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MULTIPLE CROSS-WISE ORIENTATED NERA-PANELS AGAINST SHAPED CHARGE WARHEADS

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Studies of non-explosive reactive armour, NERA, as add-on armour against shaped charge warheads, has been performed with focus on the effect of introducing more than one consecutive panel and the influence of the mutual orientation of the panels. As a NERA-panel affects the jet mainly in the plane of obliquity, using cross-wise orientated panels, where the disturbance will occur in non-coinciding directions should increase the protection capability of the armour.

The study is based on numerical simulations and ballistic experiments. The NERA-panels consisted of a rubber layer between two thin steel plates. A simple calibre 84 mm shaped charge warhead was used and tested against a single NERA-panel, two parallel NERA-panels and two cross-wise orientated NERA-panels respectively. The experiments as well as the simulations show that use of cross-wise orientated panels considerable increase the protection capability against shaped charge warheads.

INTRODUCTION

Non-explosive reactive armour, NERA, is of interest as add-on armour against shaped charge warheads for lightly protected vehicles [1-3]. NERA-panels consist of two thin metal plates separated by an inert filling. When a NERA-panel is hit by a shaped charge jet, part of the kinetic energy of the jet is transferred to the filling, accelerating the plates in opposite directions. If the NERA-panel is inclined relative to the jet, the moving plates will interact with the jet and disturb it. The disturbance is oriented in the plane of obliquity (the plane spanned by the jet direction and the normal to the plate).

To increase the protection capability, several consecutive panels can be used. If the panels are oriented parallel to each other, the increase in protection is only marginal. The first panel affects the jet so that a bulge is created in the plane of disturbance. This jet bulge erodes material in the next panel, creating a wide, oval channel letting the following undisturbed part of the jet through. However, if the panels are oriented in non-coinciding directions also the second panel will generate disturbances on the jet and consequently a better protective effect should be achieved.

In this paper, results from ballistic experiments as well as numerical simulations are presented. The protection capability of this kind of cross-wise orientated panels (CWO-NERA) is compared to corresponding multiple parallel and single NERA-panels. The warhead used in the study was a calibre 84 mm shaped charge, typical of the ones used in handheld shaped charge weapons.

EXPERIMENTS

An ordinary calibre 84 mm shaped charge warhead for man-portable weapon was tested against non-explosive reactive armour panels. The liner is a 2.0 mm thick straight copper cone with a 25° half apex angle. The charge is point initiated and the main HE filler is cast octol 70/30. The claimed penetration capability is 450 mm armour steel at the optimal stand-off 350 mm.

The NERA-panels consisted of a 5 mm thick rubber layer between two 3 mm thick steel plates (Domex Protect 300), dimension 300×150 mm. Flash X-ray pictures were used to study the interaction between the panel and the jet, Figure 1, and the resulting disturbed jet, Figure 2.

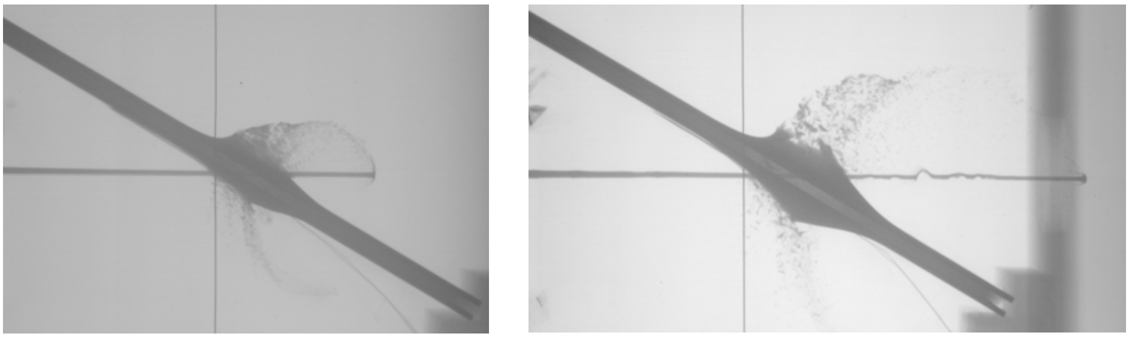

Figure 1. Flash X-ray registrations of the interaction between a NERA-panel and a jet, at two consecutive times.

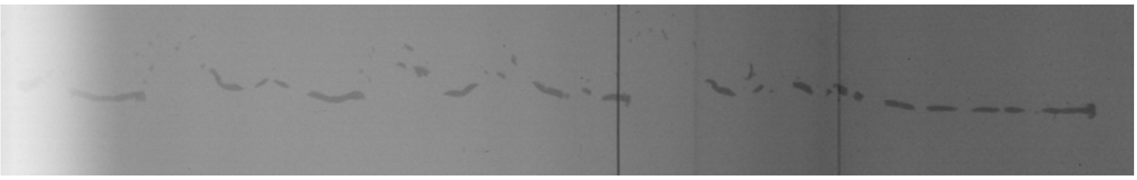

Figure 2. Flash X-ray registrations of the disturbed jet after interaction with a NERA-panel.

In the study, four different armour configurations were tested: a reference of homogeneous armour, a single NERA-panel, two parallel NERA-panels and two cross-wise orientated NERA-panels, see Figure 3.

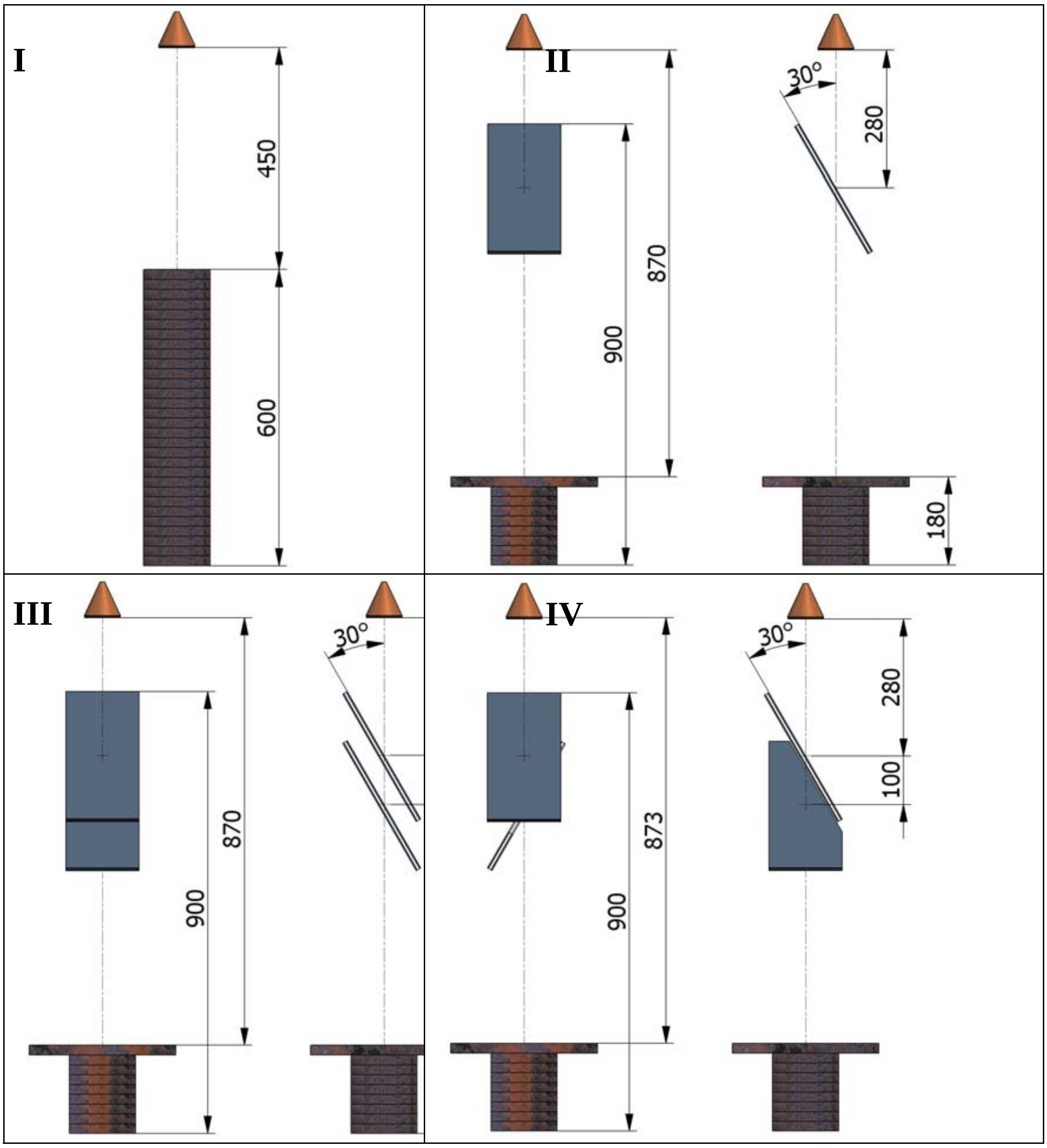

Figure 3. The four different armour configurations tested. (I) homogeneous armour, (II) a single NERA-panel, (III) two parallel NERA-panels, and (IV) two cross-wise orientated NERA-panels.

In each configuration the total length between the rear end of the armour and the base of the warhead was 1050 mm. The distance to the aim point in the middle of the panel was 280 mm which corresponds roughly to the sum of the built-in stand-off of the warhead and the distance from the edge of the panel to the aim point. The panels had an obliquity of 60°. When two panels were used, the distance from centre to centre in the jet direction was 100 mm independent of the mutual orientation of the panels. When using the dimensions chosen above, the CWO-NERA does not permit a distance of 100 mm between the panels without being modified. Thus a corner of the second panel was removed, see Figure 4.

The residual penetration was measured in a pile of 20 mm thick armour steel plates with a total height of 180 mm except for the reference case with no NERA-panels where the total height was 600 mm (due to the above restriction on the total length).

The residual penetration depth in the armour stack was used to evaluate the protection capability achieved.

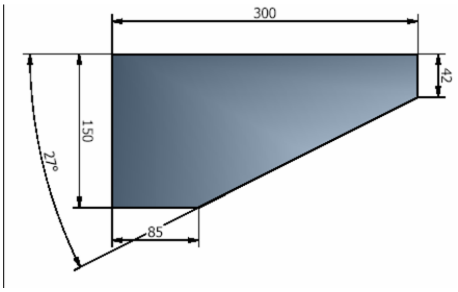

Figure 4. Lower NERA-panel with removed corner for cross-wise orientation.

SIMULATIONS

Numerical simulations were performed to study the interaction between the shaped charge jet and the NERA-panels and the subsequent decrease in residual penetration in steel armour. The hydrocode used was AUTODYN-3D (v 6.1) with a Lagrange formulation for the jet and a multi-material Euler formulation for the panels. In the case of CWO-NERA, inherent limitations in AUTODYN inhibited full Eularian description of the panels. In this case the second panel was modelled with a Lagrange formulation. For the Lagrange formulations a simple erosion strain criterion was used.

The jet was modelled as a number of connected truncated cones. The radius and initial velocity of each cylinder was prescribed with values according to experimentally deduced jet data, see the flash X-ray picture of the jet in Figure 5.

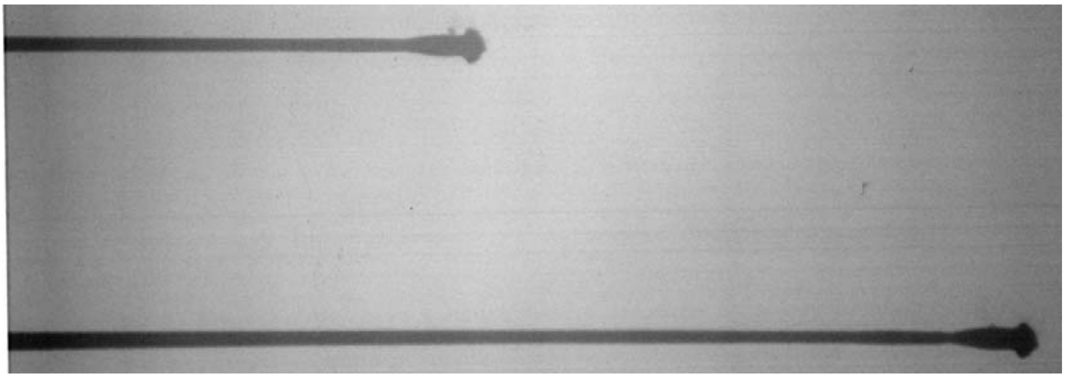

Figure 5. Double flash X-ray exposures of the shaped charge jet, 55 and 70 μs after initiation. The early exposure corresponds to the time of impact on the first NERA-plate.

For the jet and the steel plates, the Johnson-Cook strength model was used. The equation of state used for the copper jet was of the Mie-Gruneisen type, while for the steel plates a constant bulk modulus was used. Material data were taken from the AUTODYN library, OFHC copper [4] for the jet and steel SS 2541-3 [5] for the plates. AUTODYN does not include specialized rubber models and therefore a Mie-Gruneisen equation of state without material strength was used with the polyrubber material data.

The spatial extension of the computational domain was kept to a minimum to allow a very fine resolution in the interaction area. The dimensions of the panels in the model were therefore smaller than the ones used in the experiments. However, the size of the domain was considered large enough for boundary effects to have negligible effect on the overall behaviour.

RESULTS

The results from the numerical simulation with two parallel and two cross-wise orientated panels respectively, are shown in Figure 6. In the case of parallel panels all disturbances occurs in the plane of plate obliquity, while the CWO-panels introduce disturbances in all directions.

The residual penetration in armour steel behind two parallel panels as compared to steel penetration without any panels was simulated and the penetration capability decreased by 72%.

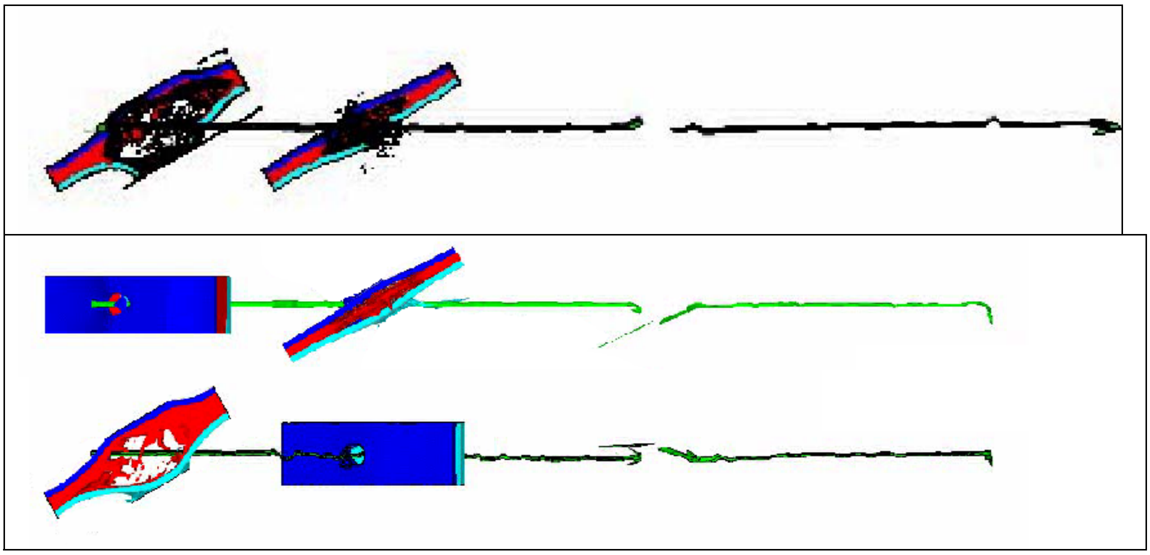

Figure 6. Simulation results indicating the disturbance of the jet after penetration of (i) two parallel NERA-panels and (ii) two cross-wise oriented NERA panels. For the CWO-panels the disturbance in two perpendicular plan is shown.

The result of the experiments is shown in Table 1 and Figure 7. In Figure 7 the plates affected of the jet are shown. In case I and II (no panels and a single panel respectively), the last plate was half penetrated while in case III and IV (two panels) the last plate just indicates a hit but no penetration.

Table 1. Evaluated penetration depth for the four different armour configurations tested.

Add-on armour	Penetration depth in base armour [mm]	Penetrated area weight [kg/m^2]
I No panels	410	3200
II A single NERA-panel	70	650
III Two parallel NERA	60	675
IV Two CWO- NERA	40	520

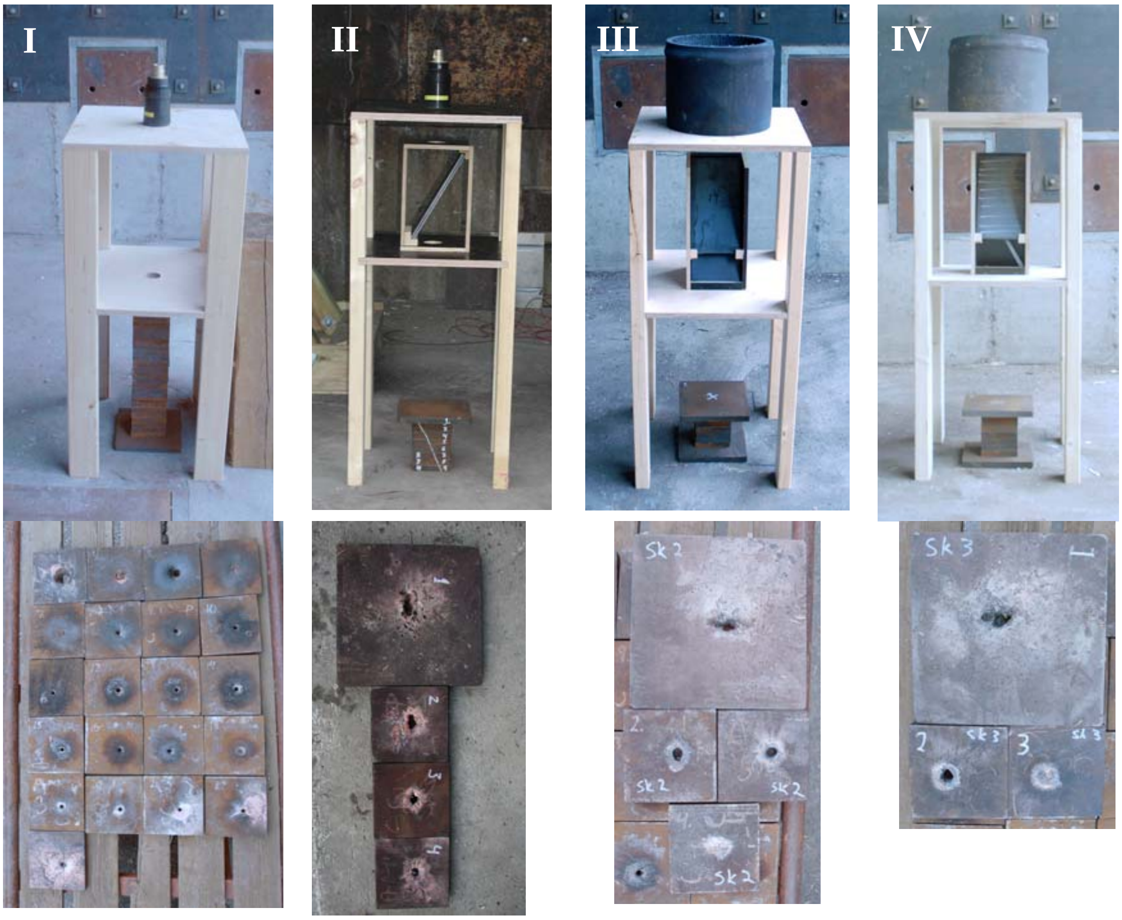

Figure 7. Test set-up (above) and number of plates penetrated (below) for the four different armour configurations tested. (I) Reference in homogeneous armour, (II) one single NERA-panel, (III) two parallel oriented NERA-panels, and (IV) two cross-wise orientated NERA-panels.

DISCUSSION

NERA-panels are effective in reducing the residual penetration capability of shaped charge jets. For light-weight vehicles, the residual penetration is still too large if only one panel is used. Both the experiments and the numerical simulations show that the benefit of using two parallel panels is small. Although the residual penetration decreases, allowing thinner base armour, the total weight of the armour is increased when introducing the second panel. However, by orienting the panels in perpendicular directions, the residual penetration (and the total weight) can be reduced considerably.

Cross-wise oriented panels are more difficult to stack in a limited space which could be a problem if the panels have large lateral dimensions compared to the thickness. Both the simulations and the experiments show that the panel area interacting with the jet is significantly smaller than the plate dimensions used here, so it should be possible to reduce the size of the panels without sacrificing performance.

The used distance between the panels was chosen in such a way that the panels should not disturb each other. To save volume it is desirable to minimize this distance. The simulations show that the two panels are well separated throughout the event and that it is possible to reduce the distance without any decrease in protection capability.

The calculated penetration depth in homogenous armour steel was less than the experimentally measured depth. In contrast, the calculated residual penetration after interaction with the NERA-panels was greater than the experimental. This indicates that the simulations underestimate the amount of disturbances generated on the jet. This could be explained by the fact that the use of erosion in the Lagrangian formulation of the jet reduces the interaction with the panel. In spite of the small disagreement between experiments and simulations, the overall interaction behaviour is reproduced correctly in the simulations.

CONCLUSIONS

A large reduction in penetration capability is obtained by the first NERA-panel. The further benefit of subsequent panels is strongly dependent upon how the panels are oriented. In this study, a comparison has been made between parallel and cross-wise orientated panels and the result was that the latter was far superior in increasing the residual protection capability.

As the NERA-principle requires relatively small panels, it is possible to arrange the panels in a cross-wise manner with just a marginal volume increase.

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