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Add-on Armour Mounting Modes

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ABSTRACT

Concepts of mounting add-on armour modules on battle tank are described. Selection of optimum mode of mounting is evaluated based on criterion function decision theory. Findings match very well with experimental observations.

1. INTRODUCTION

Higher strength-to-weight ratio offered by composite materials have attracted designers in aircraft, automobiles and aerospace industry. Likewise, weight being enemy of tank designers, fiber-reinforced plastic (FRP) composites have also been extensively studied, since World War II, as candidate armour materials. Over the years, tank designers have thus optimised variety of metallic-nonmetallic armour grade materials and utilised the density mismatch concept to their advantage. In doing so maximum protection with least weight penalty, have been achieved without affecting operational, tactical and battlefield mobility of the tank. While enhancing protection levels of vintage tanks, these composite materials have to be put on the tank surface, at select locations, in the form of add-on armour. These add-on armour modules or panels are generally fabricated in the form of box structure for obvious reasons. These armour modules will vary in size, shape, thickness and material content based on the threat analysis carried out by ballistic experts. Design of such add-on armour panels is by and large based on the principle of five 'S' namely; selecting, shaping, sizing, sequencing, and slanting. Further, armour panels so designed are to be systematically examined for their ballistic performance against variety of antitank ammunitions and results compared with simulated data. A large number of firing trials are required to be conducted on optimised armour panels, with a view to establish reproductivity and consistency of ballistic parameters. Finally, these ballistically proved add-on armour panels are required to be mounted on a vintage tank for providing additional protection, against an antitank ammunition having higher penetration capability. Tank crew will desire a simple mounting technique, wherein, damaged add-on armour modules can be removed and serviceable modules are refitted with ease and without any loss of time. Such a simple arrangement can only be feasible with the help of a nut and bolt design and will truely qualify to be called as a detachable add-on armour.

The aim of this paper is to describe the basic requirements to be fulfilled by a mounting system, adopted for mounting add-on armour panels on battle tanks. Various mounting concepts have also been discussed. Criterion-based decision theory principle has been applied in ascertaining suitability of particular type of mounting mode, based on the observations made during and after ballistic evaluation of such add-on modules.

2. NEED OF BOX STRUCTURE

As against plastic deformation, which is the main energy absorbing mechanism in metals[1], internal frictional sliding, high levels of toughness, internal fracture and multi-mechanism energy absorbing criteria such as fiber breakage, matrix cracking, fiber-matrix bonding and fiber pull-out in fiber-reinforced plastics, offer comparative ballistic performance on weight-to-weight basis[2] . In addition to FRP[3-11], ceramics[9,12-15], nonmetallic aggregates and other nonferrous metals[8-10]

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are also found to qualify as candidate armour materials in different ballistic situations[16-18]

These advanced composite armour materials often pose fabricational restrictions as they cannot be easily curved and bent as dictated by the end application on the tank. With the advancement of technology it may definitely be feasible to work on these composite materials to get the required shape, but at what cost ? . Moreover, in the process of bending these composite materials, there is also a chance of reducing their ballistic worth due to technological complexities that are likely to be involved in these processes. Additionally, some sort of protective cover will still be required for protection against moisture, during the service conditions. Protection against moisture is an important issue where such composite materials are being used. It is for this reason that the stack of material is simply packed in a container and such practice is being used by the armour designers in the world[19-21]. This decision of box making is likely to be quite simple and cost-effective without involving any loss of the ballistic performance of these add-on armour modules . For the purpose of weight saving, front-and-rear plates of this add-on armour module can form part of the ballistic stack as seen in Fig. 1, however, it is not a rigid rule and mainly depends on the choice of the designer, keeping in mind the ballistic performance and method of mounting such add-on armour modules on the battle tank.

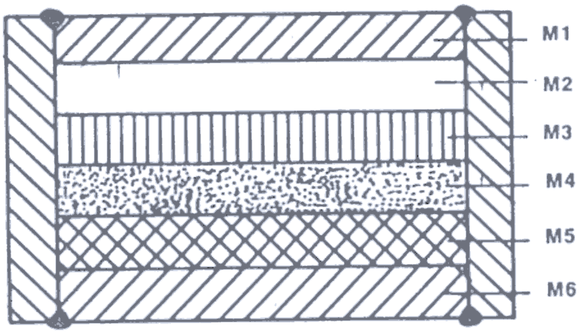
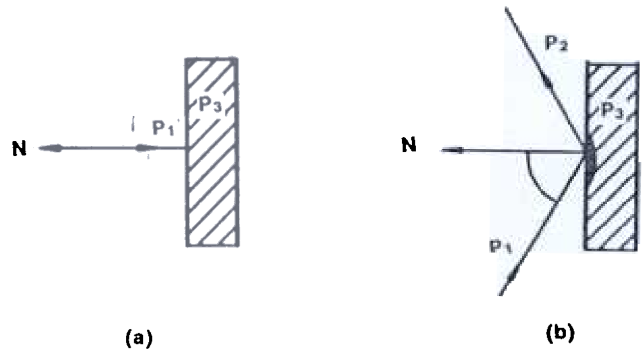


Figure 1. Constructional details of composite armour module.

3. FORCE ESTIMATION

For designing the mounting system, a basic requirement is to have an estimation of the impact force, imparted to the add-on armour panel by the incoming projectile. The magnitude of force experienced by the panels will depend on, whether the panel has been perforated or penetrated by the high velocity projectile at different obliquities. Mounting system is put to an acid test while a striking projectile gets deflected from the surface of the panel at higher obliquities. During deflection of projectile, it produces a crater on the point of impact. Depending on the depth of crater so formed on the panel, the magnitude of the force experienced by the mounting system will vary accordingly. Force measurement techniques have been developed by a number of investigators[22-27], and the emperical formulae to be utilised in the estimation of the forces have also been provided, therein. For correctly assessing the force experienced by the mounting system, it is essential to have accurate calculation of the energy absorbed in the formation of the crater and the residual velocity of the deflecting projectile. Magnitudes of the force estimated by using these emperical relations[22, 27], reveal that force is much higher than the strength of the material as these calculations do not account for the energy absorbed by the plate material which is very vital in the estimation of force experienced by the mounting system. While considering the mass of projectile, it is to be further ensured that mass of sabot at the tail end is to be further deducted from the total mass of the projectile. At projectile speeds below the ballistics limit, the maximum forces are found to be proportional to the initial velocity whereas peak forces obtained were found to be relatively independent of the initial projectile velocity for shots where perforation had occurred[22]. The various mounting concepts were thus evaluated by conducting actual firing trials in the most severe condition (i.e. at obliquities up to 75°). It is observed that mount design is a simple issue while the projectile strikes the panel at zero degree (i.e. when path of projectile coincides with the normal of the plate). In a situation like this, it is just sufficient to hold the panel with a simple nut and bolt arrangement and it does not call for a detailed design exercise. Also, at normal angle of attack, ballistic performance of armour plate is not affected even if the plate is kept in suspended form[28]. However, mount design needed to be quite robust for non-zero angle of strike, especially at angles beyond the critical angle, at which projectile starts deflecting after striking the panel (Fig. 2). A non-zero angle of strike simply indicates that the path of the incoming projectile makes an angle with the normal to the plate and it does not coincide with the normal to the plate.



N = PLATE/PANEL NORMAL.
P1 = PATH OF INCOMING PROJECTILE
P2 = PATH OF DEFLECTED PROJECTILE AFTER THE FORMATION OF CRATER ON PANEL
P3 = ADD-ON ARMOUR PANEL
(a) = PROJECTILE INCIDENCE AT ZERO ANGLE REQUIRING SIMPLE MOUNT DESIGN
(b) = PROJECTILE INCIDENCE AT NON-ZERO ANGLE REQUIRING ROBUST MOUNT DESIGN

Figure 2. Mount design complexity.

A natural question arises of avoiding use of inclined plates in armour design so that the simple mounting techniques can be adopted?. However, keeping in mind the fact, that an inclined armour offers the advantage of causing some projectiles to ricochet or to shatter and thus avoid preforation even when it is relatively thin, sloped armour design cannot be avoided. Details of effectiveness of the sloped armour in terms of the ratio of its effective thickness to actual thickness and the angle of attack is often found in literature. It is quite evident that it is of no use to incline armour, if obliquity is less than 30°. For maximum gains of protection with least weight penalty, obliquity[29] should be more than 60 - 65° The critical angle at which armour is to be inclined is related to the length, mass and diameter of the incoming projectile. At these obliquities of add-on armour, mount design thus needs careful consideration to ensure its plate holding capabilities against an impact of an incoming kinetic energy projectile, at ordnance velocities. Improper mounting arrangement involving high obliquities may reduce multihit protection capability of add-on armour module. In such situations, plate is likely to get dislodged from the tank surface and may have sufficient tendency to fly alongwith the deflected projectile, thereby exposing the tank surface to the subsequent hit by a projectile.

4. MOUNT DESIGN PARAMETERS

Add-on armour module is expected to provide multihit protection capability for the reasons explained above. Thus, mount design is as important an issue as the design of add-on armour module itself. Apart from holding the plate on tank surface, any mounting arrangement, adopted for mounting add-on armour panels, should satisfy a large number of functional requirements. Therefore, some of the important requirements to be fulfilled by the mounting system are described below:

(a) Should be light in weight,

(b) Should be able to hold the panel at all angles of strike against all types of antitank ammunitions,

(c) Should hold armour panel at all speeds of the projectile,

(d) Should be mounted with ease,

(e) Should have ease of maintenance and repair,

(f) Should be simple in design,

(g) Should be reasonably cost-effective,

(h) Should have ease of fabrication,

(i) Should not cause obstructions to crew,

(j) Should not deteriorate ballistic worth of armour panel,

(k) Should not pose problem in mounting of tool boxes

(l) Should not provide shot-trap,

(m) Should not obstruct engine removal and gun depression,

(n) Should not foul with hull, and

(o) Should not obstruct vision of the driver and gunner.

It is a necessary and sufficient condition that the mounting system should satisfy the above mentioned requirements at least to a large extent. Minor compromises with regard to certain parameters might have to be accepted by the crew. Some of the conditions are so vital that even a best mounting system may have to be rejected if it does not meet those functional requirements. It should therefore, be understood that degree of freedom in designing a sound mounting system is very restrictive in nature. Add-on armour mount design thus involves large number of design constraints which are also of primary concern to a designer.

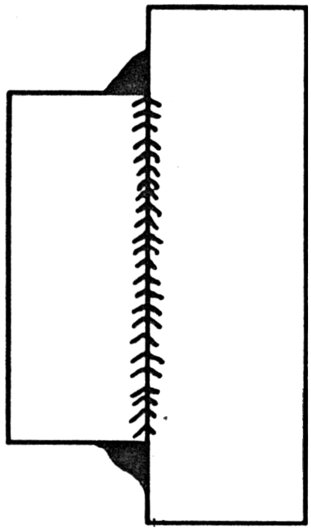


Figure 3. Mount design concept No. 1.

5. MOUNTING MODES

Six pre-design concepts including welding of the panels were evaluated through series of ballistic trials. Each concept was evaluated under identical ballistic parameters. Detailed observations were made with regard to the damage of add-on armour panel and also the mounting components. Conceptual details of these pre-design mounting systems are shown in Figs 3 to 8. Detailed description of these concepts is beyond the scope of this paper and it is provided elsewhere[30]. In all these mounting modes, presented in Figs 3-8, complexity of mount design has been avoided with a view to repairing the damaged mount system with ease and without loss of time, under the limited facilities available at the disposal of the tank crew in the field conditions. Details with regard to the damage pattern noticed in each case when subjected to impact at different obliquities and striking velocities by a particular type of kinetic energy projectile, cannot be presented due to obvious reasons. However, evaluation of these concepts is based on the observations made during actual firing trials. Summary of the basic aim of

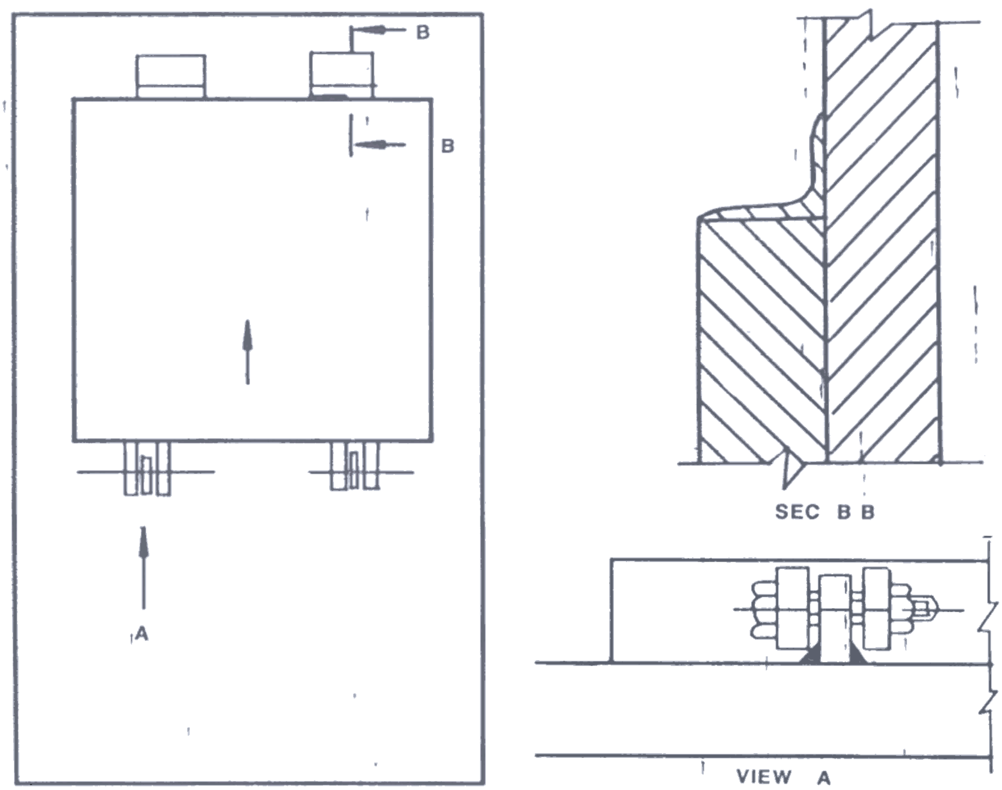


Figure 4. Mount design concept No. 2.

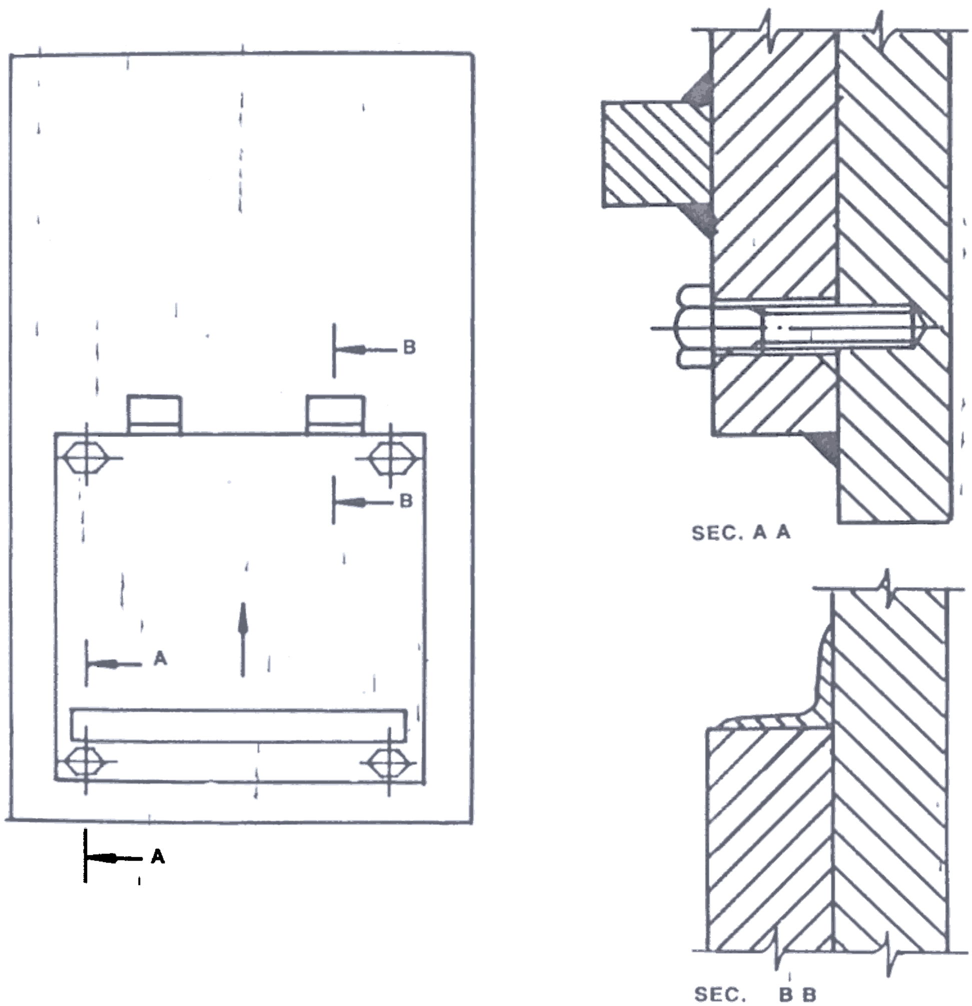


Figure 5. Mount design concept No. 3.

each design is presented in Table 1 and no design calculations are performed on any concept. It is to be understood that in the pre-design stage a suitable mounting arrangement was to be finalised by conducting ballistic experiments, which could satisfy maximum number of the above mentioned requirements, before actually undertaking a detailed design exercise. Arrow mark on the add-on armour plate in each concept indicates the direction of the incoming projectile. In these concepts, smaller plate represents the add-on armour module and bigger plate represents the base plate of the tank on which these add-on panels are required to be mounted. Decision with regard to the mounting mode to be adopted for mounting panels on tank is arrived at using a decision table prepared, based on criterion function or objective function, as described in succeeding paras.

6. OPTIMUM SOLUTION

In arriving at optimum solution, a number of important criterion variables or parameters are defined first. These parameters are assigned weightage on 1-100 scale. Individual score of these parameters is applied to each concept on 1-10 scale. Weightage and individual scores are multiplied to get the total weightage in each concept. The grand total of score is then compared and a concept, with the highest score of the total weightage is obtained to be the best solution. Criterion function is defined as follows:

$$CF = \sum_{i=1}^{i=n} ai\ xi$$

ai = Weightage Coefficient

xi = Criterion Variables

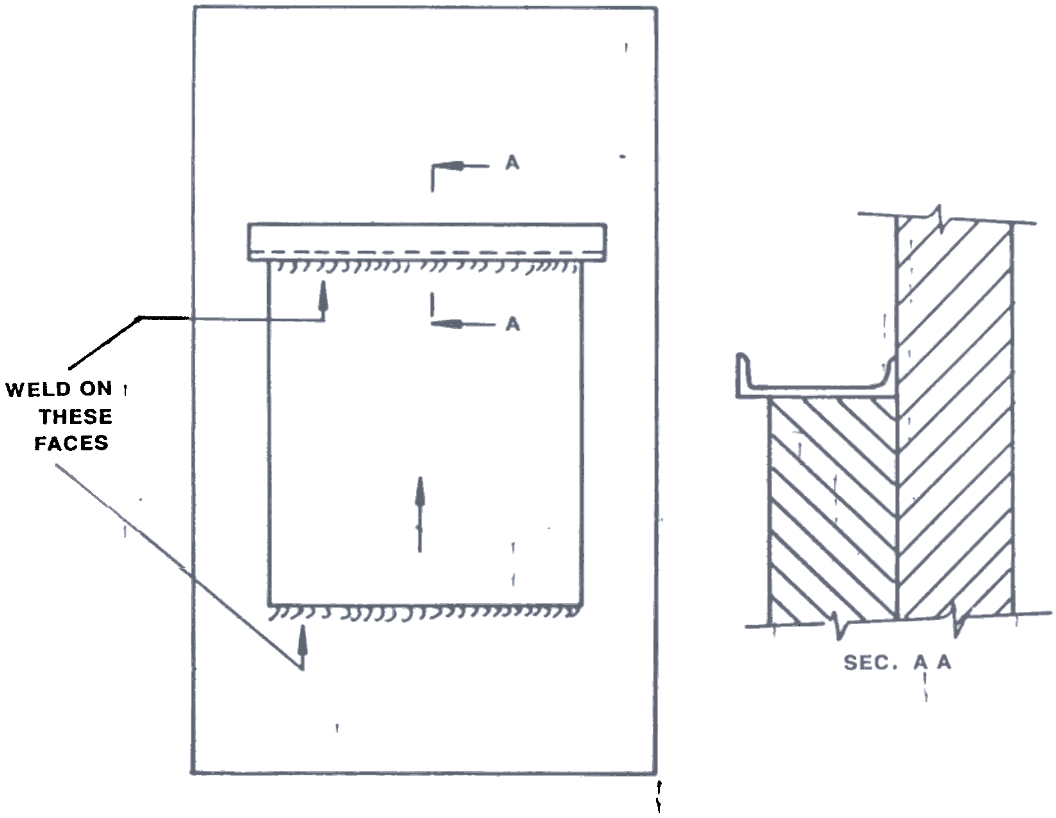


Figure 6. Mount design concept No. 4.

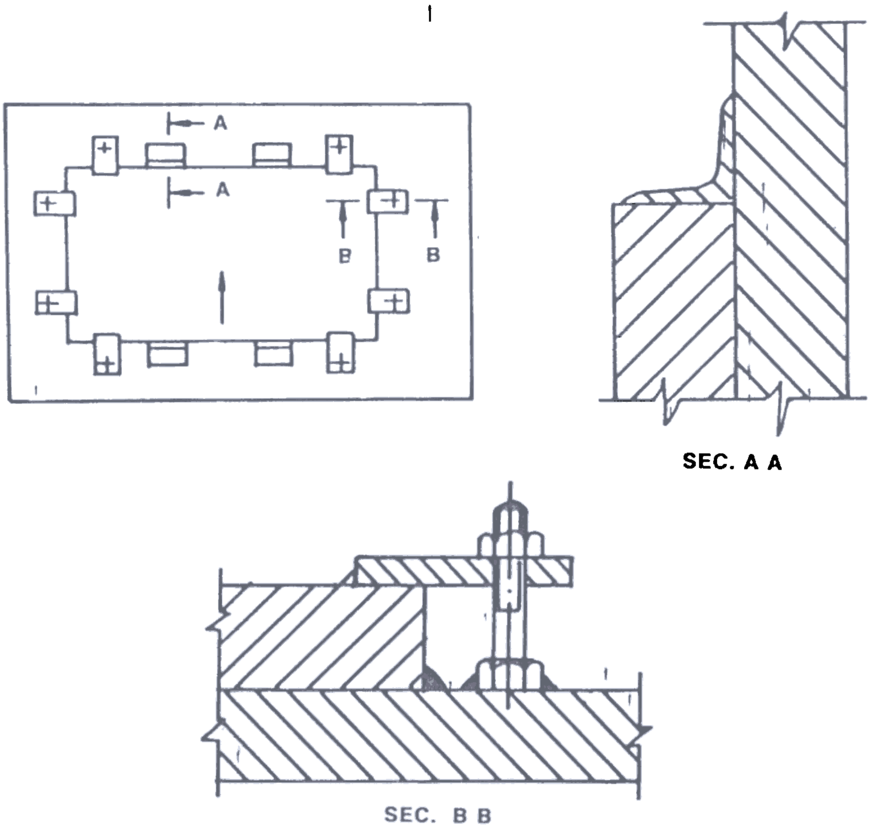


Figure 7. Mount design concept No. 5.

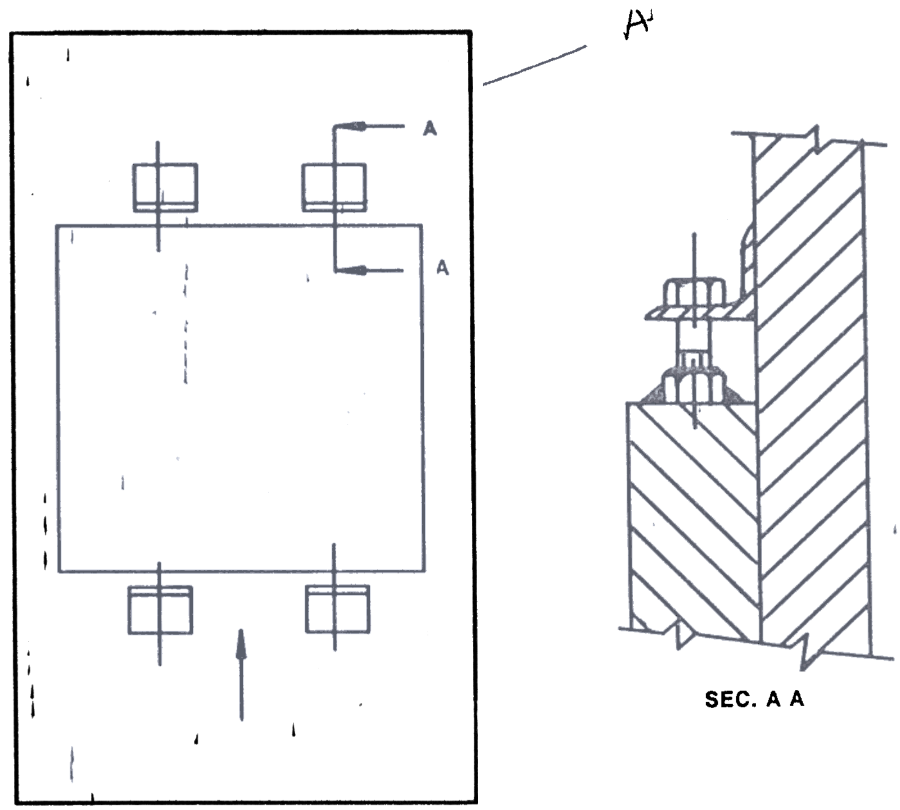


Figure 8. Mount design concept No. 6.

Table 1. Basic aim of each design concept

Concept Nos.	Aim
	Ascertaining the feasibility of full welding of add-on armour plate to avoid weight penalty
2.	Feasibility of simple nut/bolt design at one side and a stopper plate at the forward edge of plate, for semi- detachable solution.
3.	Feasibility of threaded bolt into the base armour through add-on armour along with a stopper plate at the forward edge of add-on plate, for detachable solution.
4.	Partial welding concept, having welding on one side and a stopper plate at the forward edge. No welding on sides of the add-on plate.
5.	Segmented stopper plate on front and rear sides of the add-on plate, to reduce weight penalty. Application of nut/bolt arrangement for holding add-on armour plate with an extension plate to avoid drilling and thread cutting problems through the add-on armour plate, thereby trying the idea of detachable system.
6.	Use of stopper plates along with nut and bolt arrangement with the help of L bracket for weight saving, and detachable solution.

During the process of evaluation of the best concept, it is ensured that the subjectivity is minimised and objectivity is increased. Some of the important parameters considered in the concept finalisation in Table 2 are enumerated below:

(a) Capability to hold armour at all angles,

(b) Weight penalty,

(c) Ease of repair,

(d) Ease of mounting,

(e) Adoptability by field Army,

(f) Sophisticated machining requirements,

(g) Vision obstruction,

(h) Shot-trap feasibility,

(i) Engine removal problem, and

(j) Tool boxes mounting feasibility.

7. DISCUSSION

Table 2. Mounting concept decision

Parameters	Weight	Concept No 1		Concept No 2		Concept No 3		Concept No 4		Concept No 5		Concept No 6	
	ai	*xi*	*aixi*	*xi*	*aixi*	*xi*	*aixi*	*xi*	*aixi*	*xi*	*aixi*	*xi*	*aixi*
Capability to hold armour at all angles	45	10	450	3	135	4	180	6	270	5	225	1	45
Weight penalty	15		120		15	2	30			3	45	6	90
Ease of mounting	4		12	8	32	6	24	5	20	4	16	7	28
Ease of repair	2		14	2	4	4	8	3	6	5	10	6	12
Adoptability by field army	8		64	2	16	5	40	4	32	6	48	7	56
Machining operations	2	10	20			5	10	4	8	7	14	8	16
Vision obstruction	9		81		18	3	27	5	45	6	54		63
Tool boxes mounting feasibility			30	9	27	7	21	2	6	6	18	8	24
Shot-trap feasibility		9	63		21	6	42	3	21	2	14	8	56
Engine removal problem	5	8	40	2	10	6	30	3					20
Total *aixi*			894		280		412		528		469		410

Table 2 provides details of the weightage scoring in the light of functional importance of above mentioned parameters. As per the calculations, mounting concept No. 1, emerges to be the best mode of mounting the add-on armour. It will be noticed that this concept offers some distinct advantages over other solutions presented in Figs 3-8. Least weight penalty, least machining cost/time, capability to hold armour even at higher obliquities, ease of mounting and adoptability by the field Army are such major advantages presented by concept No. 1. This concept however, calls for due precautions to be taken while resorting to welding of the add-on plates in the vicinity of turret ring. Correct estimation of the heat affected zone (HAZ), avoidance of excessive pre-heating and adherence to correct welding procedure will certainly eliminate turret ring distortion problem. Concept No. 2 appeared to be quite an inadequate method of mounting the armour. In this concept, mounted plate could not remain in position and flew along with the deflected projectile. Concept Nos. 3, 5 and 6 are quite close to each other but inferior than concept No. 4 . Though flying odd-on plate was not observed in concept Nos. 3, 5 and 6, extensive damage was noticed to the mounting arrangement. Damage was quite severe and required re-fabrication of all the brackets. Defect rectification thus involved loss of time and higher cost of production.

Concept No. 4, involving partial welding and a stopper plate shown at Sec AA in Fig. 6 did not allow flying of the plate and can be adopted for mounting armour in case of emergency and in locations on the tank where heavy welding might lead to turret ring distortions. It is quite important to note that against a strike of large calibre kinetic energy projectile, at higher obliquities (obliquity > 60-65^{o}), idea of detachable add-on armour does not prove to be successful and designer has to perforce resort to partial or full welding techniques. In constrast, add-on armour on light infantry combat vehicles to enhance its protection levels, is observed to be mounted with non-welding route; i.e. with the help of nuts and bolts as seen in open literature on the subject. Such a difference is basically related to the mass, length to diameter ratio and speed of the impacting projectile and hence to the magnitude of the force experienced by the oblique add-on armour plate. Magnitude of such force, in case of light infantry combat vehicles either being hit by a projectile of 6.2 mm diameter having a mass of 5.2 g or by a steel projectile of 20 mm dia having a mass of 110 g, is far less than the force generated by a large calibre antitank kinetic energy projectile, having a mass of 4000-5000 g.

As mentioned above, in the case of mounting the add-on armour on battle tanks, distortion of turret ring can be a serious issue, if adequate procedural precautions are not taken during welding operation. A literature survey reveals, importance of the problem turret ring distortion noticed during such a programme of modernisation of a tank. Modernisation of M-48 tank by USA, came to halt due to the problem of turret ring distortion experienced during welding/cutting operation. In this modernisation programme, welding operation in the vicinity of turret ring was required for the purpose of fitting new engine with higher rating[31], which basically involved cutting of a heavy plate in the fighting compartment, in close vicinity of the turret ring.

Thus mounting of add-on armour modules with the application of full or partial welding appears to be the best method. It is interesting to note that welding operation is also involved even in concept No. 2 to 6 to some extent, for the welding of stopper plate and bolts. It can be safely concluded that welding operation cannot be avoided for mounting add-on armour modules on battle tanks. For accurate estimation of the force, energy absorbed by different materials during the penetration process is required to be determined in detail, at different velocities and obliquities. Information of this nature will be valuable in finalising the design of mounting brackets for the add-on armour modules.

8. CONCLUSION

The following conclusions are drawn from the present study:

(a) In the light of the functional parameters considered in this paper, full and/or partial welding appears to be more efficient way of mounting add-on armour modules on battle tanks at higher obliquities. However, due precautions are required to be taken during welding to avoid any chance of turret ring distortion.

(b) Concept of detachable add-on armour for protection against large calibre projectiles does not seem to work efficiently.

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