OCIMF

Ship Security – Bridge Vulnerability Study

To determine the effects of weapons fired at the bridge of tankers and to recommend effective ship hardening measures to mitigate the threat.

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The Oil Companies International Marine Forum (OCIMF)
is a voluntary association of oil companies with an interest in the shipment and terminalling of crude oil, oil products, petrochemicals and gas.

Our mission is to be the foremost authority on the safe and environmentally responsible operation of oil tankers, terminals and offshore support vessels, promoting continuous improvement in standards of design and operation.

Contents

1. Introduction

Increasing maritime crime worldwide has resulted in the need to understand the vulnerability of merchant vessels to attacks from a range of small arms fire. Analysis of recent incidents has shown that the bridge, being the command and control centre, is the main target area for attackers as they attempt to force a vessel to slow down or stop and allow the attackers access to the vessel.

OCIMF engaged a multinational defence technology company, QinetiQ, to conduct a two-phased study using computer software simulations to investigate the vulnerability of the bridge of a selection of tanker tonnages (from 30,000dwt to 300,00dwt) when coming under fire from an attack.

The aim of the study was to determine the likelihood of injury to, and the physical vulnerability of, seafarers on the bridge of a vessel when the vessel was subjected to attack by small arms weaponry. Simulations were carried out in order to determine the:

1. Effects of firing a variety of weapons from numerous positions both in terms of range from the vessel and angle off the bow.
2. Likely penetration into the bridge.
3. Likely secondary fragmentation resulting from the shattering of windows.

Subsequent simulations were conducted with the vessels being hardened, firstly with bridge windows protected with shatterproof film, and then again with the steelwork reinforced.

Recommendations (section 6) to increase a vessels protection are based upon conclusions of the study.

This Paper has been developed to highlight the results of the study to promulgate recommendations relating to the hardening of the bridge structure, which may be considered both for existing tonnage and new build vessels.

2. Executive summary

The study used computer software to simulate the effects of an attack. It looked at the effects of weapons commonly used in attacks (including AK-47s and RPG-7s) against the bridge of a variety of tankers (45,000dwt MRX, 115,000dwt AFROMAX, 300,000dwt VLCC and 160,000m3 LNGC).

Standard bridge designs built from 7mm mild-steel plating and plate-glass windows were initially explored. The exercise was then repeated using additional layers of protection designed to reduce the exposure and vulnerability for personnel on the bridge.

Phase one: The first level of protection added was to prevent window fragmentation if hit. This could be achieved using several methods such as shatterproof film, or the use of laminated glass.

Phase two: Preventing window fragmentation, plus creating a bridge structure that met the agreed standards of ballistic resistance by 7.62mmx39mm assault rifle fire. See section 3.2 for weapon descriptions, and the Annex for the European Standards and Underwriters Laboratory Standards (US).

The study showed that it is possible for all of the threat weapons (except the 5.56mm round) to cause crew fatalities from secondary fragmentation on an unprotected vessel.

With a hardened vessel the probability of a crew member being killed can be reduced considerably by preventing the windows from fragmenting. In addition, glazing the bridge windows with laminated glass manufactured to EN 1063, UL 752 or equivalent ballistic resistance standards can prevent penetration of a round up to 7.62mm.

The application of armour protection to the bridge resulted in only a small additional reduction in crew vulnerability, notably when attacked by 12.7mm bullets, the heaviest calibre weapon tested.

Based on the results of this study a package of protective measures are recommended.

Figure 2.1 *Double chain link fence*

Immediate measures

- Ensure that bridge windows do not shatter upon impact causing secondary fragmentation. Check that the glass is either laminated to a minimum Standard, (EN 1063 BR6 or its equivalent as discussed in the Annex to this Paper), or that a shatterproof film is attached to reduce the likelihood of glass fragments, this being of a comparable Standard. While noting that the study simulations only modelled fragmentation from glass (rather than other lining materials found on a bridge of a ship) ensuring that bridge windows do not shatter upon impact is the most important single measure found to limit injuries to bridge crew.
- Fit RPG protection to the bridge wings, either using proprietary net technology or a double chain link fencing arrangement. This must be used in association with a policy of keeping crew protected inside the superstructure to limit injuries caused by fragments from externally detonating rockets.

Longer term measures:

- Add armour protection to the bridge. Protection against 7.62mm bullets can be afforded by an equivalent of 15mm of Rolled Homogeneous Armour (RHA). This might be achieved by bolting 10-12mm of RHA to the outer faces of the existing bridge structure. If armour is added to the bridge there will be a risk of spall, (fragments of plating), from the armour if it is attacked by a more severe threat than the protection is designed to defeat. This can be mitigated using a spall liner as the innermost layer of material inside the bridge. Overall the additional weight of armouring the bridge of a vessel in this way could amount to between 4-6 tonnes and cost between £25,000 and £40,000 to purchase.

The longer term measures may be considered at the design stage of a new build vessel. Cost implications could be mitigated to some extent by incorporating the hardening of the bridge structure as a shipyard standard cost, rather than an owners requested additional requirement. Weight considerations can also be mitigated by use of Kevlar or similar, however while weight is considerably reduced, cost is proportionally increased.

3. Study parameters

3.1 Vessels modelled

The phased study used computer models of:

- A 45,000dwt product tanker in the laden condition with a height of eye of 22.4m above the waterline
- A 115,000dwt Afromax tanker in the laden condition with a height of eye of 19.8m above the waterline.
- A 300,000dwt VLCC in the laden condition with a height of eye of 26m above the waterline.
- A large LNG carrier of 160,000m3 capacity with a height of eye of 30m above the waterline.

All vessels were modelled upon standard bridge designs taken from existing ships plans, and were manned by four personnel – the master and helmsman close to the front centreline of the bridge, a lookout on the starboard side of the bridge and an Officer of the Watch at the chart table to the rear of the bridge.

The vessels were modelled using standard construction techniques with the superstructure being 6-7mm steel and bridge windows being annealed (heat treated) glass. The models also included the protection offered from incoming fire by the decks immediately below the bridge, and by external structure such as bridge wings.

The description, as given above, was used to determine the vulnerability to weapons upon an unprotected bridge, and the results are given in section 4.1.

3.2 Weapons used to determine vulnerability

The study simulated an attack from a range of weapons and rounds typically carried by criminals (see table 3.1). The inclusion of a 12.7mm heavy machine reflects usage in some parts of the world, notably the Gulf of Guinea, and the possibility of use on mother vessels in East African piracy.

Table 3.1 shows the weapons and associated munitions used in the study. This Paper will not attempt to explain differences between ball munitions and armour piercing since, from the mariner's perspective, it is irrelevant. However it was necessary to include both munition combinations in the study in order to reach informed conclusions about the standard of protection in place and to determine improvements that could be made.

Weapon	Round	Muzzle velocity (m/s)
M16	5.56mm x 45 Ball	930
M16	5.56mm x 45 Armour Piercing	930
AK47	7.62mm x 39 Ball	725
AK47	7.62mm x 39 Armour Piercing	725
DhSk (heavy machine gun)	12.7mm x 108 Armour Piercing	825
RPG 2	HEAT (High Explosive Anti Tank)	N/A
RPG 7	HEAT (High Explosive Anti Tank)	N/A

Table 3.1: *Weapons and associated munitions used in study*

3.3 Parameters used for simulated attacks

Attacks from the range of weaponry described above were simulated at distances from the vessel of 75m, 150m, and 400m. In addition, the attacks were made at an angle of 45 degrees and 90 degrees off the bow, and on the beam. All modelling was based upon the weaponry being fired from a small fast craft and the angle of elevation is important when determining the results. It should be noted that the above is relevant to both sides of the vessel.

The simulation was based upon a single round of ammunition with no account being taken of multiple bullet strikes. The results however did take into account the effect of fragmentation, both from bridge windows and, to a lesser extent, internal bulkheads.

Figure 3.1: *Attack skiff*

4. Results of the study

4.1 General comments

Tables 4.1 and 4.2 give the probability of a fatality expressed as a percentage, for the following scenarios:

- Vessels with an unprotected bridge.
- Vessels with bridge windows protected.*
- Vessels with bridge windows protected and adjacent bridge superstructure hardened.

** Bridge Window Protection refers to the fitting of shatterproof film to the bridge windows to prevent secondary fragmentation.*

In each scenario an attack on the beam offered limited additional protection from the bridge wings which reduced the ability of the ammunition to penetrate the bridge superstructure with the exception of the heavy machine gun (12.7mm) and the RPGs. In all cases the 5.56mm ball ammunition was insufficient to penetrate any of the bridge structure.

It should also be noted that the height of eye of the bridge, and the length of the bridge wings/size of the bridge were also factors. In general, a shorter bridge wing and a reduced height of eye offered less protection.

The study showed that as range increases there is a drop in the impact velocity of the round, and thus a reduction in the ability to penetrate the bridge superstructure. Range does provide the attacker with a superior line of sight to the vessel's bridge and an increased likelihood the round may be accurate. Conversely when the attacker is close to the vessel the steeper angle can encounter more obstacles prior to reaching the bridge superstructure and can limit penetration to a small corner of the bridge itself. The study also took into account the effect of the angle of impact of a projectile and whether it would ricochet. If so then the possibility of penetration was considered, given the reduced velocity.

For an RPG, the weapon detonates on impact. The effective range of an RPG2 is approximately 200m in a direct line, whereas an RPG7 has an effective range of 800-900m. An RPG has a high penetrative capability and standard steelwork offers little protection. In addition, if the RPG detonates on contact with the bridge structure, then lethal fragments are generated which can travel more than 100m.

The majority of RPG rounds are designed to detonate upon impact. Upon impact the shaped charge within the warhead of the RPG detonates to forms a very high velocity molten projectile that can penetrate the target, and is capable of penetrating steel. Proprietary RPG netting and double chain link fencing are not designed to stop detonation, but instead to initiate it to prevent it from taking place against the target. If the detonation of takes place even a very short distance away from the target it has the effect of reducing or stopping the penetration of the target.

For an unprotected bridge the effect of shattering of bridge windows and internal bulkheads was considered. The model used the basis that if the window fragments, then the effect will be for glass, over a 60cm diameter to extend out over an arc of 30 degrees.

4.2 Unprotected bridge

Table 4.1 shows the probability of a fatality to a single crew member upon the bridge when subjected to a single round from the various weapons as discussed in section 3.2. The probability is expressed as a percentage.

Table 4.1: *Results for an unprotected Bridge*

Results for an unprotected Bridge

	90 degrees from the bow			45 degrees from the bow		
	75m	150m	400m	75m	150m	400m
5.56mm ball	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5.56mm AP	0.0%	3.2%	3.2%	11.8%	1.9%	0.0%
7.62mm ball	0.0%	3.2%	3.2%	11.9%	0.0%	0.0%
7.62mm AP	0.0%	28.5%	17.8%	11.9%	25.1%	39.1%
12.7mm AP	35.1%	30.2%	36.0%	21.0%	26.4%	43.6%
RPG2	36.2%	32.6%	N/A	21.0%	31.1%	N/A
RPG7	36.2%	32.5%	38.0%	20.9%	31.2%	43.6%

Table 4.1: *Results for an unprotected Bridge*

4.3 Bridge windows protected

Table 4.2 shows the probability of a fatality from fragmentation when the bridge windows have been protected. The probability is expressed as a percentage.

Table 4.2: *Results with Bridge Windows protected*

Results with Bridge Windows protected

	90 degrees from the bow			45 degrees from the bow		
	75m	150m	400m	75m	150m	400m
5.56mm ball	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5.56mm AP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7.62mm ball	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7.62mm AP	0.0%	1.1%	0.0%	0.8%	2.7%	0.0%
12.7mm AP	1.3%	1.1%	4.8%	2.6%	5.4%	8.0%
RPG2	3.9%	3.4%	N/A	0.0%	5.4%	N/A
RPG7	3.9%	3.4%	6.0%	0.0%	5.4%	8.0%

Table 4.2: *Results with Bridge Windows protected*

4.4 Bridge windows protected and superstructure hardened

Table 4.3 shows the probability of a fatality when the bridge windows have been protected from fragmentation and the vessels have been fitted with armoured steel plate (13-15mm RHA). The probability is expressed as a percentage.

Table 4.3: *Results with Bridge Windows protected and superstructure hardened*

Results with Bridge Windows protected and superstructure hardened

	90 degrees from the bow			45 degrees from the bow		
	75m	150m	400m	75m	150m	400m
5.56mm ball	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5.56mm AP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7.62mm ball	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7.62mm AP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
12.7mm AP	1.3%	1.1%	4.2%	1.7%	5.4%	1.1%
RPG2	3.9%	3.4%	N/A	0.0%	5.4%	N/A
RPG7	3.9%	3.4%	6.0%	0.0%	5.4%	8.0%

Table 4.3: *Results with Bridge Windows protected and superstructure hardened*

5. Conclusions

The risk of incurring fatalities through fragmentation is far greater than the risk of impact by a projectile.

The results of the study clearly demonstrate the following:

- The risk of a fatality in a vessel where the bridge windows have been protected is considerably reduced (in percentage terms) compared to a vessel with no bridge protection.
- The additional risk reduction achieved by hardening the steelwork is negligible, with the exception of the 12.7mm DhSk heavy machine gun.

An attack using an RPG would be expected to cause increased vulnerability. In tests conducted although RPG fire was able to penetrate the armoured bridge, the windows did not shatter inwards causing fragmentation. Secondary fragmentation was the dominating result. The absence or reduction of primary fragmentation gives a lower probability of a fatality. In order to provide effective crew protection from an RPG attack to the bridge, the fitting of RPG netting or double chain link fences is recommended. This provides a barrier preventing the ordnance striking and detonating on the bridge structure, mitigating the risk of fragmentation injuries to the crew.

6. Recommendations

The results of this study enable recommendations for both existing vessels and vessels to be built.

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6.1 Recommendations for Existing Ships

In modifying an existing vessel, the simplest and most effective protection for the bridge is the installation of shatterproof film to the windows. As a guide it would cost in the region of £2,000 to protect the bridge windows of a single vessel.

The conclusions of the report only show a marginal improvement of protection if the superstructure bulkheads are hardened. Bolting on of 10mm RHA plating to a ballistic standard that would defeat an AK47, (EU Standard 1522 – FB6) would cost in the region of £25,000 - £40,000, and would incur additional weight of approximately 4-6 tonnes. Full protection may not be cost effective. However a partial installation, carefully sited may be beneficial, for example on the bridge wing area where it may provide additional protection from incoming projectiles on the beam of the vessel.

Existing vessels may provide additional protection against an RPG by fitting either proprietary net technology around the outer edges of the superstructure deck, or by fitting double chain link fencing. The former is available from the majority of defence manufacturing companies but is expensive. The latter is effective and cheap to install.

6.2 Recommendations for New Build Tonnage

For a new build vessel the following protective measures should be considered at the design stage.

- Bridge windows, bridge wing doors and all accommodation portholes could be fitted with windows that are protected to EU Standard EN 1063 BR6.
- The bridge superstructure could be designed to provide ballistic resistance standards offering protection against rounds up to 7.62mm x 39 (EU Standard 1522 FB6). This would involve 15mm RHA in lieu of the existing 7mm mild steel. Should weight considerations make this undesirable then Kevlar could be used, but weight savings would be countered by additional cost.
- Bridge wings and the bridge front could be constructed with the ability to ensure that fitting of either RPG netting or double chain link fence is made simple and portable.

Annex – Ballistic Standards

There are a number of ballistic standards available, but the following are the more common ones which may be considered:-

European Standards All ballistic testing for ballistic resistant doors, windows, and other materials is conducted to Euro Standard EN 1522 (the test method is EN 1523). In addition, any security glazing testing incorporated in these materials must comply with EN 1063.

The standards define type of weapon and calibre in seven categories from pistols up to armour piercing rifles. For ballistic resistant materials the classifications are FB1 to FB7 and for glass the classifications are BR1 to BR7. There is an additional classification as to whether glass will splinter (S), or is shatterproof (NS).

Class	Weapon	Calibre	Bullet	Range
FB 1 / BR 1	Rifle	0.22 LR	Lead bullet, round nosed	10 metres
FB 2 / BR2	Handgun	9mm Luger	Full jacket bullet (steel), round nosed, soft core (lead)	5 metres
FB 3 / BR 3	Handgun	0.357 Magnum	Full jacket bullet (steel), cast nosed, soft core (lead)	5 metres
FB 4 / BR 4	Handgun	0.44 Rem Magnum	Full jacket bullet (steel), cast nosed, soft core (lead)	5 metres
FB 5 / BR 5	Rifle	5.56 x 45mm NATO	Full jacket bullet (copper), pointed nose, soft core (lead) with steel reinforcement	10 metres
FB 6 / BR 6	Rifle	7.62 x 51mm NATO	Full jacket bullet (steel), pointed nose, soft core (lead) with steel reinforcement	10 metres
FB 7 / BR7	Rifle	7.62 x 51mm NATO	Full jacket bullet (copper), pointed nose, hard cast	10 metres

The essential difference between FB6 and FB7 is that latter uses armour piercing bullets. Ballistic resistant doors, windows, and other materials would require protection to FB6/FB7 depending upon the type of ammunition being used, (armour piercing or not).

Underwriters Laboratory Standards (US) The ballistic standards are UL 752 and these range from Level 1 (9mm Luger) to Level 9 (0.30 Calibre – armour piercing),

The classification is similar to the European Standard

Class	Weapon (e.g.)	Ammunition
Level 1	9mm Luger/Super 38 Automatic	9mm Full Metal Copper Jacket with Lead Core
Level 2	0.357 Magnum	0.357 Magnum Jacketed Lead Soft Point
Level 3	0.44 Magnum	0.44 Magnum Lead Semi-Wadcutter Gas Checked
Level 4	0.223 Remington	0.30 Calibre Rifle Lead Core Soft Point (0.30-06 calibre)
Level 5	0.308 Winchester	7.62mm rifle Lead Core Full Metal Copper Jacket, Military Ball (0.308 calibre)
Level 6	9mm Uzi	9mm Full Metal Copper Jacket with Lead Core
Level 7	M-16 / AK47	5.56mm Rifle Full Metal Copper Jacket with Lead Core (0.223 calibre)
Level 8	M-14	7.62mm Rifle Lead Core Full Metal Copper Jacket, Military Ball (0.308 calibre)
Level 9	M-2 30-06	0.30 calibre full metal jacket, armour piercing

The thickness of the materials being used will depend upon the type of material being considered and the small arms which are being defended against. Materials may be steel, Kevlar, or a composite aggregate. In general the more lightweight and thinner materials will prove to be more expensive. When assessing the level of protection required it is important to determine the suitability and effectiveness of the materials for the intended use, location, and the maximum length of time for which the citadel is intended to be used, which may differ dependent upon the vessels trading pattern(s).

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