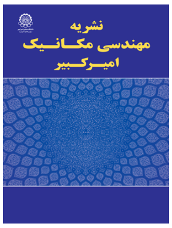

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(Special Issue 6) (2021) 955-958
DOI: 10.22060/mej.2021.19334.7001

Experimental investigation and mathematical modeling of the response of circular metallic plates under successive intense dynamic loading

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ABSTRACT: In the current research, the plastic behavior of circular plates under dynamic loading was investigated. In the experimental section, a ballistic pendulum apparatus and aluminum alloy plates were used. To investigate the deformation profile and the failure pattern of the specimens, dynamic loads were applied in a wide range from 6.49 to 24.69 Ns. To test the behavior under successive loading, each experiment was continued up to 5 loadings. Experimental observations indicate a large plastic deformation of the structure along with the thinning of the test specimens at fully clamped boundaries and the rupture of some in the same area. The results showed that with increasing the number of explosions and the charge mass, the maximum deflection increases, but the progressive deflection decreases exponentially. In the modeling section, some closed-form relations were proposed using the dimensional analysis approach to predict the maximum permanent deflection plates. In these relations, the effect of various parameters such as the plate geometry, inertia of the applied load, and strain rate sensitivity of material was considered. Comparing the results of the model with the experimental results showed that there is a very good agreement between the experimental results and the predictions of the model.

Review History:

Received: Dec. 03, 2020
Revised: Jan. 24, 2021
Accepted: Jan. 28, 2021
Available Online: Mar. 03, 2021

Keywords:

Intense dynamic loading
Successive loading
Circular plate
Mathematical modeling
Dimensional analysis.

1- Introduction

Over the past two decades, many experimental, analytical, and numerical studies were conducted on the large plastic deformation and failure mechanism of single- and multi-layered metallic plates under single uniform and localized blast loading [1]. However, structural elements such as beams, plates, and shells which are widely used in vehicle, marine, and building structures may experience repeated blast loading during military operations and weapon bombing attacks. In the general form, the blast energy is dissipated by large plastic deformation and failure of structures around the contact zones. During the repeated blast loading, the plastic deformation can accumulate and the permanent deflections will be characterized by the number of blasts and the severity of the loadings. In some cases, moderate repeated blast loading may engender disastrous consequences and result in notably severe damages. Hence, the assessment of dynamic plastic response and failure mode of monolithic and multi-layered metallic plates subjected to repeated blast or impulsive loading is a significant topic and of practical engineering interest. Nevertheless, few fundamental and pivotal investigations have been presented on this topic, i.e., under multiple uniformly and locally distributed blast loadings, and several limited investigations mostly concentrated on the performance of cylindrical shells, square tubes, reinforced concrete, composite structures, and rocks.

To the best of our knowledge and the description provided, there has been no experimental study and empirical modeling on the plastic deformation of single- and multi-layered aluminum plates and also multi-layered mixed configurations under multiple uniform blast loading so far. Therefore, the current study brings forward the experimental results of an investigation into the dynamic plastic response of circular metallic plates subjected to five consecutive blast loading. Deformation and failure modes of tested specimens, as well as a quantitative analysis of experimental results including the influence of different charge masses, layering configurations, layering arrangements, layer thicknesses, stand-off distances, and the number of blasts, are discussed in detail. Furthermore, an empirical model based on the new dimensionless numbers is presented to predict permanent central deflections of single- and multi-layered circular plates subjected to repeated uniform blast loading

2- Experimental Work

To study the dynamic plastic response and failure mechanism of single- and multi-layered circular plates without any gap in-between under repeated uniform blast loading, a total of 112 single-, double-, and triple-layered specimens were designed and fabricated. Different materials, layering thicknesses, and layering arrangements were considered for this series of experiments. The ballistic

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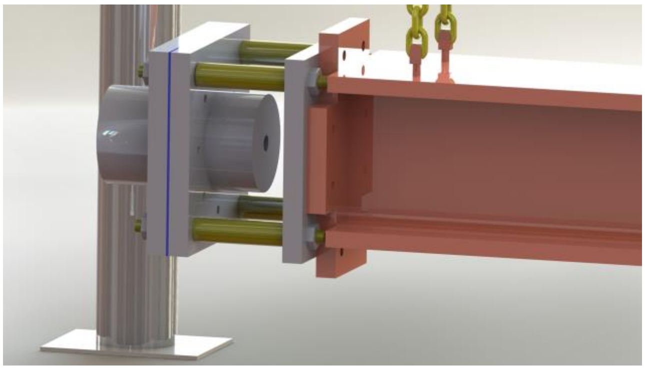

Fig. 1. Ballistic pendulum

pendulum apparatus designed and manufactured at the Impact and Blast Laboratory of the University of Guilan (IBLUG) was used to conduct 112 experimental tests. The experimental study consists of two distinguished sections: 1) description of the test specimen and its mechanical properties; 2) experimental setup and loading conditions.

All experiments on single- and multi-layered plates under repeated uniform blast loading were carried at the Impact and Blast Laboratory of the University of Guilan (IBLUG) using a ballistic pendulum, as shown in Fig. 1. This figure shows that the ballistic pendulum comprised a steel I-beam suspended on four spring steel cables which were attached to the beam via four adjustable screws. Also, four space bars with a radius of 7.5 mm were used to attach the clamping frames to the front of the ballistic pendulum. It is assumed that clamping steel frames are rigid bodies due to their thicknesses, i.e., they do not experience significant inelastic deformation in comparison to thin test specimens. Each specimen was bolted and fully clamped between thick steel frames with seven bolts around a circular region with a radius of 85 mm. For the reduction of the pressure build-up at the edge of the plate, clamping frames were chamfered. Furthermore, to provide a mean for the direction of the blast wave towards the specimens, two mild steel cylindrical tubes with the same inner radius of 50 mm, the same outer radius of 60 mm, and different lengths of 200 mm and 300 mm were fitted onto the front clamping frame. In all experiments, the length of the cylindrical tube was defined as the stand-off distance which is the distance between the nearest face of the explosive charge and the specimen surface.

To create a blast load, the plastic explosive charge (PE4) was used and formed into a disc with a radius of 17.5 mm. The charge was spread onto a polystyrene foam pad with a thickness of 15 mm and it was centrally located at the end of the cylindrical tube along its longitudinal axis. An instantaneous electrical detonator taped to 1 g of explosive was attached to the center of the charge in a hole cut out in the polystyrene pad. In this series of experiments, the charge was detonated at different stand-off distances of 200 mm and 300 mm, and its mass was changed from 1.5 g to 12.5 g at a constant radius by increasing the height of the charge in the experiments. During this process, the influence of the polystyrene foam pad on shock-wave propagation was ignored. To apply repeated blast loading on the test specimens, each specimen was again left in the testing section of the apparatus and was subjected to further blasts with the same previous loading condition. This process was repeated for a required number of blasts up to five times depending on the failure mode of the test plate. During each blast loading, the amount of the transmitted impulse was measured and recorded. Based on previous studies, it was assumed that the distribution of the blast load is uniform over the entire deformable area of the test plate because the ratios of the explosive charge diameter to stand-off distance were assigned to be 0.175 (35/200) and 0.117 (35/300).

3- Results and Discussion

In general form, the post-test inspection of the tested monolithic and multi-layered plates under repeated blast loading shows that all specimens exhibited different levels of large plastic deformation (Mode I failure) with the dome-like shape on the back, middle, and front layers. This type of deformation mode is indicative of uniformly distributed impulsive loading on specimens for different load intensities as presented by Jacob et al. [1]. Besides, for some of the tested specimens, the other failure modes such as Mode Ia and Ib, i.e., large plastic deformation with necking around part of the clamped boundary and the entire boundary, and Mode II* and Mode II, i.e., large plastic deformation with partial and complete tearing around the clamped boundary, were observed. As the plate deformation increases, shear stresses and membrane actions along with the evidence of rupture are present. Different types of deformation and failure modes including large plastic deformation, necking, thinning, and tearing around the boundary are illustrated in Fig. 2.

For both monolithic and multi-layered aluminum plates, large global plastic deformation (Mode I) of specimens is observed and significant tensile deformation happened at the center of specimens. As expected, larger permanent deformations produce by increasing the number of blasts and charge mass for a given stand-off distance. Since the plate was secured between two thick supporting frames by seven bolts, no plastic deformation, crack, and in-plane slip occurred at the constrained zone of the plate and bolted holes. Thinning at the clamped boundary occurred for both monolithic and multi-layered plates subjected to higher impulsive loads by increasing the charge mass or a combination of repeated blast loading.

4- Conclusions

The present research study brings insight into the experimental results on the structural response of monolithic and multi-layered metallic plates under repeated uniform impulsive loading. The impulsive load was generated by the detonation of different quantities of charge mass with a constant charge radius of 17.5 mm at two different stand-

Fig. 2. Typical specimens after blast loading

off distances of 200 mm and 300 mm. A ballistic pendulum was used to carry out 112 experiments on monolithic, double-layered, triple-layered, and triple-layered mixed configurations made of aluminum alloy and mild steel materials.

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HOW TO CITE THIS ARTICLE

M. Ziya-Shamami, H. Babaei, T. Mirzababaie Mostofi, H. Khodarahmi , Experimental investigation and mathematical modeling of the response of circular metallic plates under successive intense dynamic loading , Amirkabir J. Mech. Eng., 53(Special Issue 6) (2021) 955-958.

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