# OBSERVATIONS FROM THE SHOCK TRIALS OF THE INSHORE MINEHUNTERS.

The careful textbooks measure,
(Let allwho build beware)
The load, the shock, the pressure,
Material can bear,
So when the buckled girder,
Lets down the grinding span,
The blame of loss or murder
Is laid upon the man,
Not on the stuff - the man.

RUDYARD KIPLING 1935 (courtesy RN Shock Manual)

## INTRODUCTION.

The Inshore Minehunter (MHI) HMAS Shoalwater is the first (and so far only) naval vessel to be shock trialled within Australia. The conduct of this trial, where the fully crewed and operational vessel was exposed to severe underwater explosions, was the outcome of many years planning within the RAN Design Branch. The first part of the paper gives an overview of the the phenomena of underwater shock and the work which goes into designing a naval vessel to it. Mention will then be made to the way these rules were applied during the design of the MHI. The second part of the paper will then review the process of shock testing which was applied to the MHI to ensure that the vessel met its specified shock requirements.

## PART ONE. SHOCK DESIGN AND PHENOMENA.

### SHOCK DESIGN.

1. The ideas outlined below are only a very brief overview of design underwater shock but it is hoped they will give the reader a general feeling for the importance and complexity of a subject about which there is a dearth of easily available published information.

2. The first question to ask is what is a shock? Shock is a phenomena characterised by energy release over a short duration and of sudden occurence. More formally "a simple shock may be defined as a transmission of kinetic energy to a system which takes place in arelatively short time compared with the natural period of oscillation of the system while transient phenomena (also termed complex shocks) may last for several periods of oscillation of the system".

3. The next question to ask is why design a ship for shock? The answer is the primary aim of control of shock in ships is to allow the vessel to meet its operational requirements. The level to be designed for depends on the vessels intended use. For combatant naval vessels the need for shock design will normally be extensive. The actual level of shock to be designed for is dependant on operational requirements and is often defined by means of standard military specifications (eg in the US Mil-Specs, and in the UK DefStans).

4. Wartime experience and experimental work has shown in the vast majority of instances it is non contact underwater explosions which cause the greatest shock damage. Therefore it is normally this case which receives the predominant design effort. However the other causes of shock such as air blast from incoming weapons or from discharge of ones own weapons should not be ignored because they may be of primary cause of concern in specific circumstances.

HISTORY

5. the potential for underwater explosions to damage a ship has been recognised from at least the late nineteenth century. however it was World War II (WWII) where the damaging potential of non contact explosions and the resultant shock pulse was first fully appreciated.

6. In the UK this lesson was sharply taught by damage to the cruiser HMAS Belfast. A non contact explosion caused only minor hull flooding of the ship but she became immobile and inoperable due to major equipment damage. As a result of this experience the British undertook urgent research into the problem and a number of adhoc design methods and solutions were developed. These included the development of the first shock test machines (with parts reputedly scrounged from local scrapyards) which created their shock pulse by swinging a large hammer against an anvil onto which was mounted the equipment under test. It is interesting to note with limited further development these machines are still used for the most commonly quoted equipment shock test US Mil Spec 901.

7. Post war much research continued and immediately post war a large number of full scale trials were conducted using the abundant supply of spare vessels. A major topic of research in the immediate post war period was the extension of knowledge gained of the shock effects from conventional explosives out to the nuclear case.

8. At the present time research continues and much effort is now put into developing effective scientifically rather than empirically based design tools. An important factor which is now given major consideration is the "probabilistic" nature of shock problems which arises from the infinite number of attack geometries which can arise and the large variety ways which details in a structure effect its shock response. The probabilistic nature of the problem means that it is important that design methods adopted do not overmatch the design analysis procedures to the available database.

PHENOMENA OF UNDERWATER SHOCK.

9. Before we can effectively design for underwater shock we need to have an appreciation of the phenomena involved. Over the last 70 - 80 years (and especially during WWII) much research has been conducted into what physically occurs during an underwater explosion. The process of underwater explosions can be loosely summarised as follows:

(i) The explosive initially exists as a solid in the body of water.

(ii) On detonation (approximately 1/20,000 second) the explosive becomes a gas bubble at a very high pressure (typically in the order of 1 million PSI) occupying the same volume as the original solid explosive.

(iii) Because this gas bubble is instantaneously at a very high pressure with respect to the surrounding water a shock wave is passed out into the water in the form of a spherically spreading compression wave. This wave spreads out from the site of detonation initially at very high velocity but then falling to the speed of sound in water (1530 m/sec) within a few charge diameters. The spreading then continues at this velocity.

(iv) The pressure in this shock pulse rises almost instantaneously (1 ten-millionth of a second) to a maximum and then decays exponentially with time. Due to the spherical spreading of this shock pulse the peak pressure seen at a distance from the charge will not be the same as close to the charge but will be reduced by a factor approximately proportional to the inverse to the distance from the charge.

(v) This shock pulse obviously has energy and as it moves outwards this imparts a velocity to the water particles it passes through of approximately 1.5 ft per second per 100PSI of peak pressure (typical peak pressures are in the range of 1000 to 10,000 PSI). The water therefore gains considerable momentum.

(vi) As the shock pulse moves outwards the gas bubble which initiated begins to expand since it is at a very much higher pressure than the water surrounding it. This expansion initially starts slowly but then gains velocity until it is moving so fast that the water at the interface with the bubble has so much momentum it causes the bubble to overshoot the equilibrium position. This in turn leads to the pressure within the bubble falling below hydrostatic .

(vii) The increasing negative pressure eventually halts the expansion and the bubble begins to contract. Again the water gains a momentum and again the bubble will overshoot the equilibrium position and contract until the gas pressure within it is very high again. This high pressure then causes a secondary pressure pulse to be transmitted through the water. This secondary pulse will typically have a peak pressure of 10-15% of the initial pulse but it can be very important in damage mechanisms.

(viii) During the above expansion contraction process the bubble will usually be rising towards the water surface.

(ix) The gas bubble oscillations continue until all the energy available within the bubble (Approximately 50% of the total) is used up or the bubble breaks the through the water surface.

(x) The proximity of a water surface has a major influence on the shock pulse. When the pulse hits the water surface it is reflected as a tension pulse. This reflected tension pulse will then interact with the original compression wave causing cancellation of that wave in certain regions.

10. The actual pressure pulse seen at the ship will be an amalgam of the main pressure pulse and the surface cut off effect plus any bubble pulses. It may also contain elements due to other phenomena such as ground shock, bottom reflected pulse and bulk cavitation at the ships structure as it reacts to the shock load. The intrusion of these additional phenomena mean that the actual pressure pulse seen at the ship will be very complex in shape.

11. The sub surface phenomena described above lead to a number of effects being visible on the water surface:

(i) As noted above, when the pressure pulse strikes the water surface it is reflected as a tension wave. The passage of the shock at the water surface has given the water particles a velocity. Since water can only withstand a limited amount of tension the water at the surface is thrown upwards whilst the water just below the surface forms a bulk cavitation region. These effects are greatest immediately over the centre of the charge where the peak pressure at the surface will be a maximum and then falls of as you move outwards. The result of this activity is the white spray dome seen over underwater explosions.

(ii) As noted above the gas bubble tends to migrate towards the water surface. This occurs at considerable velocity and if breaks the surface before all its energy is expended it will throw spectacular plumes of water through the air. These normally burst through the spray dome but can occur some time after it depending on the particular charge geometry used.

SHIP RESPONSE

12. The below can only be considered a very brief and simplified summary of ship response to underwater explosions.

13. The shock pulse as we have seen initially consists of an almost instantaneously rise in pressure. When this pressure pulse strikes the ship it very abruptly imparts a motion to the ship plating. The initial motion is essentially caused by the plating being pushed by the water which has gained a significant velocity due to the pressure pulse. The pressure pulse however decays very quickly so soon after the initial motion of the plating has occurred the plating starts to outrun the water. As water cannot withstand tension bulk cavitation behind the plate occurs. The plate eventually stops moving inwards slows to a halt and then begins to return. At some point during this process the plating will come into contact with the afterflow of the original pressure pulse which will then reload the plate. Additionally some time after the initial motions have decayed the bubble pulse will arrive and reload the plate thus restarting the process. Depending on the severity of the shock pulses the plate may remain in the elastic region during this motion, it may move into the plastic region leading to permanent deformations or it may fail.

14. Where a small explosive charge is detonated close to the ship the effect will be localised plating damage along the lines described in the paragraph above. However where a larger charge at a greater distance from the hull is detonated the whole ship hull girder will be excited. In this case the length of the ship will see different peak velocities dependant on the distance from the explosion and the angle of attack. This variation combined with the varying section area of the ship over its length will lead to bending of the hull girder. It will also obviously lead to pitch and heaving of the hull. Bending of the hull and its response will be further affected by the later arrival of the bubble pulses. If the stresses due to this hull bending become excessive the ship will break its back.

15. The shock motion of the ship structure is obviously imparted to the internal structure of the vessel and to equipment attached to this structure. This is the cause of equipment damage. By nature of the loading motions are normally severest in the vertical plane and then followed by athwartships and finally fore and aft.

16. As may be expected as the shock pulse is transmitted through the ship it is attenuated. Therefore shock accelerations seen by equipment mounted high above the water line or inboard in a ship will obviously be less than for those equipments mounted on the shell.

DESIGN PROCEDURES.

17. When designing a vessel to survive shock it is neither necessary or sensible to design everything to survive the same shock levels. RAN philosophy as used on the MHI, and in line with overseas navies procedures, usually specifies three increasingly severe shock levels:

(i) Operational capability - Up to a specified shock level the vessel must be capable of undertaking its design role. Note it is usually acceptable for purely domestic equipment to fail, at some lower level as long as it does not become a danger at this level.

(ii) Propulsion and Control -Up to a higher level the vessel may not be able to undertake its role but it is capable of returning to port under its own power.

(iv) Hull Lethality - Below this level the ship must stay afloat. Beyond this level loss of the ship is accepted.

18. The actual shock levels specified for each of these levels may vary from class of ship to class of ship and will be dependant on the vessels combat importance.

19. Design methods adopted to ensure equipment and structure can survive the shock loads generally fall into 1 of 3 camps namely:

(i) Quasi Static - that is designing equipment to an equivalent static acceleration level. This is the earliest, and still most commonly used, shock design method. When using it the following should be borne in mind. Firstly the equivalent static acceleration used has little connection with the actual accelerations seen under shock it is simply a number which practical experience has shown gives adequate shock protection to most equipment. Secondly that ideally these methods should not be used for equipment on resilient mounts because no account is taken of the dynamic characteristics of the mount (practicality often means this requirement is often not possible to achieve).

(ii) Quasi Dynamic - here strain energy in a structure is equated to maximum kinetic energy input into the structure. This method assumes a knowledge of appropriate velocity levels.

(iii) Fully Dynamic - here the full acceleration time history for a structure is used in the design process. Requires a detailed knowledge of the likely shock input and also design methods (eg finite element or similar) capable of accepting a dynamic input when analysing a structure.

20. When designing for shock the following general considerations should be borne in mind:

(i) Materials ,- should be ductile.

(ii) Weight - where possible should be minimised.

(iii) Stress Concentrations - to be avoided.

(iv) Unsupported Masses - Avoid cantilevers.

21. Some specific considerations to be borne in mind when designing hulls are as follows:

(i) Design to minimise the target area. - eg shallow draft

(ii) Avoid discontinuities in the structure eg big changes of the second moment of area of a hull girder.

(iii) Consider transmission paths - stagger bulkheads on successive decks.

(iv) Minimise hull openings.

(v) Avoid overhanging decks.

22. Likewise some specific considerations to be borne in mind for equipments are:

(i) Inherent Robustness versus Shock mounting (equals weight versus space considerations)

(ii) Where shock mounting is necessary the practicality of rafting large amounts of equipment together.

(iii) likely equipment location - requirements will be less severe if it can be mounted inboard of the shell and/or high up in the ship.

(iv) Minimise weight

(v) Allow adequate clearance for shock deformation.

23. After designing a piece of equipment for shock it is usual to test the item to see if it actually achieves the design requirements. This is called proof testing and is usually done using a shock test machine or for very large equipments a shocktest barge.

24. Whilst it is possible to shock test all items of equipment going into a ship to prove their shock hardness, and to design a hull along conventional lines so that there is good confidence in its inherent strength this may not be sufficient to ensure that the finished ship meets its planned shock performance. A ship is a complex assembly of many items and under shock these items may interact in many unpredictable ways. For this reason it is normal practice in many navies to conduct ship shock tests of the first of class of major warships. This shock testing involves subjecting the completed and operational ship to a controlled explosion of a specified level. The ship shock test of the MHI which is described in the second part of this paper is one such test.

# PART II SHOCK TESTING THE MHI

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## INTRODUCTION

1. The Royal Australian Navy is currently evaluating a new class of inshore minehunters (MHI) designed by the Naval Engineering Services Branch. To fully evaluate the design of these vessels, two prototypes have been built. One of the major milestones of the evaluation period was achieved with the successful shock trialing of the second of the two prototypes, HMAS SHOALWATER. This trial which took place at Halifax Bay, North Queensland in November/December 1987.

## BACKGROUND

2. Before discussing the shock trial of HMAS SHOALWATER in detail, it is intended to give a brief review of the development work which took place prior to the trial.

3. Initial shock trial work centred on proving of GRP and foam sandwich hull materials would meet the RAN's specified shock requirements. To this end a series of small flat panel shock tests were commenced in 1977. Fig 1 shows typical details of the flat panels and their testing method. In all, 38 panels were tested. The initial panels in this series were used to evaluate different types of materials, and the later panels to investigate materials from different manufacturers and construction details. These panel tests provided useful data at relatively low cost,and in a quick timescale.

4. To gain data which was directly comparable with overseas results, a large flat panel (3m x 3m) was built of the MHI's proposed construction material and sent to AMTE Durfermline UK for underwater shock testing in 1979. The results from this panel indicated that the GRP foam sandwich construction technique would give the required shock resistance.

5. To further validate the proposed materials plus obtain information on various equipment mounting details, in 1980 a full scale shock section of the centre portion of one hull was built (Fig 2). This test rig was then extensively shock tested using explosive charges and proven to meet the RAN's required shock standard.

6. After the decision to build the MHI was confirmed, planning for the ship shock trial began to be developed in earnest. Since this was Australia's first ship shock trial, and was being developed from a minimal base of practical experience, it was decided the trial should be developed in the following 3 Phases:

Phase 1: Shock Trial proving of the proposed ship instrumentation package.

Phase 2: Logistics trial to prove methodology to be used to support Phase 3.

Phase 3: Ship Shock Trial.

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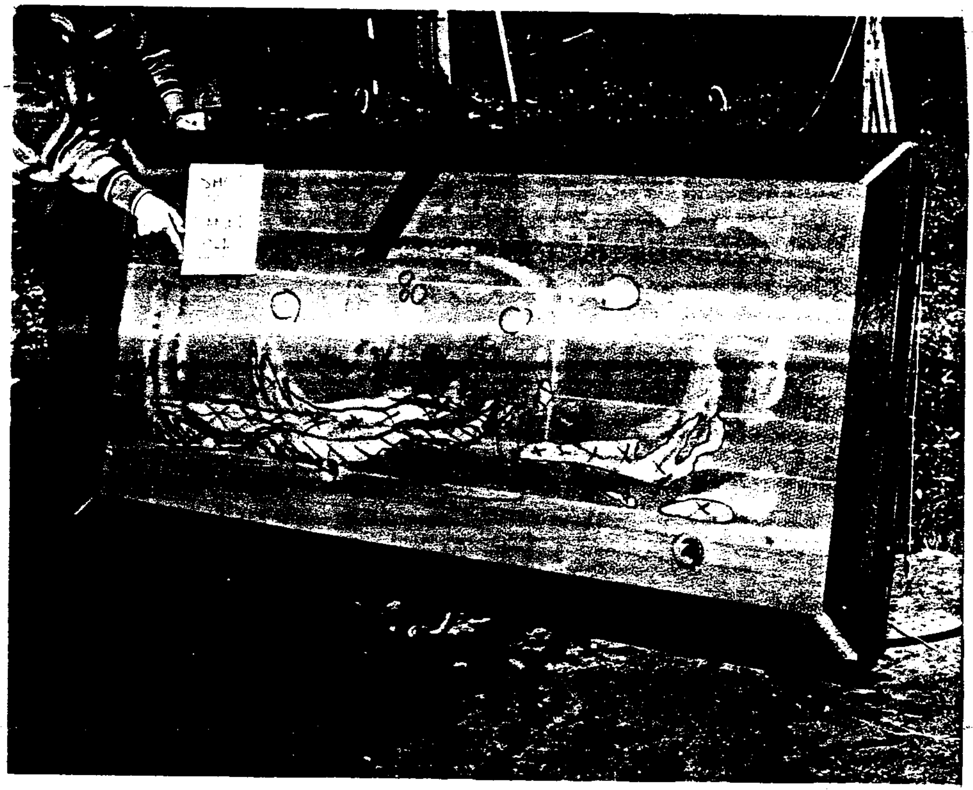
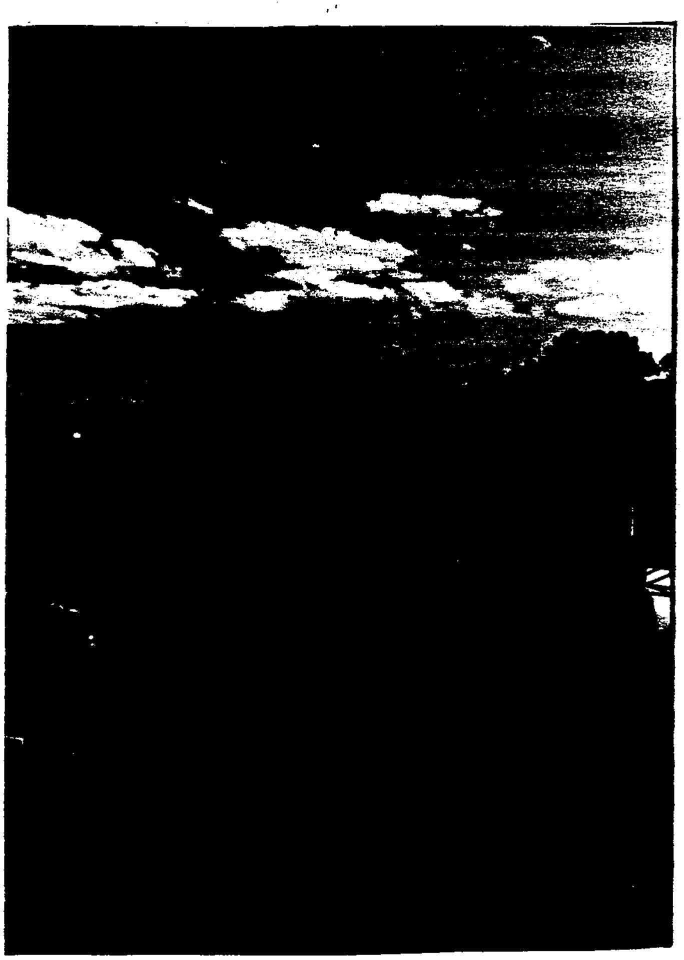
FIG 1 : FLAT TEST PANELS





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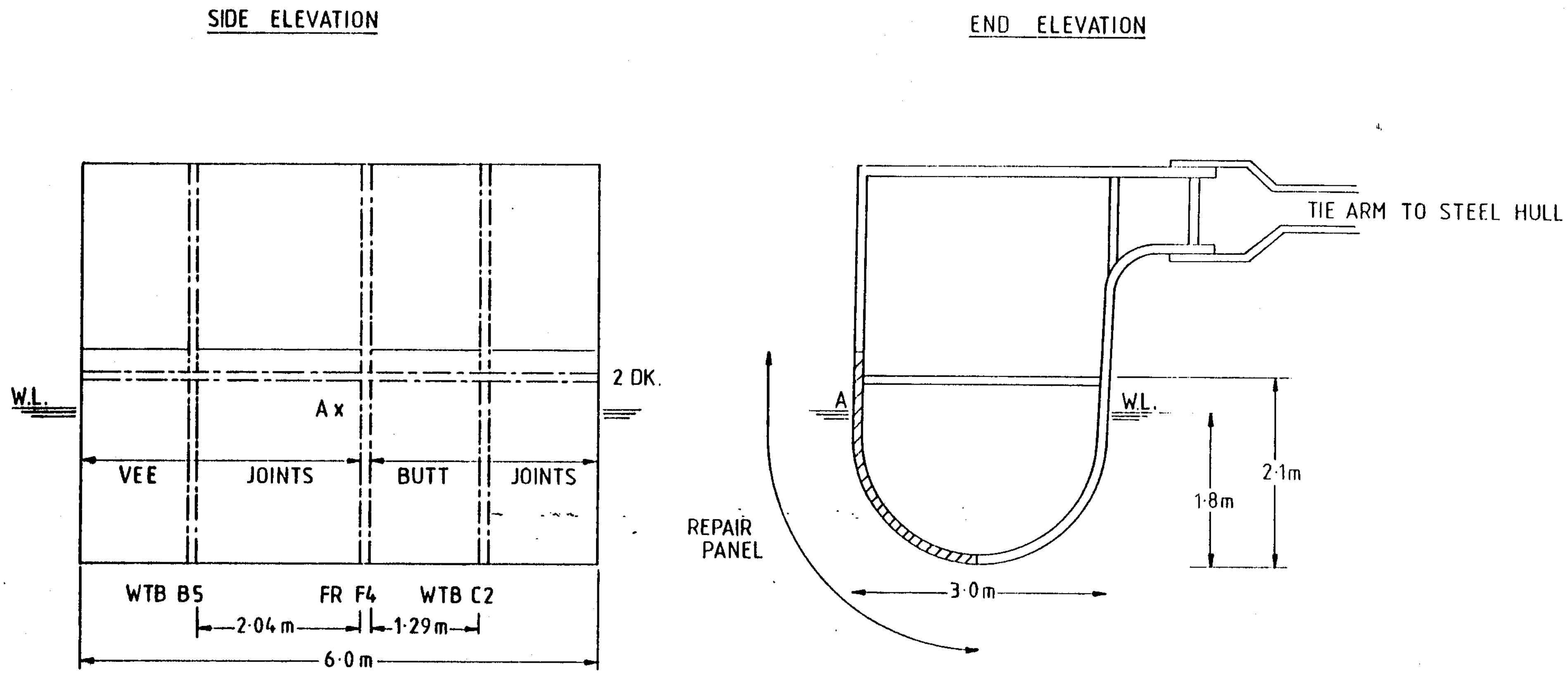


NOTE: HORIZONTAL STANDOFF FOR EXPLOSIVE CHARGES MEASURED PERPENDICULAR TO RIG SIDE AT POINT A.

fig 1 G.R.P. Test Rig - (Showing Repair Panel For 1985 Trial)

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7. Phase 1 took place in 1985 and successfully validated the proposed shipboard instrumentation. This was done by mounting the instruments on the full scale test section, which had been refurbished for this trial, and then extensively shock testing the rig. This test also provided further information on the shock performance of the hull materials, construction details, and also validated proposed hull repair techniques.

8. Phase 2 took place in 1986. It was originally intended that this would purely be a logistics trial to identify potential problems of conducting a shock trial at a comparatively remote site. Later an additional purpose was added, this was to investigate the characteristics of the seabed explosions at the trial site.

## MHI SHOCK TRIAL

9. After completion of the Phase 2 Shock Trial planning for Phase 3, the Ship Shock Trial, gained momentum. The objectives of this trial were as follows:

a. To test the MHI to the requirements of A NATO STANDARD.

b. To test the MHI to the operational shock level of the RAN's Approved Ship Characteristics (ASC). MHI specified machinery and equipment necessary for continued minehunting operations will not sustain damage beyond the capabilities of ship staff to repair within A SPECIFIED TIME using onboard spares. Purely domestic equipment does not have to continue to function but must be restrained so that it does not become a missile that could cause damage to personnel or operational equipment.

c. To assess the effect of quartering shots and associated torsional whipping on the catamaran structure.

### Instrumentation

10. To meet the above objectives it was necessary, early in the planning stages, ~~to identify what~~ instrumentation would be required on the ship. After extensive discussions between the Directorate of Naval Ship Design (DNSD) and Material Research Laboratories (MRL) (part of the Defence Science & Technology Organisation) and after consideration of the space constraints on the MHI the following package selected:

22 Strain Gauge Channels
10 Accelerometer Channels
3 High-Speed Cine' Cameras
4 Underwater Pressure Gauges
5 Velocity Gauges

11. The selection of instrument positions were based on the following general criteria:

a. Strain Gauges: Placed in areas predicted to have high strains (eg turn of cross structure fore and aft, stiffeners and shell below WL).

b. Accelerometers: The majority were placed in a vertical line amidships in order to measure the attenuation of the shock pulse vertically through the structure. Accelerometers were also placed fore and aft on 1 deck to measure the varying shock response along this deck. Additional accelerometer positions were provided to measure transverse and fore and aft accelerations at two locations, and at various equipment locations.

c. Pressure Gauges: The four pressure gauges were hung over the ship side nearest the blast. One gauge was positioned forward, two amidships, and one aft. The gauges were hung so that they were several metres out from the ship's side (to avoid reflected pulses over the time of interest) and were at keel level. These were used to determine stand-offs and other shock pulse parameters.

d. High Speed Cine Cameras: Three of these cameras were available. One was deployed on a support ship to film the MHI and the explosion plume. The other two were moved around the MHI to view the motions of various systems and equipments under shock loading.

e. Velocity Gauges: Although not part of the main instrument package, five velocity gauges were also fitted to the MHI for the duration of the trial. These were positioned alongside accelerometers and were fitted to give comparative results and to allow development of software by MRL for interpreting velocity gauge results.

## Explosive Charges

12. Early in the planning of the trial considerable attention was given to selecting the appropriate charge size to be used for the ship shock trial. The eventual decision was to test the MHI with two sizes of charge. These represented the opposite ends of the likely range of threat mine sizes.

## Shot Programme

13. The programme for the shock trial called for eight shots to be achieved (with a possible extra two available if things went ahead of schedule). This programme was based on working six days out of seven and achieving one shot per day. It was realised that this programme was very tight but it was hoped it could have been achieved. In the end external circumstances which delayed the start of the trial one week plus some poor weather during the trial resulted in only six shots being achieved. The planned and achieved shots are shown in Table 1.

14. As was discussed earlier the objectives of the trial were to test the ship to NATO STANDARD and then to prove its ability to withstand repeated shocks in line with its Approved Ship Characteristics. The first three shots (achieved) of the programme met the first requirement, whilst the last three substantially achieved the second. The last two shots of the trial were detonated off the ships quarters instead of abeam in order to investigate torsional whipping of the catamaran form.

## Damage To The Ship

15. The performance of the ship and its systems under shock exceeded expectations. A detailed list of damage incurred during the trial is included in Annex A. As can be seen this list is quite short. In summary the following can be said:

a. Structural: To assist location of damage, all GRP surfaces, with the exception of external surfaces and bulkheads and decks in accommodation and action areas, had been left unpainted. In the accommodation and action areas although all bulkhead and decks had been painted, the connections between them had been left unpainted.

After each shot and at the conclusion of the trial all these surfaces (including the inside of the cross structure) were inspected and no delaminations to shell or connections were found. Minor delaminations around 4 or 5 pipe hangers on the underside of 1 deck. were observed. These delaminations occured where self tapper screws went into the GRP. In all cases where this occured the initial delamination was about 100 $cm^2$ and did not increase on subsequent shots.

b. Mechanical: The major problem to occur in the mechanical area was the shutting down and inability to restart the engines after shot 2. Subsequent investigation by the Minehunter Support Group identified the cause as a dropped porting plate in the Propulsion Steering Unit (PSU). Rectification took only 2 hours and a modification prevented the problem re-occuring on subsequent shots. For all the subsequent shots the engines shut down during the shot but could be immediately restarted Otherwise mechanical systems showed minimal problems which did not affect ship operability.

c. Electrical, Communication and Weapons Systems. All these systems suffered only minor problems throughout the trial. The problems which did exist were generally caused by poor assembly (ie not using available locking devices) and were all rectified quickly. Redesign of some connections and fittings has now been made and will further enhance the system shock hardness.

d. General. Problems occured with some furniture suffering damage, light fittings coming off the deckhead, minor equipment coming off at fastenings, etc. All these problems had no effect on the ship operability and were quickly removed or rectified at site. Where considered desirable these items have now been redesigned to improve their shock performance.

16. As can be seen from the above the level of damage to the MHI was minimal, ~~and~~ with the exception of the engine problem at shot 2 (subsequently cured) none of them would have prevented the MHI continuing to operate.

Energy Level In Each Shot

17. The NATO STANDARD , does not require any proof that the shock pulse from a shot was of the level specified. However, to ensure that the MHI was tested to the required shock level, pressure traces were taken for each shot. From these traces the energy in the pulse and hence the shock factor seen by the ship has been calculated. This has proved that the MHI's shock test was in excess of the NATO requirements.

CONCLUSIONS

18. Based on site results and post trial analysis of the Shock Trial the following conclusions are drawn:

a. Minor damage did result from some of the shots. The majority of these did not affect operational capability. Those that did were either rectified and proven during the trial or, the deficiencies revealed have been easily correctable to ensure full shock resistance is achieved. Other minor non-operational type failures can also be easily rectified, if considered necessary.

b. Generally the Shock Trial was most successful and provides excellent confidence in the MHI's ability to withstand repeated shocks at their required operational level. Further, from correlation with previous tests, the MHI structure should be able to withstand much greater shocks (2-3 times testing level) before substantial hull damage and/or breaching occurs.

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## HMAS SHOALWATER - SHOCK TESTING PROGRAMME

### PLANNED PROGRAMME

| SHOT | LEVEL | CHARGE SIZE | ASPECT |
|---|---|---|---|
| 1 | 1/3 | SMALL | ABEAM |
| 2 | 2/3 | SMALL | ABEAM |
| 3 | FULL | SMALL | ABEAM |
| 4 | FULL | SMALL | ABEAM |
| 5 | 1/3 | LARGE | ABEAM |
| 6 | 2/3 | LARGE | QUARTERING |
| 7 | FULL | LARGE | QUARTER-ING |
| 8 | FULL | LARGE | AHEAD/ ASTERN |
| 9 | FULL | SMALL | QUARTER-ING |
| 10 | FULL | SMALL | AHEAD/ ASTERN |

### ACHIEVED PROGRAMME

| SHOT | LEVEL | CHARGE SIZE | ASPECT | COMMENTS |
|---|---|---|---|---|
| 1 | 1/3 | SMALL | ABEAM | Complies with NATO STANDARD Requirements |
| 2 | FULL | SMALL | ABEAM | |
| 3 | FULL | SMALL | ABEAM | |
| 4 | 1/2 | LARGE | ABEAM | To assess -Large V Small Charge -Quartering Shocks |
| 5 | FULL | LARGE | QUARTER-ING (STERN) | |
| 6 | FULL | LARGE | QUARTER-ING (BOW) | |

NOTES:

1. Level refers to the proportion of the full NATO STANDARD Requirement.
2. ABEAM shots were alternated from port to starboard.

TABLE 1 PLANNED VERSUS ACHIEVED SHOTS

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# PRELIMINARY SUMMARY OF SHOCK TRIAL DAMAGE

| SYSTEM | | DAMAGE | SHOT NO. | COMMENTS |
|---|---|---|---|---|
| HULL STRUCTURE | | MAJOR DAMAGE NONE | - | - |
| | | MINOR DAMAGE | | |
| | (i) | Escape Scuttles - opened after each shot and gradually distorted throughout the trial. | 1 to 6 | New Design Scuttle now fitted |
| | (ii) | Delamination at approximately five pipehangers (subsequent shots caused no increase in damage). | 2 | Not of sufficient size to require repair. |
| | (iii) | Delamination at mounting of 24v rectifier (subsequent shots caused no increase in damage). | 2 | Not of sufficient size to require repair. |
| | (iv) | Wood seats of Emergency Diesel Fire Pump and F.W. pump showed slight debonding from bedding compound. | 4 | No repair required. |
| | (v) | Minor items secured with "divilette" broke free (eg microphone box, handrails etc). | Various shots | Where necessary fastening arrangements have been upgraded. |
| | (vi) | Distortion of structural door hinges and brittle fracture of one hatch dog. | Progressive from shot 1 | Strengthening plates now incorporated in all hinges. Door dogs now made in a stronger material. |

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| SYSTEM | | DAMAGE | SHOT NO. | COMMENTS |
|---|---|---|---|---|
| PROPULSION SYSTEM | | MAJOR PROGLEMS | | |
| | (i) | Main engine stopped during shot and could not be restarted due to the PSU motor porting plate having dropped. Base Support Staff assistance required to overcome this defect. | 2 | Modifications made by Base Support Staff prevented this reoccurring during subsequent shots. |
| | | MINOR PROBLEMS | | |
| | (i) | Main engine stopped after all other shots due to temporary loss of hydraulic boost pressure. Immediate restart available. | 1, 3, 4, 5 & 6 | Modifications to boost system should have overcome this problem. |
| | (ii) | Minor leaks occurred at some flanges in S.W. and fuel transfer pipework. | 1 to 6 | Flange bolts tightened as required. |
| ELECTRICAL | | MAJOR DAMAGE NONE | | |
| | | MINOR DAMAGE | | |
| | (i) | Light bulbs failed. | 1 to 6 | Expected failure. |
| | (ii) | Light fittings dropped from deckhead - temporary securing was then arranged to prevent reoccurrence at subsequent shots. | 2 to 6 | Light fitting base plates construction was of varying quality. Redesign has been undertaken to prevent this problem reoccurring. |
| | (iii) | Approximately 50% of Automatic Emergency Lanterns failed to work after shot. | 2 | Due to poor maintenance. Cleaning and careful refitting of batteries prevented this being a major problem for subsequent shots. |
| | (iv) | Cable tray covers came off (temporary securings prevented this reoccurring in subsequent shots). | 2 | Permanent securing now arranged. |

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| SYSTEM | | DAMAGE | SHOT NO. | COMMENTS |
|---|---|---|---|---|
| ELECTRICAL (Cont'd) | (v) | Equipment using clip in type terminals (ie Navigation Light panel, air conditioning units, 24v Battery charger and Bridge switch panel) suffered intermittent problems of terminals pulling out). | 1 to 6 | Terminals have provision to be wire secured. This is now being utilised. |
| | (vi) | Brackets supporting PCB's in Navigation Light Panel cracked. | Not known which shot | Problem not considered significant enough to warrant redesign or modification. |
| | (vii) | Fan in transformer box failed. | 5 | Repaired at site - design of ventilation now modified. |
| | (viii) | Fuse in Static Frequency Converter popped out due to lack of retaining spring tension. | 1 | Repaired at site. |
| | (ix) | Screw type cable connections in 24v Battery Charger let go. Caused loss of 24v power. | 2 | Cables reconnected in 10 minutes at site. Modified connections now used. |
| COMMAND AND SURVEILLANCE | | MAJOR DAMAGE NONE | | |
| | | MINOR DAMAGE | | |
| | (i) | Port Navigation Light cracked lens. | 2 | Problems occurred where navigation lights were "stacked" on top of each other. Problem not considered significant enough to warrant redesign or modification. |
| | (ii) | One of the 3 mast head lights cracked. | 2 | As above. |
| | (iii) | Chart recording echo sounder came off bulkhead due to failed mounting plates (not refitted for remaining shots). | 2 | Mounting plates were inadequate. Chart recording echo sounder is now shock mounted. |

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| SYSTEM | | DAMAGE | SHOT NO. | COMMENTS |
|---|---|---|---|---|
| COMMAND AND SURVEILLANCE (Cont'd) | (iv) | Gyro units became unstable after each short and took sometime to restabilise. (Note "A" gyro removed after shot 2). | 2 to 6 | One gyro is now shock mounted. |
| | (v) | Miniranger aerial units dropped from mast (stronger mountings improvised for subsequent shots). | 2 | Improved mounting arrangements now installed. |
| | (vi) | Miniranger console on bridge became partially detached (stronger mountings improvised for subsequent shots). | 2 | Improved mounting arrangements now installed. |
| | (vii) | Fire detectors dropped off deckhead due to failure of securing rings (temporary securing arranged for subsequent shots). | 2 | Detectors in the Machinery Compartment which were fitted in a protective wire guard suffered no problems. Similar guards now fitted to remaining detectors. |
| | (viii) | Operational Lights dropped from Bridge and ORC deckhead (temporary securings arranged for subsequent shots). | 2 | Due to very small size of lights this is not considered a significant defect. |
| | (ix) | Skianti transmitter failed. | 3 | Restored by dealer at end of trial. |
| | (x) | Signal Lights on bridge wings fell out of storages and resistance boxes pulled off bulkhead (temporary securings arrange for subsequent shots). | 2 | Improved securing arrangements now fitted. |
| | (xi) | Helmsmans VCS console and Navigation Light panel loosened on mountings. | Progressive during shots 2-6 | Mounting bolts retightened at end of trial. |
| | (xii) | Wire connection to whip aerial broke. | 6 | Wire now provided with greater slack. |
| | (xiii) | Glass insulater on HF aerial broke. | 3 | Caused loss of bridge window due to it hitting window. Aerial now fitted with spring in halyard to prevent whipping of mast overstraining glass insulater. |

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| SYSTEM | | DAMAGE | SHOT NO. | COMMENTS |
|---|---|---|---|---|
| COMMAND AND SURVEILLANCE (Cont'd) | (xiv) | WEAPONS SYSTEM | | |
| | | (a) Apparent loss of part of transducer array due to failure of a PCB (believed to be caused by improper fitting). | 3 | Repaired at site by KAE Staff and worked for shot 6. |
| | | (b) Furniture in ORC disintegrated. | 3 to 6 | Stronger furniture now installed. |
| | | (c) A/C unit loss charge. | 3 or 4 | Recharged at end of trial - no permanent damage. |
| AUXILLIARY SYSTEMS | | MAJOR DAMAGE NONE | | |
| | | MINOR DAMAGE | | |
| | (i) | Air conditioning Unit progressively lost charge. | 2, 3 & 4 | Recharged at site - no permanent damage. |
| | (ii) | Air conditioning unit hot gas modulator dislodged. | 3 | Refitted at site. |
| | (iii) | Dampers in A/C ducting dislodged or broken. | 1 to 6 | Dampers now redesigned. |
| | (iv) | Short length of ABS pipework to Omnipure unit broke at end connection. | 2 | Pipework supports now modified to prevent reoccurrence. |
| | (v) | Petrol stowage became detached. | 2 | Now redesigned and improved in strength. |
| | (vi) | Halon bottle in forward pump room dislodged causing breaking of $CO_2$ activation line (repaired before next shot). | 2 | Securing stamp on bottle poorly constructed so that it failed to clamp securely. |
| | (vii) | Man Overboard Marker dislodged and activated. | 2 | No problem at subsequent shot. Not considered significant. No redesign. |

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| SYSTEM | | DAMAGE | SHOT NO. | COMMENTS |
|---|---|---|---|---|
| **AUXILLIARY SYSTEMS (Cont'd)** | (viii) | Sanar Lifejacket stowage - damage to woodwork. | 2 | Stowages now redesigned and improved in strength. |
| | (xi) | Louvers on starboard ventilation exhaust plenum from machinary compartment broke free. | 2 | Alternative construction technique giving greater strength now adopted. |
| **OUTFIT AND FURNISHINGS** | | MAJOR DAMAGE NONE | | |
| | | MINOR DAMAGE | | |
| | (i) | Ships nameboards fell off. | 2 | Inadequate securing arrangements. |
| | (ii) | Aft port bridge window smashed (when glass insulator on HF serial broke and was then catapulted into it). | 2 | Unfortunate accident - aerial now modified (see above). |
| | (iii) | Furniture in accommodation area suffered damage (ie table tops left bases, bookshelves became damaged etc). | 1 to 6 | Improved strength furniture now fitted. |
| | (iv) | Chart table in Bridge suffered damage causing risk to radar display unit fitted on end of chart table). | 1 to 6 | Now redesigned and improved in strength. |
| | (v) | Furniture in stores showed slight damage (eg top of workbench and provision locker started lifting). | 2 to 6 | Minor repairs undertaken where necessary. Slight redesign has been undertaken where considered necessary. |
| | (vi) | Clocks dropped off mountings. | 2 | Clock mounting on Bridge strengthened. |

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