PRINSE Research Project

Protection of Infrastructures and Systems against Explosions – Advanced Protective Coatings

January 2019 – May 2021

Final Report

Testing — INTA

Polyurea characterization — Universidade do Minho

Testing — Portuguese Army

Wall material characterization — FCT Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa

Modelling & Simulation — Universidad Politécnica de Madrid

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PAGE OF ACKNOWLEDGEMENTS

We want to thank all those who have helped in carrying out successfully the research of the PRINSE Project.

First of all, it should be highlighted that spite of pandemic starting at the beginning of 2020, the PRINSE project has fulfilled its planned goals due to excellent work made by all Portuguese and Spanish institutions and personnel involved. Order has not any relevant meaning.

Our great appreciation to Professor PhD Raúl Fangueiro and Engineer Carlos Costa of the University of Minho (Portugal) for a very good work on elastomer characterization. Also, thanks to Professor PhD Valter Lucio from the New University of Lisbon /Faculty of Science and Technology for his accurate scientist advices and contribution on wall material characterization.

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Moreover, our grateful for the assistance given by the National Institute of Aerospace Technology (INTA), Campus La Marañosa Testing Centre located in San Martín de la Vega (Madrid-Spain) and all members of the Ballistic Area of the Department of Weapon Systems & Ballistics supporting 2019 and 2020 PRINSE tests and particularly, by Colonel Luis González-Atance, Major Luis Martínez (ESP Army) and Engineer Iván Gil.

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Finally, we want to acknowledge the invaluable help, trust and support provided from the beginning by the current C-IED COE Director, Colonel (ESP Army) José A. Cruz Moro. He has made possible to achieve the objectives planned in the PRINSE project.

Hoyo de Manzanares, 17th May 2021

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EXECUTIVE SUMMARY

INTRODUCTION

The increasing use of Improvised Explosive Devices (IEDs) as a weapon of choice by terrorist groups give particular emphasis to the protection of people and infrastructure and thereby to engineering measures that can mitigate these effects. The ability to protect the critical infrastructure and key resources of the allied countries, in homeland or in operations is vital to our security, public health and safety, economic vitality, and way of life. The level of protection provided will inevitably be influenced by the cost associated with the enhancements. While extensive blast hardening to glazing, cladding, and structural frame of the buildings or systems are possible, the fundamental requirement is the safety of the occupants/crews of the building or system.

CURRENT TECHNOLOGICAL SITUATION

There are many studies on the reinforcement of non-reinforced masonry, which are usually dedicated to:
a) Adding mass to the system, increasing the thickness with internal walls in masonry, concrete or structures based on ad-hoc metallic elements;
b) Adding vertical elements in steel, as a way to substantially reduce the free space to the wall system to be protected;
c) Using of polymers (Fibre Reinforced Polymer - FRP) glued to the surface to better withstand the high stresses induced by the explosions.

The first two have the disadvantage of involving significant disruption to the inhabitants of the facility in terms of time required for intervention and loss of interior space. The use of polymers offers great benefits for the reinforcement of masonry, allowing increasing the resistance to flexure outside the plane.

Previous studies and research based on a strong numerical and in few cases with reduced experimental component, allowed, among other findings, to realize that:

a. The façade cladding elements (masonry, window frames, and panel claddings) exhibit much lower resistance than the supporting elements, resulting in their collapse before there are more serious consequences on the supporting structure.

b. The propelling of fragments of façade elements can be lethal and need to be controlled.

Several static and dynamic tests were made to investigate the potential of using elastomeric materials for strengthening of perforated brick walls, the results having been shown to be good indicators that the flexural strength of elements substantially increased. However, credible experimental testing data under explosions is almost inexistent. This point is key to propose realistic and affordable solutions.

These solutions can be applied to concrete, metal or masonry elements, among others, reducing part of the effects of explosive actions on buildings/systems and their users. Additionally, since the coating material can be flexible, and it can be used to provide light protection to systems that normally are soft targets, like logistic convoys, tents, container-type structures, etc.

PRINSE project has studied and characterized the properties of the best quality existing commercial available coatings to obtain an enhanced protective coating against Blast and fragments that can be easily used in structures or other ground systems (e.g. logistic vehicles, container-type structures), reducing the vulnerability to the building's occupants or crews, at cheap rates.

It is therefore important to develop protective measures, materials and techniques to address essentially the following problems:

a. Control the propelling of fragments from frangible elements, which are the main origin of dead and wounded personnel from the occupants of buildings.
b. Increase the capacity of the structure or system to retain fragments or projectiles for occupant protection.
c. Develop light protection solutions for increasing the survivability against the action of explosion over soft targets.
d. Develop liners intended to avoid or mitigate the spalling effects of the protective elements (building walls or vehicle structure).
e. Present affordable and highly efficient solutions with the best practices to be applied. In this sense, it should be noted that solving this problem has guided all PRINSE project, from initial conception, planning, analysis, experimental campaign and final assessment.

REASEARCH OBJECTIVES

Research objectives were planned from two points of view as follows:

- Global objective. To study and develop blast protection solutions for several military infrastructures and systems (containers, tents, vehicles and bonnets) applicable as well to critical infrastructures.

- Specific objective. To establish a benchmark regarding with the blast protective performance of and existing commercial available coating material. In this sense, an intensive experimental campaign in Spain and Portugal was planned in order to assess protective solution.

Additionally, a Modelling & Simulation phase would create a numerical model tightly adjusted with testing data. Therefore, this would allow carrying out simulations to explore the limits of PRINSE solution against a blast threat.

To achieve objectives of the project, several lines of activity have been developed:

a. To perform a benchmarking of potential elastomers to be used.

b. To study and perform experimentation with existing commercial available materials (e.g. polymeric materials and coatings).

b. To develop full-scale tests, using models and structural elements, subjected to explosions with real scale and magnitudes.

c. To characterize coating properties and carry out an experimental campaign to check and assess protective coating performance under different blasts.

d. To complete Modelling & Simulation of the PRINSE protective solution adjusted to testing results.

TIMEFRAME

PRINSE is a two-year project (2019-20) extended until end May 2021 due to COVID-19 pandemic issues. Project timeframe and main milestones have been as follows:

I. Design, planning and procurement of materials. January 2019 to October 2019.
II. Experimental campaign 2019 - 2020:
    a) Initial test: 30 October 2019. — National Institute of Aerospace Technology (INTA) Campus La Marañosa Testing Centre (Spain).
    b) Intermediate tests:
        - 10 -11 June 2020. — INTA/Campus La Marañosa.
        - 23 June 2020. — Portuguese Army Training Range Santa Margarida.
    c) Final test. 10 November 2020. — INTA/Campus La Marañosa.
III. Final report and end of project. — End May 2021.

DESCRIPTION OF THE WORK DONE.

To achieve objectives planned, the research has developed and completed an intensive scientist and technical work detailed and compiled in several Annexes to this Executive Summary as follows:

Annex A	State of Art report. C-IED COE	
Annex B	Elastomer benchmarking report. C-IED COE	
Annex C	Polyureas characterization report. University of Minho (Portugal).	
Annex D	Experimental campaign:	
	Annex D.1	Global testing report. C-IED COE
	Annex D.2	INTA/Campus La Marañosa testing report (Spain).
	Annex D.3	Portuguese Army /New University of Lisbon testing report
Annex E	Modelling and Simulation report. University Polytechnic of Madrid (Spain)	
Annex F	Best practices report. C-IED COE	

ACHIEVED RESULTS

From the activities and works conducted during project, essentially from the experimental campaign and Modelling & Simulation tasks, some key conclusions of the PRINSE protective coating system can be pointed out:

- ✓ Reference wall without protection (no coating) collapsed by flexure but shear cracks are visible.
- ✓ In the protected solution, no fragments perforated the polyurea layer to the protected side. This means that the system worked out as it was supposed to. Rear protection is increased significantly.
- ✓ The good bond of polyurea made it work as a strengthening system (skin layer).
- ✓ An adequate spraying equipment and trained operators are essential factors to take into account.
- ✓ Thickness control is quite difficult and requires strict observance of some technical aspects (medium flow, low spraying speed, type of nozzle, etc.) to get a homogeneous polyurea layer.

- ✓ System is expected to stop secondary fragments resulting from break up of frangible elements in result of blast loads. It was always observed in all tests of the experimental campaign (close in explosion developing high pressures).

- ✓ Anchor is essential. The system could fail most likely by detachment or debonding of the polyurea on the anchor region. Final test was executed with better anchor design than previous tests and it worked properly.

- ✓ When retrofitting a structure using PRINSE solution, care should be taken regarding the anchor, avoiding to induce additional stress in the main supporting elements of the structure as columns.

- ✓ Solution designed in project PRINSE performed outstandingly in the final test conducted in 10th November 2020 when an ordinary CMU wall coated with Type 4 polyurea 7 mm thickness was able to stand after 60 kg TNT-equivalent blast at 5 m with no cracks, tears or detachment in the anchorage area. In addition, no wall fragments or debris were found on the back of the protective layer. Results were surprising even for Academia participants and testing centre personnel.

- ✓ Finally and following experimental results and Modelling & Simulation predictions it could conclude that a polyurea layer thickness of 10 mm as applied in the final test could be a very good protective system to retrofit ordinary unreinforced Concrete Masonry Unit (CMU) walls against explosions of up to 80 kg explosive at 5 m distance.

CONCLUSIONS

- ✓ PRINSE protective solution increases effectiveness in containing fragments and debris generated from masonry walls broken after blast and it adds a very valuable aspect in increasing safety of personnel and equipment inside buildings. In a real situation/scenario and for the level of blast loading, people inside a protected area would survive without injuries from fragments, which is the purpose of the system.
- ✓ Technical aspects studied/developed intend to be of easy application in expeditionary context. The protective system seems promising, if technical requirements and best practices of the application procedure as detailed in project are taken into account.

- ✓ Experimental testing and characterization has provided an accurate knowledge about this expedient protective solution against projectiles and fragments, applicable to infrastructures in general, especially focused on strengthening of infill/façade walls, but also to systems such as light containers, campaign tents and light protection of military vehicles (mainly logistic and general purpose type vehicles). It can provide as well the basic data for an attempt to enhance material properties of these advanced materials with direct benefits to all member states.
- ✓ Moreover, lightweight and good properties of high quality elastomers similar to those used in the PRINSE project at an affordable cost will help improve protection when reinforcing back side of surfaces in an easy way.
- ✓ Regarding potential end users, the set of benchmarking, best practices, guidelines and recommendations provided by PRINSE project will drive to reach maximum performances of this kind of protective coating applied on ordinary masonry walls.
- ✓ Finally, it should be highlighted that results of PRINSE research can be used to enhance C-IED mitigation options, in particular within NATO and the C-IED COE Sponsoring Nations and, in general, for the entire C-IED Community of interest.

Hoyo de Manzanares, 15th May 2021

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