BLADE Research Project

Blast Protective Walls Design Optimization

January 2019 – December 2021

Final Report
Executive Summary

NATO Counter Improvised Explosive Devices Centre of Excellence (C-IED COE)

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1. INTRODUCTION

An increased perception of current and future threats against governmental and public facilities in NATO countries has highlighted the need to protect those structures and personnel. At the same time, when NATO troops are deployed in operational environments sometimes there are a lack of adequate infrastructure for settling down of the allied forces. This circumstance leads to re-using existing buildings where important activities take place (e.g. command and staff, munition depots, storage of critical material,..) or have a considerable human presence (e.g. billeting, food areas, etc.). Thus, there is a clear demand within NATO borders as well in operational scenarios in order to save lives and at the same time increasing protection of infrastructures providing economic and efficient methods to retrofit existing conventional structures. Within this scope T-wall barriers are typically used for providing additional protection and designing proper protection measures is more than welcome.

The R&D Project BLADE (Blast Protective Walls Design Optimization) funded and lead by the Counter Explosive Devices Centre of Excellence (C-IED COE) is focused on theoretical and experimental research to characterize a mitigation solution that intends to design and test several Energy-Absorbing Devices or Connectors (EADs or EACs) that would improve the performance of the reinforced concrete blast walls (T-walls) commonly used in mission areas and also to assess potential use of EADs in retrofitting facades of military buildings/critical infrastructures.

Project has simulated Small Vehicle Borne IEDs attacks using the maximum amount of explosive allowed by the Testing Centre. Six tests were done in June (2) and November (4) 2020 assessing two EADs solutions designed in BLADE R&D project.

Last test can be considered as a concept validation test. Two protection T-wall barriers were tested at the same time, the first barrier was reinforced with both BLADE solutions and the second without any additional protective system.

Complex tests were carried out in 2020 in the National Institute of Aerospace Technology/INTA Campus “La Marañosa” Testing Centre (INTA/La Marañosa), located in San Martín de la Vega – Madrid, Spain.

After experimental campaign, several scientific studies (Modelling & Simulation, Analytical Models) have been developed and some valuable conclusions and recommendations are presented in the Final Report.

Finally, it should be highlighted successful cooperation on C-IED research at national and international level among BLADE project participants: C-IED COE and some Spanish and Portuguese organizations, Testing Centre and Academia.

2. PLANNED OBJECTIVES

This research project has focused to study, develop, design and test mitigation solutions based on Energy-Absorbing Devices (EADs) that would improve up to 100% the performance of the reinforced concrete blast walls (T-walls) commonly used in mission areas.

BLADE solutions are based on two configurations: (1) EADs hollow tubes (HTC) lateral compressed and (2) EADs invertubes (ITC) axial compressed. Both configurations are able to improve the performance of reinforced concrete walls (T-walls) when forming a perimeter protection barrier. In particular, the first configuration HTC is an easy solution to be implemented on T-walls on operational scenarios and the second one, ITC, is very promising in reinforcing building vertical facades and critical infrastructures.

BLADE project objectives can be summarized as follows:

- Design some mitigation solutions based on different types of EADs that would improve the performance of the reinforced concrete blast walls (T-walls) **up to 100%** considering their energy absorbing capacity.
- Characterize the blast wave behaviour when shock wave impacts with T- wall with and without EADs.
- Conduct an experimental campaign to characterize the aforementioned blast walls response to impulsive loads equivalent to VBIED blasts.
- Evaluate the energy-absorption capacity of the mitigation system using solutions based in two different EADs types, hollow tubes and invertubes.
- Create a model with LS-DYNA (finite elements software) in order to
  - Design numerical models of both two types of Energy Adsorbing Devices.
  - Validate this numerical model by means of using experimental data recorded and assessing model's accuracy.

- Simulate explosions of different explosive charges at several distances and simulate effects and damage produced by blasts on T-walls.
- Open new lines of research in the field of retrofitting critical infrastructures.

3. RESEARCH ACTIVITIES AND EXPERIMENTATION CAMPAIGN

3.1 Timeframe.

BLADE project started at the beginning of 2020, spite of pandemic COVID, the experimental campaign planned was fulfilled during June and November 2020, and the Final Report is delivered at the end of 2021.

3.2 Research activities.

Regarding research activities, the C-IED COE research team has designed BLADE mitigation solutions, leading and coordinating main tasks as follows:

(1) Design of mitigation solution based on two types of EADs. C-IED COE.

(2) Material characterization to determine mechanical properties of material used to build T-walls and reinforced concrete plates used in the experimental campaign. The NOVA School of Science and Technology (FCT NOVA), Lisbon (Portugal).

(3) Material characterization of the Energy Adsorbing Devices (EADs). FCT NOVA. Characteristics assessed were:
- Material characterization (concrete and steel main physical properties),
- Mechanical characterization (tensile/compression properties, stress/strain curves).

(4) n analytical model of T-walls barrier performance has been developed by FCT NOVA. Model has been applied using the EAD hollow tube approach (in the context of a MSc Thesis) and also the EAD invertube approach (under a PhD Thesis).

(5) Experimental campaign carried out in INTA/La Marañosa, Madrid (Spain).

(6) Modelling and Simulation (M&S). Methodology applied can be see below:
- Design of numerical models of both BLADE solutions using LS-DYNA software.
- Calibration of numerical models according experimental data recorded.
- Simulations of numerical models in order to assess potential performance of BLADE mitigation solutions using a combination de different explosive charges (up to 260 kg TNT) and stand-off distances (2.20 m to 5 m).

(7) To collect Best Practices for a better application of BLADE mitigation solution.

3.3 Experimental campaign

Several tests were planned and designed to assess BLADE mitigation solutions. The experimental campaign was execute during 2020 in INTA/La Marañosa, Madrid (Spain).

a) Six tests was carried out in June (2) and November (4) as indicated below:

- One test 25 kg $TNT_{equivalent}$ detonated at 5 m on 10th June 2020 using reinforced concrete plates (2.75x1.00x0.20m) and both EAD hollow tubes and invertubes.
- Four tests of 60 kg $TNT_{equivalent}$. Three tests at 5 m on 11th June, 12th and 16th November and one test at 2,5 m on 17th November 2020. In all tests were used reinforced concrete plates (2.75x1.00x0.20m; 1.44 tons) and both EADs types.
- One concept validation test was done on 17th November 2020 with 60 kg $TNT_{equivalent}$ at 2,2 m using two protection barriers. One barrier was made with 6 ordinary T-walls without EADs and other with 6 T-walls retrofitted with mitigation solutions proposed (T-walls with concrete plates plus EAD hollow tubes and invertubes).

b) Sixteen T-walls (2.70x1.05x1.30m; 0.30m thickness; 2.82 tons) were precast.

c) Two different EADs were designed, manufactured and tested. Hollow tubes 200 mm diameter x 8 mm thickness (100 mm, 160 mm, 260 mm length) and 48 invertubes (64 mm, 54mm and 41 mm diameter). Furthermore, many steel pieces as supports, connectors, bottom interfaces, plates and others metallic items were designed and manufactured in order to assembly EADs for testing.

d) A complete set-up for testing was designed. Two high speed cameras (HSC), a drone, pressure sensors, force sensors, accelerometers and mechanical displacement measuring devices were used to record experimental data and effects produced by explosions.

4. DELIVERABLES

Additionally to this Executive Summary, project has produced next deliverables:

4.1. State-of-the art (Annex A by C-IED COE)

4.2. Quasi static experimental campaign
- Material Characterization (Annex B1 by FCT NOVA)
- Invertube preparation (Annex B2 by FCT NOVA)

4.3. Full scale Blast tests of the system
- Blast tests observations and analysis (Annex C1 by C-IED COE)
- INTA testing report (Annex C2 by INTA/La Marañosa)

4.4. Modelling &Simulation (M&S)
- M&S on EAD hollow type (HTA) (Annex D1 by FCT NOVA)
- M&S on EAD invertube type (ITA) (Annex D2 by INTA)

4.5. Analytical models for application (Annex E by FCT NOVA).

4.6. Best Practices and conclusions (Annex F by C-IED COE).

5. MAIN RESULTS ACHIEVED

The mitigation solution based on energy absorbing devices (EADs) can increase, more than 200% the performance, according different BLADE solutions, in terms of pressures and specific impulses (incident and reflected) of a conventional T-Wall, mitigating at the same time the breakup of the concrete wall.

The change in the center of gravity of the T-Wall (2.82 tons) by the add-on panel and the mass increase (1.44 tons) played a decisive role in increasing resistance and resilience, for this blast load level (and expectably for much higher levels). The essential requirement for the performance is to allow the T-Wall barrier to slide what means that the system base cannot be clamped/buried on the ground.

From Modelling & Simulation annexes and from scientific study conducted in FCT NOVA, the protected T-wall system based on BLADE mitigation solutions and tested is able **to increase at least 300% the resistance** of the system (simulations have shown that the system can withstand “easily” 150Kg TNTequivalent at 2.2m, which is an acceptable load to a VBIED). The unprotected system typically tend to breach and if the load increases, most likely many concrete fragments will be produced. The system with an add-on panel tend to push the complete system without overturning/toppling if it’s free to move. This energy absorbing mechanism can reduce significantly the possibility of wall breaching and simultaneously the creation of fragments. In practical terms, the breach of the wall is undesirable in such way that allows possible adversaries to penetrate in the protected area. Thus, the protected system fulfilled the purpose of the design.

However, a specific study on ways to reinforce joints between T-Walls, providing some kind of improved monolithic behaviour is recommended in order to complete design of protective solutions.

Even though showing an excellent performance in vertical position, the EAD invertube configuration (ITC) is not suitable for using in T-Wall due to the sloppy position and a very much more difficult assembly process that increases probability to produce sloppy positions, misalignments and no perfect axial compression. Nevertheless, EAD invertube approach could be a very suitable system to retrofit vertical surfaces of buildings and critical infrastructures.

Finally, EAD hollow tube configuration (HTC) with concrete panels performs very well in reinforcing T-Wall barrier and increase its resistance performance. In addition, it is a cheap system and its assembly on site can be considered easy and quick. It is a potential solution to be implemented on operational scenarios.

6. OUTCOMES AND BENEFITS FOR NATO AND C-IED COMMUNITY OF INTEREST

Results indicate that BLADE solution is feasible and highly effective as a system to increase up to 300% in strength terms the performance of the reinforced concrete blast walls (T-walls), validating the planned objectives. At this point it's worth to mention that this increase in performance is related to the solution tested in the project. Higher performances are expected to be possible with changes in the protective solution (e.g. increase the hollow tube diameter). Furthermore, BLADE solution based on hollow tube configuration is more easy and suitable on retrofitting T-wall barriers and BLADE solution based on using invertube configuration is more efficient and suitable to reinforce vertical facades of buildings or critical infrastructures.

BLADE R&D project also provides to all member states and end users a complete set of best practices, guidelines and recommendations on selection and application of BLADE solutions proposed. BLADE R&D project is a clear example of research focused to be applied by end users.

Finally, this final report and all information collected in its annexes, can be useful for NATO community and for the C-IED Community of Interest and in particularly for technical groups or specialists dealing with infrastructure protection.

Hoyo de Manzanares, 09th December 2021.

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