Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Based on the experimental tests and corresponding numerical studies using software's the following conclusions are drawn:

• A new numerical methodology in the form of Optimal Interface Numerical Technique (ONIT) for the shape optimization of high velocity penetrator nose has been demonstrated. The Thomson's formulation for the 'Dynamical work' is the starting point. Non-linear differential equation is solved using the Interface Theory. The Non-linear equation is linearized before the application of Interface Theory. The boundary conditions (Dirichlet) help in arriving at a parabolic expression for the shape. The drag force during impact also varies parabolically along the length axial to the penetrator. The Interface Theory used as a mathematical tool provides a new direction to the numerical solution. By simple terms, it gives optimal solution to the linear system with redundancy in unknown variables.

• Based on the experimental tests and the corresponding numerical studies using LS-DYNA, the ballistic perforation resistance of monolithic plates has been investigated. It can be concluded from experimental and numerical studies that, an armour plate of 6.5mm thickness is capable of resisting an SLR bullet hit with a velocity of 850m/s. And in double layered target plates perforated combination can resist penetration, which was not possible in case of non-perforated layered targets. For the perforation geometry, circular perforation with 10mm air gap between plates, maximum erosion of the bullet was seen in the plate having a configuration of 5mm diameter holes with 10mm hole distance and the configuration gave the mass reduction of 19.67% compared to non-perforated double layered target plates. . It is confirmed that numerical results and experimental results are closely matched.
• The efforts to obtain the best geometric configuration that would provide maximum penetration depth and optimum penetration efficiency are considered. The closed form solution for L/D ratio and the penetration efficiency at different impact velocities for both monolithic and segmented penetrators is well supported by the results obtained through computational analysis using PAM CRASH. The analytical solution finds its base in the hydrodynamic theory of penetration; on the other hand the computational analysis is governed by the J-C model which is in good agreement with the experimental results published. In various forms of the three nose shape designs the outcome suggests that the concave nose with L/D ratio 6:8 is the best for the penetrator made of tungsten as the material. This configuration for a segmented penetrator is further considered for analysis. The S/D ratio of 4:5 gives better performance than monolithic. The spacer has been made of tungsten in the segmented penetrator with steel as the main body material, reducing the weight and hence the cost.

• The blunt projectile gives the best damaging result compared with the conical and hemispherical projectiles for the impact velocity of 300 m/s on a vertical target plate, and again it is compared with segmented projectile. For the results obtained the segmented projectile shows slightly better performance with the stationary target. Both the bulge and the hole were circular in normal impact and elliptical in oblique impact. In the case of segmented projectile, segmented rods always show slightly better performance with the stationary target. The outstanding penetration performance of the segmented rods can be observed. This trend is due to the interaction between the plate and the projectile. The extent of the interaction relies on the impact velocities of the projectiles, and the plate angle. It is found that the numerical experimental results are validated.

• Three-dimensional numerical simulations have been performed to study the behavior of ductile targets subjected to normal and oblique impact by monolithic unitary projectile with nose blunt, conical, hemispherical and by segmented projectile. The material used for the unitary projectile is tungsten and for the segmented type combination of tungsten and titanium is used for the impact
velocity of 300, 350, and 400 m/s. In all the cases, targets were impacted at vertical (0°), 45°, and 55° obliquity.

- At the highest impact velocities, plastic deformation of the projectile may become severe and this absorbs a lot of initial kinetic energy. The decrease of impact velocity is grater for the blunt nose projectile when compare to a cone and hemispherical projectile. Compare to a monolithic unitary projectile with different nose head, the segmented projectile gives a greater penetration depth. The energy loss due to eroded elements and the deviation of projectile for inclined target with different ballistic limit initial velocity. In comparison of monolithic and segmented projectile the decrease of impact velocity is less compare to monolithic for every decrease of target inclination. For the every decrease inclination in target angle, the projectile decreases with decrease in impact velocity. The experimental trend of the decrease in ballistic limit velocity with the increase in target strength for blunt projectiles could not be predicted using the numerical models presented in this thesis. The prediction of the ballistic limit velocity becomes non-conservative.

7.2 Scope for future work:

- In the current study we have used the Johnson-Cook constitutive model. Other constitutive models available in the literature can be used to simulate the phenomenon.

- As temperature plays a role in deciding the properties of the materials at high velocities and high strain rates, the simulations can be carried out with thermal considerations.

- No failure criterion is considered in the study. Hence more accurate results can be achieved by considering a damage or failure criterion such as those suggested by Johnson-Cook or Zirilli-Armstrong.