Equivalent shock environment test conditions based on shock damage mechanisms

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Abstract

Although widely used, absolute acceleration shock response spectrum (AASRS) cannot properly represent the severity of all kinds of shock damages. To formulate more precise shock environment and reduce the level of shock tests conditions and experiments costs, equivalent shock environment test conditions based on shock damage mechanisms is studied in this paper. Firstly, the relationship between AASRS, PVSRS and DSRS are discussed. Then, by explicit dynamic simulation, PVSRS and DSRS are used to estimate the severity of the stress damage and displacement damage respectively. And finally the equivalent shock environment test conditions are studied.

Introduction

Absolute acceleration shock response spectrum (AASRS) is widely used to estimate the severity of the damage of the shock environment [1,2]. The same level of AASRS is considered to produce equivalence damage. Actually, AASRS cannot properly represent the severity of all shock damage mechanisms. As an example, fragile components such as ceramic and glasses are more sensitive for high stress. Pseudo velocity shock response spectrum (PVSRS) is reported to represent the severity of high stress damage [3, 4]. Flexible structures in narrow spaces are more sensitive for high displacement. Obviously, displacement shock response spectrum (DSRS) is more responsible for this kind of shock damage. The aerospace components experience severe shock environment due to stage separation, which could be as high as 10^5 g. Using this high level AASRS as shock environment test condition exceeds the ability of light gas gun. Only pyrotechnics explosion separation experiments can meet the high AASRS level, however，unavoidably brings more expensive costs.

To reduce the level of shock tests conditions and lower costs, equivalent shock environment test conditions based on shock damage mechanisms is studied in this paper. Firstly, the relationship between AASRS, PVSRS and DSRS are discussed. Then PVSRS and DSRS are used to estimate the severity of the shock stress damage and displacement damage. And explicit dynamic simulations are conducted to formulate the equivalent shock environment test conditions.

Relationship between AASRS, PVSRS and DSRS

The SRS is first developed by Biot in his PhD thesis [5], based on a single degree of freedom (SDOF) system. Define the relative displacement $z = x - y$, damping coefficient $\xi = \dfrac{c}{2km}$, natural circular frequency $\omega_n = \sqrt{\dfrac{k}{m}}$. If we ignore the damping, by Duhamel integral, one can get

$$z(t) = -\frac{1}{\omega_n}\int_0^t \ddot{y}(\tau)\sin\omega_n(t-\tau)\,\mathrm{d}\tau; \quad \dot{z}(t) = -\int_0^t \ddot{y}(\tau)\cos\omega_n(t-\tau)\,\mathrm{d}\tau; \quad \ddot{x}(t) = \omega_n\int_0^t \ddot{y}(\tau)\sin\omega_n(t-\tau)\,\mathrm{d}\tau \qquad (1)$$

The AASRS, PVSRS and DSRS are $\max_t(|\ddot{x}(t)|)$, $\max_t(|\dot{z}(t)|)$ and $\max_t(|z(t)|)$, respectively, under different excitation frequency. If we define *A*, *V* and *D* as AASRS, PVSRS and DSRS, respectively, it can derivate that

$$\frac{A}{\omega_n} = V = \omega_n D \qquad (2)$$

Equivalent shock environment test conditions of high stress damage

PVSRS is reported to represent the severity of high stress damage by shock loading [3]. To study the equivalent shock environment test conditions, a steel plate with two free edges and two fixed edges is simulated utilizing explicit dynamic method in Fig. 1. Different shock pulses are applied on one side of the plate. By changing the duration and magnitude of each shock impulse, we maintain the maximum stress of each shock consistent, i.e. generating the same stress damage potential. Finally, PVSRS and AASRS generated by each shock impulse are given in Fig. 2. and Fig. 3.

As shown in Fig. 2 and Fig. 3, under the same severity of stress damage, the magnitudes of PVSRS are mainly the same. Differently, the magnitudes of AASRS increase with the frequencies of knee point. So the result in Fig. 3 suggest that we can effectively lower the shock environment test conditions and keep the severity of stress damage unchanged by reducing the frequency of knee point. The result also follows the relationship of Eq. (2).

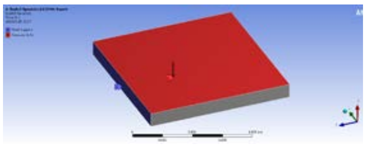

Fig. 1 Simulation model of a plate

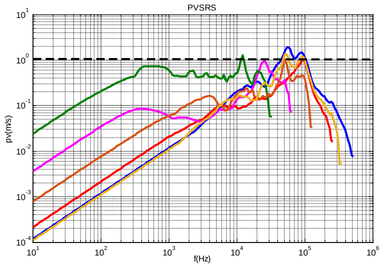

Fig. 2 PVSRS of the response generated by each shock impulse

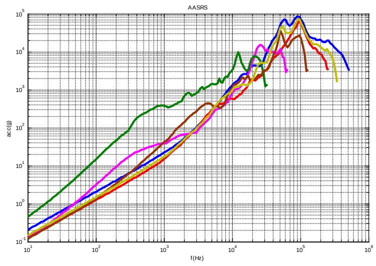

Fig. 3 AASRS of the response generated by each shock impulse

Equivalent shock environment test conditions of high displacement damage

A thinner steel plate with the same boundary conditions as Fig. 1 is simulated as shown in Fig. 4. Similarly, different shock excitations are applied on the plate to generate the same maximum displacement, i.e. generating the same displacement damage potential. We finally get the DSRS and AASRS by each shock impulse in Fig. 5. and Fig. 6. It can be observed that under the same severity of displacement damage, the magnitudes of DSRS are mainly the same. Differently, the magnitudes of AASRS increase with the frequencies of knee point. So the result in Fig. 6 suggest that we can lower the shock environment test conditions and keep the severity of displacement damage unchanged by reducing the frequency of knee point. The result also follows the relationship in Eq. (2).

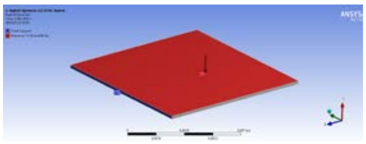

Fig. 4 Simulation model of a thinner plate

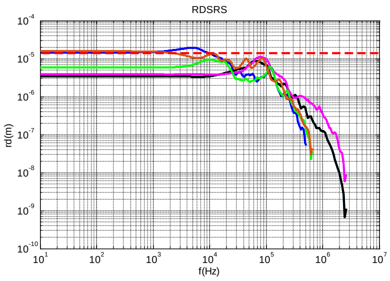

Fig. 5 DSRS of the response generated by each shock impulse

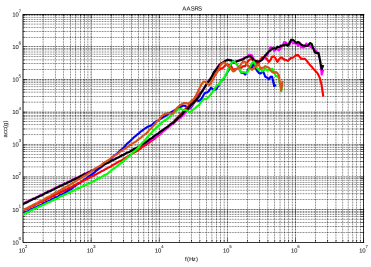

Fig. 6 AASRS of the response generated by each shock impulse

Conclusion

Through mathematic derivation and numerical simulation, we acquired the following finding. Different structures have different damage mechanisms. By design knee point frequencies of AASRS, we can acquire equivalent shock environment test conditions of stress damage and displacement damage. Through lower the frequency of knee point, the shock environment test condition can be reduced effectively, to the ability of light gas gun. Consequently, we can formulate more precise shock environment and reduce the experiments cost remarkable.

Acknowledgements

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