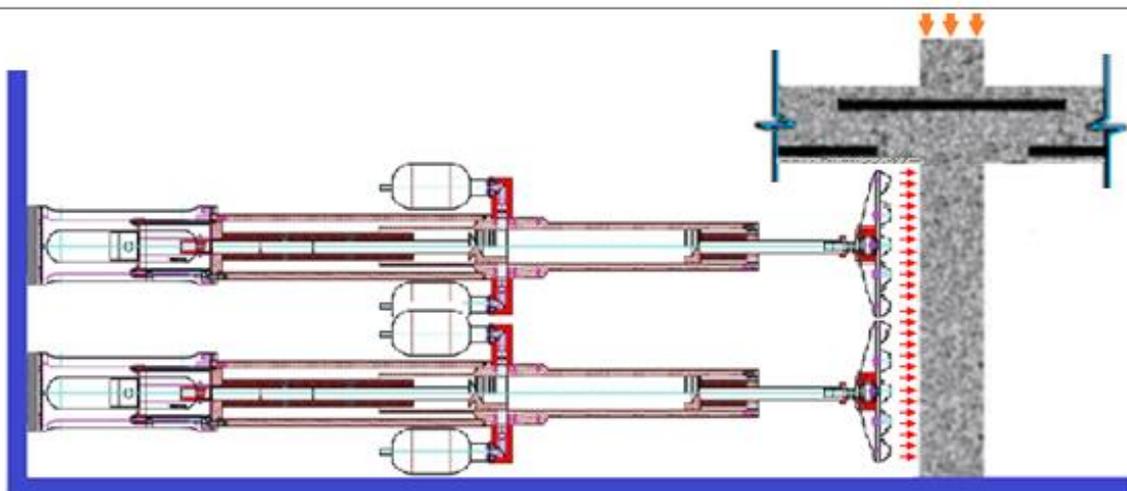


# Blast Simulator Setup Requirements

Administrative Arrangement No JRC 32253-2011 with DG-HOME  
Activity A5 - Blast Simulation Technology Development  
Deliverables 5.3, 5.4

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2013



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JRC79971

EUR 26018 EN

ISBN 978-92-79-30842-0 (pdf)

ISBN 978-92-79-30843-7 (print)

ISSN 1831-9424 (online)

ISSN 1018-5593 (print)

doi:10.2788/17387

Luxembourg: Publications Office of the European Union, 2013

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Printed in Italy

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N° HOME/2010/CIPS/AA/001-A1, ABAC N° 30-CE-0471931/00-60

Activity A5 - Blast Simulation Technology Development

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February 2013



# 1. Introduction

Critical infrastructures in fields such as energy, health, communication, government, transport etc. are made of physical structures, or are housed in physical structures. Such structures may naturally become the target of terrorist bombing attacks. Measures to protect them will certainly be taken, involving prevention, intelligence, detection, deterrence ..., but if everything fails, it is very important that the mechanical structure itself mitigates some effects of the explosion and maintains certain functionalities.

A typical pressure wave curve (which eventually will load a structure) at some distance from an explosion is shown in Figure 1a. Its main characteristics concerning damaging effects on structures are the magnitude of the overpressure, the duration of the positive phase and especially its impulse, i.e., the area under the curve over the positive phase. This impulsive load will be delivered to a structure in a few milliseconds forcing it to respond or fail in a peculiar mode. The blast pressure can, for example, destroy a column in the perimeter of the building, and this could cause an excessive deflection and the failure of the girder above due to the loss of its primary support, Figure 1b, 1c. This local failure, if not arrested through appropriate initial design features, may propagate to adjacent structural members leading to progressive collapse and extensive damage and human casualties. This has been the case of the Oklahoma City bombing of the Murrah Federal Building in 1996, Figure 1d.

In order to avoid such catastrophic events and provide protection to critical built-infrastructure and its occupants a risk analysis has to be conducted and a credible attack scenario to be established. This analysis should indicate criticalities and buildings of a certain importance may have to resist blast or at least be able to mitigate some blast effects and remain operational. This in turn can be achieved with proper design features either incorporated from the beginning in a newly constructed building, or a-posteriori through blast retrofitting/hardening interventions for existing buildings. However, design towards this objective necessitates that computational models and construction techniques be thoroughly validated with reliable data from field explosion tests. Such tests with actual explosions are expensive and they are usually performed within military grounds.

Thus alternative testing methods are desirable, and this has been the case at the University of California in San Diego, where the first blast simulator facility has been built (2006). As claimed, the effects of bombs are generated without the use of explosive materials. The facility produces repeatable, controlled blast load simulations on full-scale columns and other structural components. The simulator recreates the speed and force of explosive shock waves through servo-controlled hydraulic actuators that punch properly the test specimens.

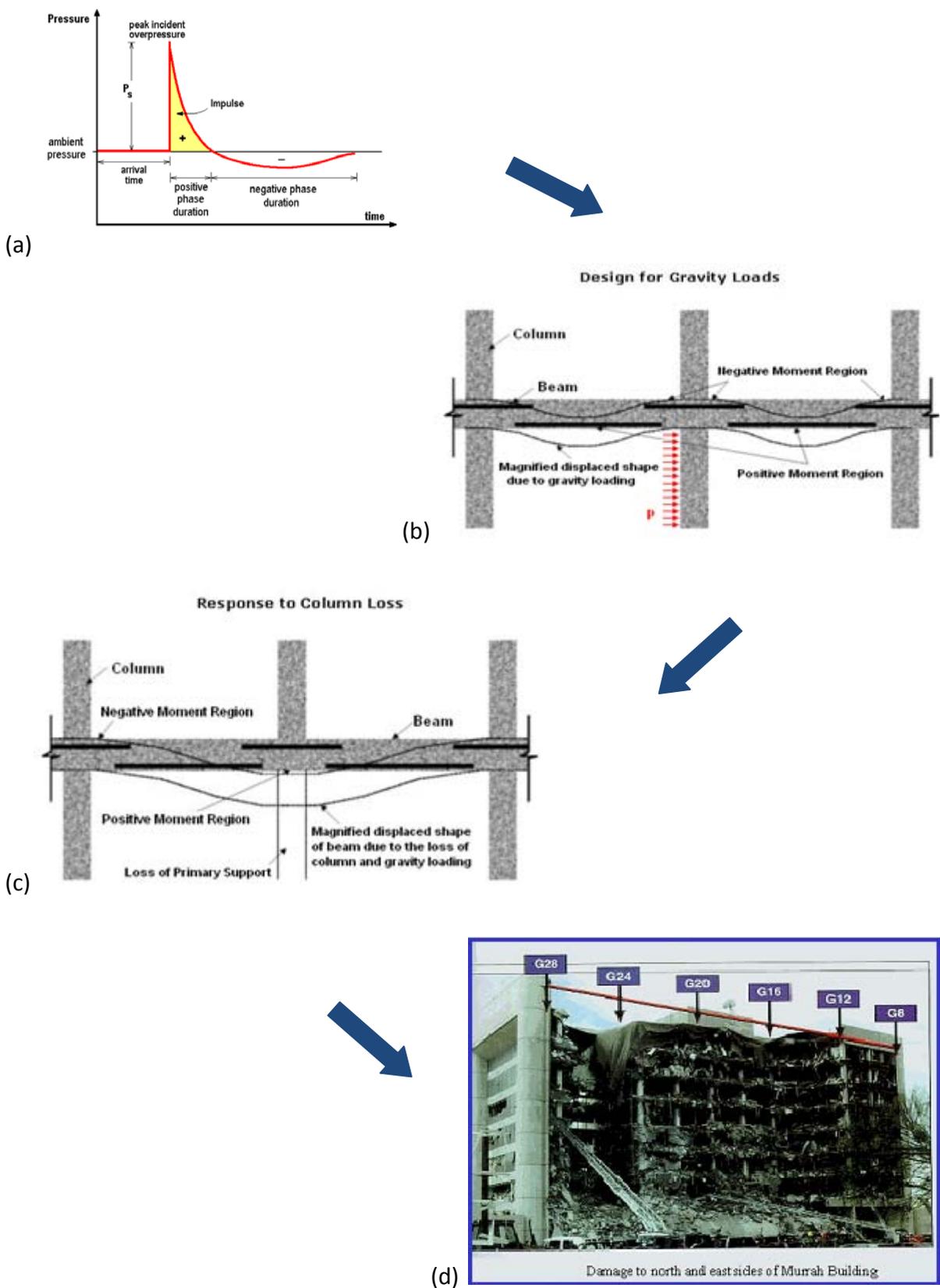


Figure 1. Blast wave pressure curve characteristics and possible response sequence of a building leading to its progressive collapse.

With this work a similar blast simulation capability is proposed to be developed within the EU by the JRC. The staff of the ELSA Unit has a long and strong experience in the servo-controlled actuators. In fact some of these devices have been constructed in-house and relevant technology has been transferred to other European laboratories. Concerning the currently required fast actuators, an alternative design concept will be implemented, which is believed to be capable of generating impacting loads resembling closer those of real explosions of Figure 1a. This will allow the realistic testing of components to “simulated” explosions and will provide the necessary data for the verification and validation of the computer tools.

Figure 2 presents the concept and shows schematically the mode of functioning for a column testing, in a configuration comprising two fast actuators. As indicated, the impacting masses at the end of the actuator shafts punch the specimen generating locally pressures equivalent to those of an explosion, as in Figure 1b. Clearly more actuators will have to be employed if other structural elements, e.g. a masonry wall, is to be tested.

The development of this technology will be important both for the research and the practicing engineers and architects who need design rules and guidelines. Besides characterizing blast effects on structural systems, the methodology will contribute to evaluating technologies for hardening and retrofitting buildings and bridges against terrorist bomb attacks. Further, as mentioned above, it will help in the investigation of the problem of progressive collapse, i.e., the phenomenon where a local failure propagates in a disproportionate manner to lead to global failure (Oklahoma city bombing case).

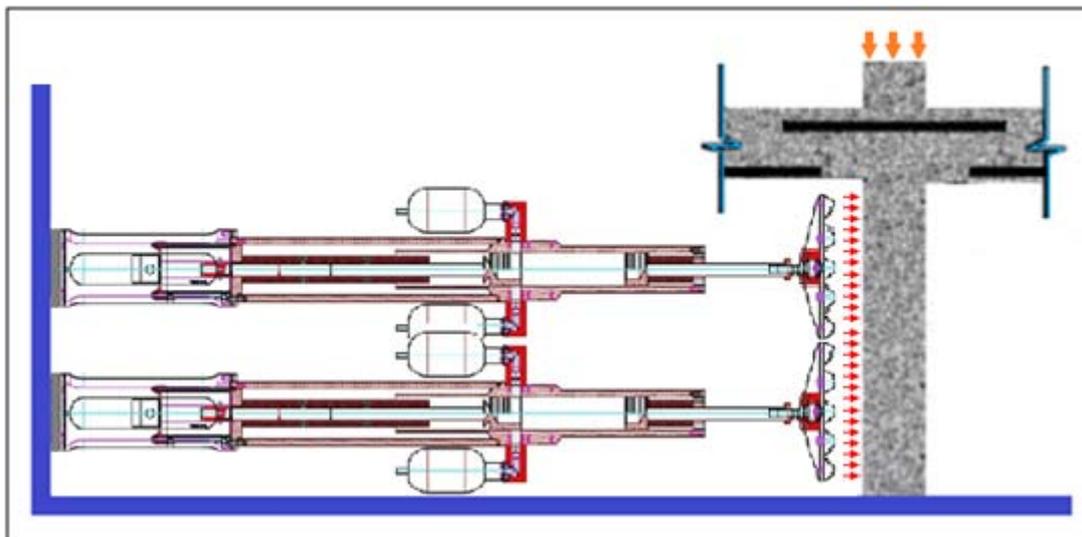


Figure 2. Principle of concept of the JRC Blast Simulator schematically shown with a battery of two fast actuators.

The Blast Simulator project is structured in the following phases:

- Blast actuator design and manufacturing of the first prototype;
- Development and testing of first prototype in order to evaluate the performance of the new equipment. Tests will be carried out only on the blast actuator and no structures or components will be included in this phase;
- Study of impacting mass and “blast” testing of small structures or components with the prototype blast actuator;
- Design of an optimized blast actuator and manufacturing of a small number of them;
- Final testing with a series of blast actuators against small structural components (for example columns) and a small structural assembly.

## 2. Test setup geometry and operation

The blast simulator, as designed at the moment, is a pneumatic/hydraulic facility and the sketch below summarizes the main parts of the equipment and its functioning in a simplified manner, Figure 3.

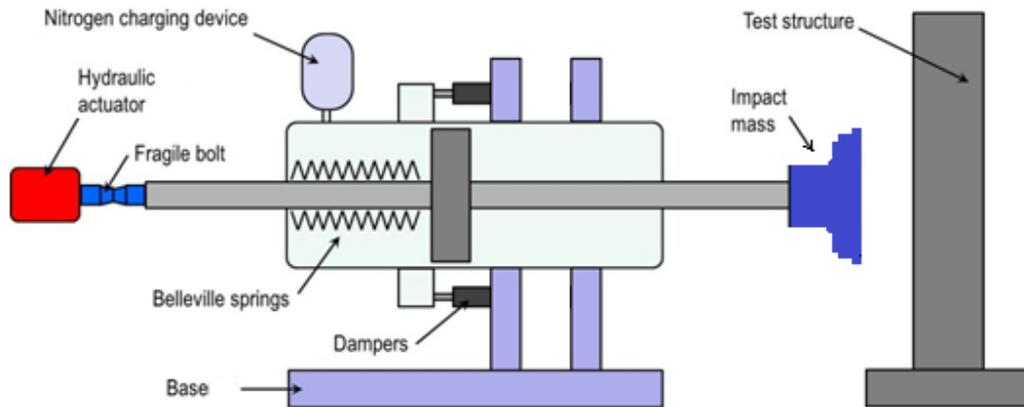


Figure 3. Sketch of Blast Simulator with one fast actuator.

The operating principle of the testing rig is quite straightforward:

- the shaft is pulled to the starting position with a hydraulic jack and this action compresses a series of Belleville springs inside the blast actuator;
- at this point the piston is kept in this initial position by a fragile bolt, with a calibrated notch made of high strength steel;
- to start the test the pressure inside the active chamber of the blast actuator is increased by charging it with nitrogen, up to a maximum pressure of 100 bar;
- when the spring reaction and the increasing pressure produce a force onto the piston greater than the strength of the fragile, the bolt suddenly breaks and the piston and shaft of the blast actuator rapidly accelerate pushing the impacting mass, attached at the other extreme of the shaft;
- when the piston has done most of its stroke, it forced to decelerate through the activation of a combined pneumatic and rubber device inside the cylinder;
- at the instant that the shaft starts decelerating the impacting mass is detached from it and collides with the tested structure reproducing local impact pressures similar to those of a blast wave;
- the decelerated shaft/piston transfers its remaining kinetic energy to the whole actuator, which in turn transmits it through a series of high performance energy absorbing dampers to the supporting base and to the floor.

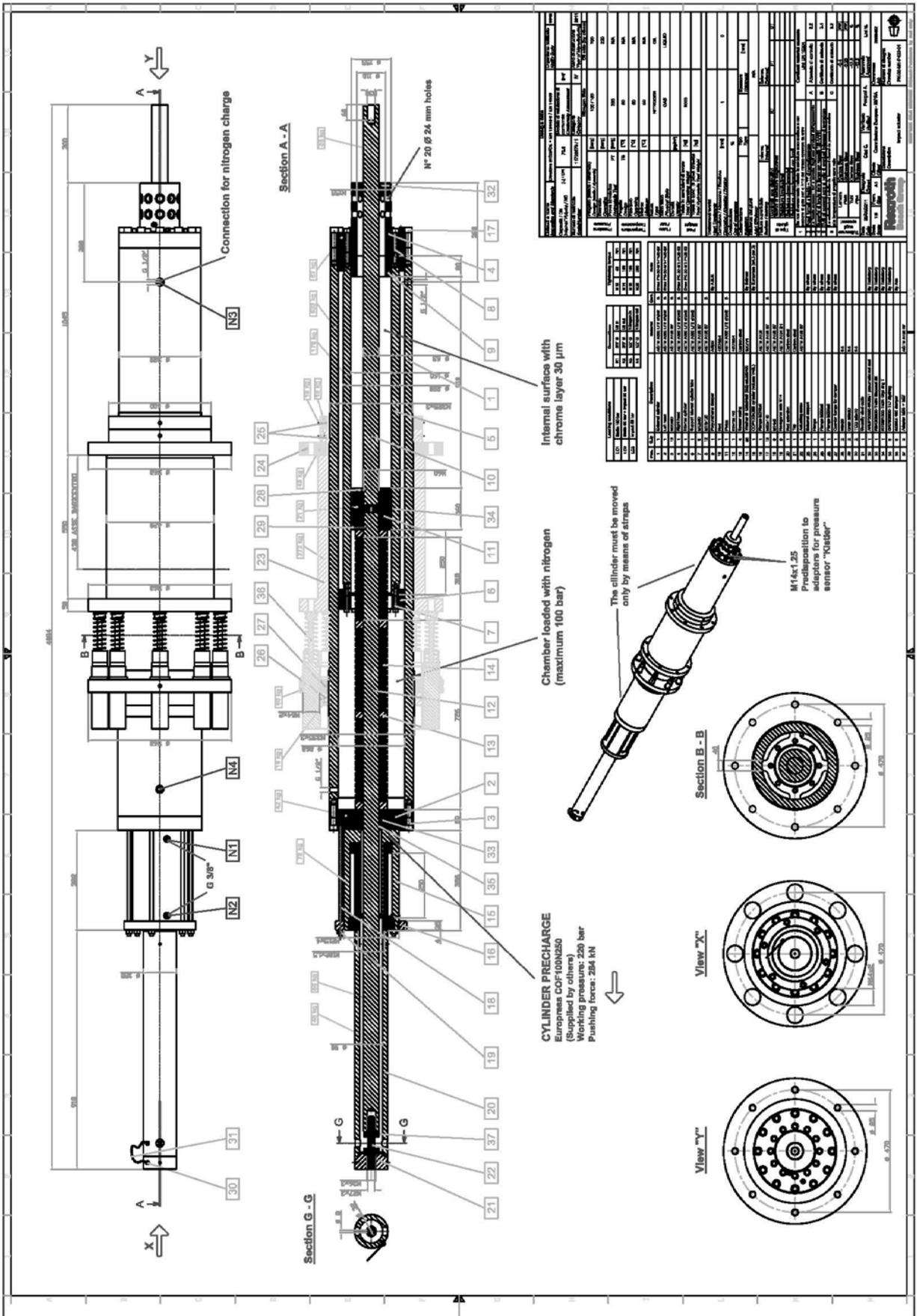


Figure 4. Prototype design of fast actuator.

The actuator has been designed by the ELSA researchers, and with the technical guidance and support of the ELSA technical staff it has been manufactured by the firm Bosch Rexroth. The final design of the prototype is shown in Figure 4 and the realization of it in Figure 5. The actuator has been supplied with a declaration of conformity to directive 97/23/CE (PED), concerning the operation of pressure devices in the EU.



Figure 5. Prototype of Blast actuator as manufactured by Bosch Rexroth.

The nitrogen charging system has been supplied by Interfluid s.p.a., it uses an air-operated gas booster (I Curtiss Wright Flow Control Company), and is accompanied by a certified test report (Figure 6).

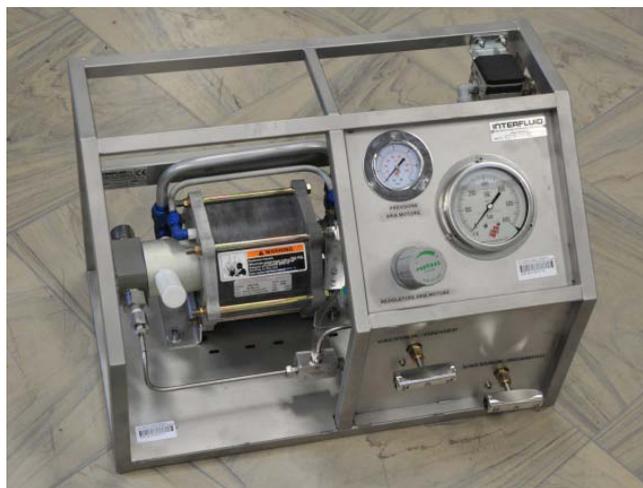


Figure 6. Nitrogen charging system.

The mechanical base, for holding the actuator and for fixing the whole system to the floor of the laboratory, has been designed by the ELSA technicians and it is made of high stiffness steel plates, as shown in Figure 7. The connection between blast actuator and steel base is made by means of a cylindrical sleeve and a series of dampers (Figure 8), which absorb the kinetic energy transmitted by the shaft/piston to the cylinder at the end of the test, as explained above.



Figure 7. Metallic base for mounting the fast actuator and the dampers.

The last mechanical parts of the actuator/base connection (steel sleeve etc.) are being manufactured at the JRC Central Workshop, and are expected to be delivered by 15<sup>th</sup> Feb. 2013. On this basis, it is estimated that the prototype blast actuator will have been assembled by the end of February, and it will be possible to commence with the trial tests in March 2013.



Figure 8. Damper for energy absorption.

### 3 Risk analysis and related actions

A Procedure de Consultation (PdC) has been conducted with the JRC competent services (14/02/2013), where the associated risks to the first phase of the experiment have been identified and appropriate measures have been proposed.

#### 1. Main risk related to fast moving parts

The blast actuator in practice is a device that accelerates a mass to a maximum velocity of approximately 50 m/s. Although the first trial tests will be conducted without any impact mass, account must be taken of the fact that the piston of the equipment moves very fast and it can apply a huge force.

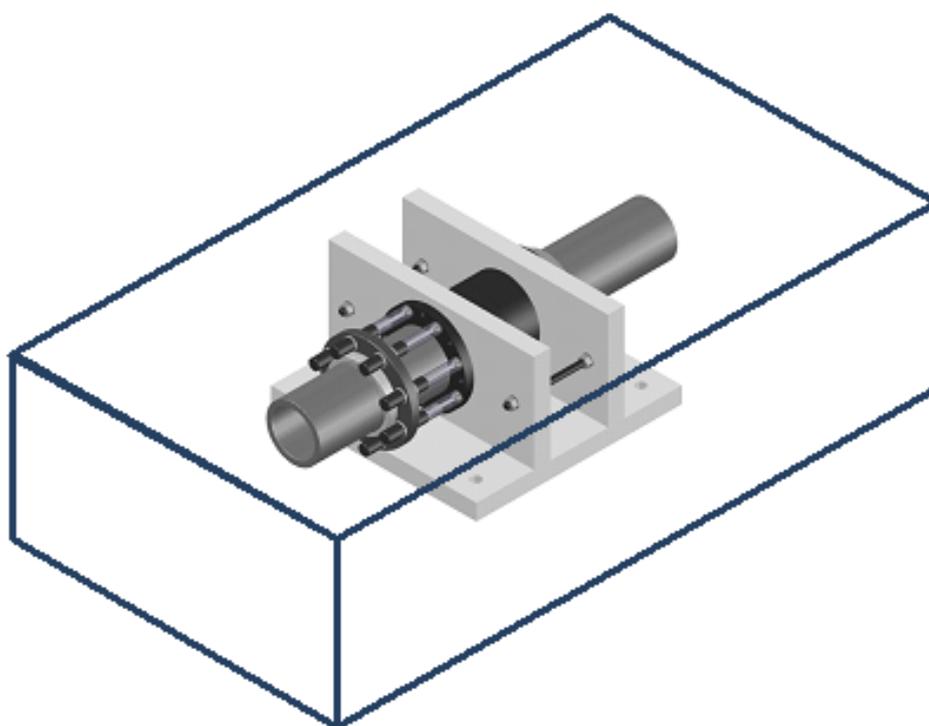


Figure 9. Metallic base and actuator with damping system, and safety frame/box.

*Measure 1.a)* Covering safety frame. In order to avoid the presence of persons in the proximity of the equipment during the test, a safety frame will be placed all around the testing rig to totally prevent any access, Figure 9. The safety frame/box will be made of aluminium profile Bosch-Rexroth with Plexiglas panels with an approximate size of 1m x 1.5m x 5.5m. The use of Bosch-Rexroth profiles is justified by the need of experimental flexibility, in order to rapidly handle changes in instrumentation and/or re-designs. In addition Plexiglas panels, being transparent, can guarantee the possibility of taking high-speed photo sequences of the experiments, and also have good capability of energy absorption for what concerns flying debris or direct impact.

## 2. Secondary risk related to noise

The break of the fragile bolt and the fast movement of mechanical parts can generate a certain level of noise. This is not easily predictable because it depends on test parameters that can be changed during the explorative test campaign (for example the strength of the fragile bolt, the nitrogen pressure in the cylinder, etc.).

*Measure 2.a)* Safety frame/box. The safety frame guarantees also a good acoustic insulation.

*Measure 2.b)* Restricted access to the test zone and use of personal safety devices, such as isolation headphones.

## 3. Secondary risk related to flying debris

In the assessment campaign no flying debris will be generated during the test because no structural components will be tested. Anyway, in case of an unpredictable and improbable failure of a mechanical component, few debris can be generated during a test.

*Measure 3.a)* Safety frame/box. The whole apparatus is placed inside the protecting box. The use of 10 mm thick Plexiglas panels prevents any danger due to flying debris generated during a test.

The subsequent phases of the development of the Blast Simulator (when a specimen is used, when more than one actuators are employed, its permanent position etc.) and their associated risks and relevant safety measures will be the subject of a forthcoming study.

## 4 Impact mass design

The trial tests with the single prototype actuator are expected to commence in March 2013. Provided that the maximum foreseen velocity ( $\sim 50$  m/s) of the shaft/piston is achieved, the next critical step is the choice of the impact mass to be attached at the end of the shaft. This mass should get detached from the shaft (when this starts decelerating), and impacting the structure under testing should exert on it local pressures and impulses similar to those of explosions, Figure 1a.

The mass and the velocity of the impact mass determine its momentum, which is transferred as impulse to the specimen. The duration of this impact should be of the order of milliseconds, and depends strongly on the nature of the contacting surfaces impactor / specimen. The current orientation is to employ an elastomeric material between the impact mass and the specimen in order to better distribute the generated impulsive force and to adjust the impact duration. The final design of the impact mass will be aided by numerical simulations with finite element techniques so that the optimum materials, masses and dimensions are selected. Clearly, depending on the specimen and the loading to be applied, several sizes of impact masses will have to be prepared and utilised.



Figure 10. Prototype fast actuator and metallic components before their assembly.

# 5 Equipment position in ELSA Lab

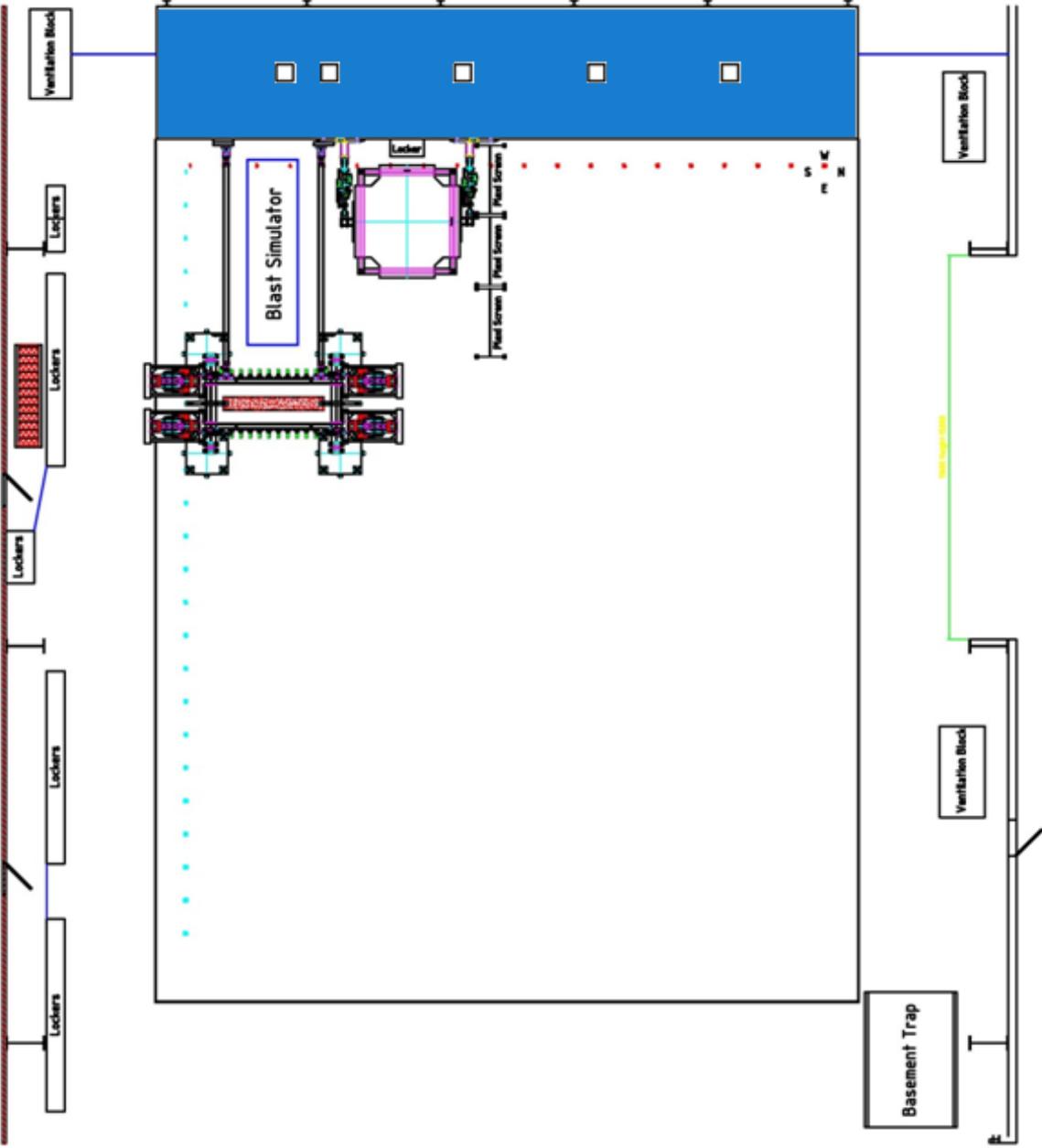


Figure 11. Position of single prototype blast actuator in front of the Reaction Wall (blue).

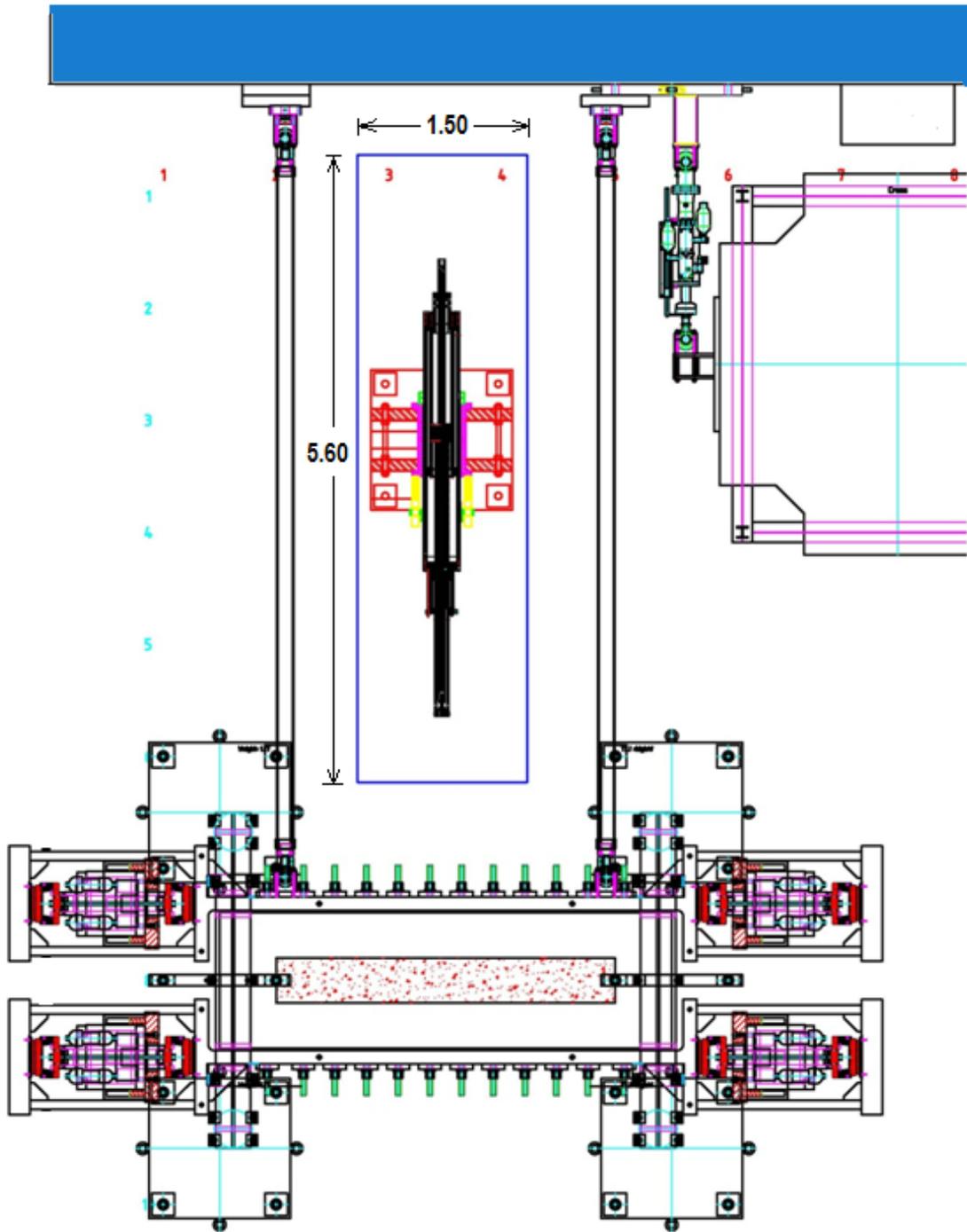


Figure 12. Details of position of single prototype blast actuator over area  $1.50 \times 5.60 \text{ m}^2$ , in front of the Reaction Wall (blue), among the other experimental setups.



European Commission  
EUR 26018 EN – Joint Research Centre – Institute for the Protection and Security of the Citizen

Title: Blast Simulator Setup Requirements

Authors: Marco Peroni, George Solomos, , Georges Magonette, Bernard Viaccoz, Pierre Pegon

Luxembourg: Publications Office of the European Union

2013 – 20 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (online), ISSN 1018-5593 (print)

ISBN 978-92-79-30842-0 (pdf)

ISBN 978-92-79-30843-7 (print)

doi:10.2788/17387

## Abstract

Built infrastructure is often the target of terrorist bombing attacks. Technology for alternative blast testing methods is being developed at the JRC, where the effects of bombs on structural members would be generated without the use of explosives. New fast hydraulic actuators have been designed for this purpose and a prototype already manufactured. The principle of its functioning, the mechanical components and the technical requirements of the testing setup are presented in this report. A risk analysis of the experimentation has also been conducted and the necessary safety measures taken are described.

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Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.