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DESIGN OF A STRUCTURAL IMPACT RIG

M. Alves
Department of Mechanical Engineering, University of São Paulo
05508-900 – SP – SP – *maralves@usp.br*
R.S. Birch
Impact Research Centre, University of Liverpool
L69 3GH, Liverpool – UK – *rsb123@liv.ac.uk*

Resumo. *Structural tests are fundamental to validate a theory, to give insight in new phenomena and to provide experimental information on situations where a theoretical model is not fully applicable. This article describes the various phases of the design and manufacturing of an impact rig built with the purpouse of testing material and structures under severe regime of impact loads.*

Key words: *Impact, structural tests*

1. INTRODUCTION

Crash simulation using computer based technology is becoming established as a standard tool in vehicle construction industries as a convenient way to predict, to a certain extent, the mechanics of a crash and the response of an occupant or cargo (Haug and de Rouvray, 1993). However, there are shortcomings in experience and understanding of structural analysis under these extreme conditions of a crash (Zaouk, Bedewi, Kan and Marzougui, 1998). In particular, information relating to the structural behaviour and material characteristics under crash condition remains limited. Ongoing research into the effects of impact consider ranges of velocities and energies which may correspond to automotive collisions or hypervelocity impact of debris on space vehicles in orbit.

Research methods used to investigate the effects of impact, employ a variety of apparatus such as catapults, Hopkinson bar methods, pendulums, gas guns and the simple free falling weight or drop hammer. Drop hammers are applicable to research topics such as crashworthiness of transportation vehicles, e.g., ships, automobiles and rail, where tests using relatively low velocities and high impact masses are required. Although the basic concept of the drop hammer apparatus appears simple, in practice, there are several important features which need to be considered when designing an apparatus suitable for research purposes.

The purpouse of this article is to describe some basic features of the design of a drop hammer which need to be addressed in the light of structural impact dynamics. The article uses a real case design and manufacturing of a drop hammer to shed light on the main topics considered.

2. BASIC DESIGN

The basic drop hammer design comprises vertical rails that guide a falling mass (tup) onto a structural or material specimen that is mounted onto an anvil. Clearly, any test results are completely meaningless unless the basic parameters of initial impact energy and boundary conditions are known. Moreover, it is necessary to assure that the impact energy is transmited completely to the specimen. The reason for this is related not only to the efficiency of the drop hammer. It allows to work out the energy absorbed by the specimen under test, a parameter very important in structural impact. To have an energy efficient device, one needs to design the anvil properly.

3. ANVIL DESIGN

The measurement of the initial impact energy simply requires the measurement of the mass of the tup and velocity at impact. However, the effects of boundaries where the specimen rests are more difficult to determine and may lead to significant errors in the results of a test. Commonly, in order to eliminate this problem, a well defined boundary having a stiffness several orders of magnitude higher than that of the specimen under test should be provided.

Consider a dynamic compression test where the experimental system can be idealised as a simple spring–mass model representing the foundation support and anvil, respectively. During the impact process, some initial kinetic energy is transferred to this system and it is seen as kinetic and strain energy in the anvil and support, respectively. In the case of a support with infinite stiffness then no such loss would occur and it could be assumed that all of the initial kinetic energy would have been absorbed by the test specimen.

In the real case, stiffness has a finite value and therefore it is necessary to consider the spring mass model. When assuming the anvil as a simple one degree system and the tup motion to be decelerated by an impact process of constant force, P, the anvil spring mass system will have a sinusoidal response. At the point where tup and anvil have equal velocities then the impact process can be assumed to be at an end and the remaining energy in the system will be dissipated by material and mechanical damping effects and, therefore, is a loss to the process. It can be shown (Birch and Jones, 1988) that, for high values of P, the energy loss fraction approaches the ratio $\eta = \frac{m_1}{m_1+m_2}$ where m_1 is the mass of the tup and m_2 is the mass of the anvil.

Observe this equation does not involve the stiffness of the support. In practice, values of P as high as 1000kN are achievable in severe tests such as dynamic shear (Jouri and Jones, 1988). Clearly, the mass of the anvil, m_2, is a controlling feature of the potential energy loss to any test.

In reality, an anvil may comprise a system of several degrees of freedom with damping, where the sum of the masses might imply a minimal energy loss. However, the effective mass and stiffness are those immediately in contact with the impact process itself.

4. TUP DESIGN

The design of tup mass is another critical feature of a research drop hammer. Ideally, the tup should be of a homogeneous design or as near as possible to this. On impact, the transmission of a stress wave causes the tup to ring with a natural frequency dependent on its stiffness and density. In applications, such as impact tests for automotive crash protection, the ringing frequencies are several orders of magnitude higher than those produced by the collapsing structure under test and do not have a significant influence.

Unfortunately, practical tups require the facility to alter mass easily (a test variable), normally, within some predefined range in reasonable steps using bolt on masses that form a free body linked mass system. Similarly, as in the case of the anvil, a free body spring mass idealisation can be applied where the springs represent stiffnesses of the fixings between the masses, but, it is unlikely to have significant damping. When excited by an impact test on a specimen, such a system will vibrate with natural frequencies that are superimposed onto the forcing impulse $F(t)$. Effectively, the true nature of $F(t)$ can be radically altered by this superposition of frequencies if they approach those which may be experienced in the test itself.

In order to avoid this problem, the natural frequencies of the tup should be kept as high as possible. Clearly, for a fixed mass tup, the stiffnesses of the linking elements should be high and large diameter bolts are necessary.

Maintaining the correct orientation of the tup from release until impact can present problems in a drop hammer. Normally, this is achieved by having two or more vertical guides, although, unguided free fall drop testing is not uncommon. Tensioned wire ropes or rails are typical designs. Friction between the tup and guide rails can result in significant energy loss prior to impact on the specimen. Guide rollers can offer a means of reducing this loss, but care needs to be taken in their design in order to minimise rotational kinetic energy losses. Repetitive shock loading of the roller guides means that their design needs to be robust i.e., having significant mass. Therefore, on impact, the rollers themselves may posses significant rotational kinetic energy; an energy which is not available to the impact process. Simple fixed guides offer a more practical solution to maintaining tup orientation. A low friction material such as PTFE can be used at the interface between guide and rail.

5. TUP POSITIONING AND RELEASE MECHANISM

In an impact test using a drop hammer, it is necessary to positioning and release the tup mass. Of course that the ideal case is to perform these operations remotely. Moreoever, the specified height in a test should be reached within an accuracy of say 0.1%. For a height of 10m this means a precision of 10mm, which can be achieved confortably nowadays.

Also, the release mechanism of the tup should cope with extreme drop masses. In many situations, for instance in ivestigating the buckling of axially impacted shells and rods (Abramowicz and Jones, 1997; Karagiozova and Jones, 1996), it is necessary to use high velocities and low mass or small velocities and high tup mass. Typical values for the released mass range between 1kg and 200kg. For safety reasons, it is necessary that the mass be released automatically, which asks for a mechanism operated electrically.

6. INSTRUMENTATION

An impact test is an event that takes place within miliseconds. It is necessary to use good frequency response instrumentation if details in time of the behaviour of some variables are required. A major information to be extracted from an impact test is the load evolution. This is a difficult parameter to measure in the time scale of an impact test. A sophisticated approach here is to use a tup velocity measurement based on laser, as described in (Birch and Jones, 1989).

The idea behind laser Doppler velocimeter is to differentiate the trace to obtain acceleration and, hence, load upon the multiplication by the tup mass. The recorded signal can also yield the displacement by integration, thus providing an ellegant experimental technique to record the load–displacement response of a structure.

7. DESIGNING AND BUILDING A DROP HAMMER

Aimed at to investigate the buckling of shells in the plastic range under axial impact, a drop hammer was design and built at the Department of Mechanical Engineering of University of São Paulo.

The equipment comprises two I beams nearly 10m in length, set up vertically along the building wall. These beams were fixed transversely at the top by other two U beams. The I beams are fixed to the building by two more or less equally spaced along their length embraced frames, forming square rigid frames around them.

Figure 1 shows an overview of the drop hammer.

The I beams are fixed at the bottom by a square frame which stands nearly 2m from the bottom. This square frame is supported by four legs with their extremeties resting on the ground. This solution is appealing because leaves the operator with space to work on the anvil, where the specimen is.

On the face of these two I beams there are the guides. These are guides used in comercial lifts and have a good surface finished. It is on these guides that the drop mass slides down. They should be fit to the I beams very carefully in order to allow the drop mass to fall as free as possible.

Through these guides slides the tup mass, which comprises two masses of 50kg, three masses of 20kg and four masses of 10kg, making a total of 200kg, if they are all fitted. These masses are made of rigid blocks of steel and fixed to each other by bolts. They are also fixed to two plates with side notches in the shape of the guides to allow a nearly frictionless fall.

The release mechanism comprises four levers which are always in a locked position in a way that the heavier the drop mass the stronger is the closing force. These levers form a hook and can move around bolts by the action of a solenoid. This movement open the jaws responsible for holding the drop mass. The energy to the solenoid is fed through a steel wire running parallel to the guides.

The hook, connected to a steel cable, can move up and down by the action of an electrical motor connected to a gear box and to a drum where the cable is winded. This d:/papers/submitted/cobem99/overview.eps

Figura 1: Overview of the drop hammer.

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Figura 2: The bottom end part of the drop hammer.

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Figura 3: Top part of the 3.67ton anvil.

power system is at the very top of the building and it is controlled by a computer.

The computer is responsible to control an inversor which allows to set on and off the electrical motor. Moreover, the inversor receives a signal from the computer, sent only when a specified number of revolutions of the electrical motor is achieved. Hence, by counting the revolutions with an infrared sensor, one can estimate the height of the drop mass.

As already commented, the anvil is very important in a research drop hammer in order to provide support for the specimen under test. Moreover, it is necessary to insulate the anvil from the building foundation due to high peak loads achievable in an impact test.

The anvil comprises a 100mm thick plate with such a side dimensions that the total mass is 670kg. This plate rests on a concrete anvil weighing 3000kg. Hence, the anvil has a total mass of around 3670kg, which assures a low energy loss in an impact event. Figure 3 shows the top part of the anvil.

The anvil formed by the steel plate and concrete block rests on a 25mm thick neoprene pad. This system plate–block–pad rests on the bottom of a concrete box in a way that the pad and part of the concrete block is surrounded by concrete walls. Since the plate and block are only supported at the bottom, the anvil is, in theory, free to move sideways.

Finally, the concrete box rests on four piles around 3m long, all buried in the soil. Accordingly, the anvil is fully insulated from the building structure thus providing good conditions for impact tests involving energies as high as 20kJ.

8. SAFETY

Safety is an important issue in impact tests where high energies can easily cause irreversible damage to the surrounding area and people. In the drop hammer built at USP, this issue was tracked by using a computer password, alarm system and door switches.

As the release mechanism is controlled by a computer, it is easy to allow the rele signal to be sent only when a correct password is keyed in. Moreover, the impact mass is set free only when a door separating the operator from the test area is properly locked, as checked by an electrical switch. Finally, once the mass is ready to fall, an alarm sets off. All these precautions are compatible with a modern inversor, where electrical signs can be handled from different sources and controlled by a computer.

9. CONCLUSIONS

It was the aim of this article to describe qualitatively some basic features of the design of a drop hammer. These features were all taking into account when the drop hammer at the Department of Mechanical Engineering at University of São Paulo was buit.

The final result is a mechanical device where structural impact test can be performed to investigate many features of dynamic phenomena.

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