 2 t_d = 1 ms

important for loading duration g reater than Tn/2 (t_d = 20 ms) where Tn is the fundamental period of the structure. In T Turkmen and H.S. Mecitoglu (1999), it was found that refining the mesh leads to considerable changes in the response of stiffened plates. This difference in the behaviour between the two models can be explained by the fact that the stiffeners can be subjected to almost pure bending and that using only few first order reduced integration element through the depth of the stiffener (in our case two or three) is not sufficient to model correctly the in lane behaviour and also by the influence of the stiffeners dimensions. .

Strain rate sensitivity: Strain/rate effects are included by adjusting the material dynamic yield stress at each Gauss point according to the Cowper-Seymonds relation, Eq. 4; Jones (1989):

$$\sigma_Y = \sigma_0\left[1+\left|\frac{\dot{\varepsilon}}{D}\right|^{\frac{1}{n}}\right] \quad (4)$$

Where σ_0 is the static uniaxial yield stress, σ_Y is the dynamic yield stress and D and n are parameters which are determined from experiments. In this study the following three sets of values for D and n were adopted, (1) $D = 40S^{-1}$ and n = 5, (2) $D = 240S^{-1}$ and n = 4.74 (3) $D = 6844S^{-1}$ and n = 3.91, Boh *et al.* (2004). When strain rate effect is taken into account, the yield stress increases as the strain rate increases. Thus, because the elastic modulus is higher than the plastic modulus, it is expected that the analysis with strain rate will be much stiffer resulting in a decrease in the mid-point displacement. However, the rate of decrease is dependant on the duration of loading; for instance for model 2 Fig.10, when t_d = 20 ms, the mid-point displacement is 39.48 mm without strain rate and 30.93 mm when strain rate (D = 40s-1 n = 5) is included, while for t_d = 1 ms, the values are 8.58 mm and 7.96 mm with and without strain rate (D = 40s-1 n = 5) respectively, see Fig. 11. These results are further confirmed by the observation of the history of the plastic strain energy Fig. 12a and 12b, where it is obvious that for t_d = 20 ms, the plastic strain energy with strain rate is greatly reduced compared to the case without rate indicating a stiffer response. For t_d = 1 ms, the difference in the plastic strain energy history for material with and without strain rate respectively, is very small. However, consideration of different material constants (D and n) results in a very different response. Thus, the results are sensitive to material data. Boh *et al.* (2004) have indicated that there are a lot of uncertainties concerning the strain rate effects on steel structural response and that there are studies on strain rate phenomenon which are only applicable to their investigated domain and sometimes even conflicting with other studies.

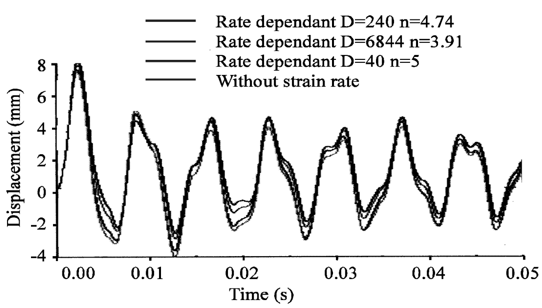

Fig. 10: Influence of strain rate t_d = 20 ms

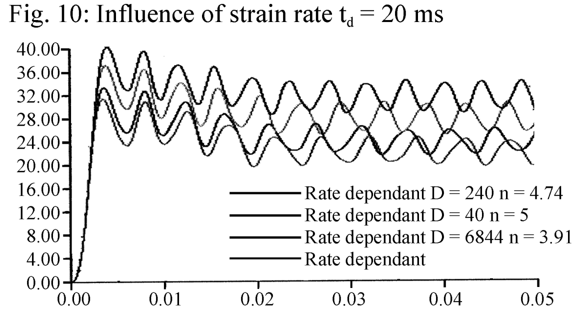

Fig. 11: Influence of strain rate td = 1 ms

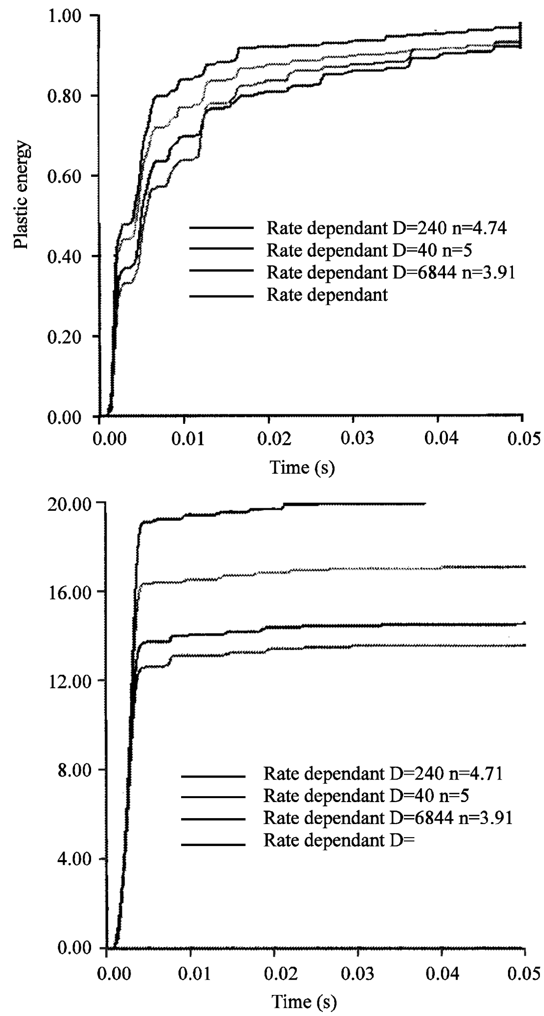

Fig. 12: History of plastic strain energy for a) t_d = 1 ms b) t_d = 20 ms

CONCLUSIONS

From the non linear dynamic finite element analyses carried out to examine the behaviour of fully fixed stiffened plates under blast loading, the following conclusions can be drawn:

- The effect of stiffeners configurations can be very important since it can affect drastically the overall behaviour of the plates as indicated by model 6
- The time duration is one of the most important parameter since it has an influence on the other parameters such as mesh density and strain rate and is largely dependant on the ratio $t_d/(Tn/2)$.
- Mesh density is not relevant for the model 1 (unstiffened plate) but for stiffened plates in can influences considerably the results especially for larger values of t_d (t_d = 20 ms).

- The inclusion of strain rate effect results in a much stiffer response, especially for larger values of t_d resulting in lower mid-point displacement, however, results are very sensitive to the values of D and n. Thus, strain effect should be taken when analysing structures subjected to blast loading.

REFERENCES

Abaqus/Explicit Manuals. Version 5.8, Hibbitt, Karlsson and Sorensen, INC, USA, 1998.

Biggs, J.M., 1964. Introduction to structural dynamics. London: McGraw-Hill Book Company.

Boh, J.W, L.A. Louca, Y.S. Choo., 2004. Strain rate effects on the response of stainless steel corrugated firewalls subjected to hydrocarbon explosions. J. Constructional Steel Res., 60: 1-29.

Buslon, P.S., 1997. Explosive loading of engineering tructures, E § FN Spon, London,.

Chopra, A.K., 2001. Dynamics of structures: theory and applications to earthquake engineering. Upper Saddle River, NJ: Prentice-Hall.

Clough, R.W. and J. Penzien, 1977. Dynamics of structures. New York: McGraw Hill.

Jacinto, A.C., R.D. Ambrosini,, R.F. Danesi, 2001. Experimental and computational analysis of plates under air blast. Intl. J. Impact Eng., 125: 927-947.

Jacob, N., S.C.K. Yuen, G.N. Nurick, D. Bonorchis, A.S. Desai and D. Tait, 2004. Scaling aspects of quadrangular plates subjected to localised blast loads experiments and predictions. Int. J. Impact Eng., 30: 1179-1208.

Jones N., 1989. Structural impact. Cambridge: Cambridge Univ. Press.

Louca, L.A. and J. Harding, 1996. Response of plates to blast loading. In: International Conference on Advances in Steel Structures. Hong Kong.

Louca, L.A., M. Punjani and J.E. Harding, 1996. Non-linear analysis of blast walls and stiffened to hydrocarbon explosion. J. Construct. Steel Res., 37: 93-113.

Nurick, K.N., M.D. Olson, J.R. Fagnan and A. Levin, 1995. Deformation and tearing of blast loaded stiffened square plates. Intl. J. Impact Eng., 16: 273-91.

Olson, M.D., 1975. Efficient modelling of blast loaded stiffened plate and cylindrical shell structures. Comput. Struct, Inc., 40: 1139-49.

Pan, Y.G., and L.A. Louca, 1999. Experimental and numerical studies on the response of stiffened plates subjected to gas explosions. J. Constructional Steel Res., 52: 171-193.

Pan, Y.G., L.A. Louca and G. White, 1997. Response of stiffened plates subjected to hydrocarbon explosions. Proceedings of the 8th Intl. Conference on the behaviour of Offshore Structures, Delft, the Netherlands.

Rudraptana, N.S., R. Vaziri and M.D. Olson, 1999. Deformation and failure of blast-loaded square plates. Intl. J. Impact Eng., 22: 449-467.

Schubak, R.B., D.L. Anderson and M.D. Olson, 1989. Simplified dynamics analysis of rigid-plastic beams. Intl. J. Impact Eng., 8: 27-42.

Schubak, R.B., M.D. Olson and D.L. Anderson, 1989. Nonlinear analysis of one-way stiffened plates under blast load. Procs. Conf. on Structures under Shock and Impact, Cambridge, MA, Elsevier, pp: 345-354.

Schubak, R.B., 1991. Nonlinear rigid-plastic modelling of blast loaded stiffened plates. Ph.D Thesis, Department of Civil Engineering, University of British Columbia.

Turkmen, H.S. and Z. Mecitoglu, 1999. Dynamic response of a stiffened laminated composite plate subjected to blast load. J. Sound and Vibration, 221: 371- 389.

Yuen, S.C.K. and G.N. Nurick, 2003. Experimental and numerical studies on the response of quadrangular stiffened plates. Part I: subjected to uniform blast load. Intl. J. Impact Eng., 31: 55-83.