DEVELOPMENTS IN SURFACE SHIP STRUCTURAL DESIGN

BY

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ABSTRACT

Over the last 20 years there has been an increasing use of more detailed and complex analytical techniques for the design of hull structure. The effect has been to produce lighter and more sophisticated designs which have a greater sensitivity to fatigue damage and corrosion in service and which are probably more expensive to build. An evaluation of the history and evolution of current designs is used to show that the most successful ship structures are the result of steady development; where a design has departed from an evolutionary approach, usually in the interests of cost or weight saving, then greater risks are taken and the structure is less reliable. Because structure is only a small proportion of ship cost it is argued that the Navy would be better served by more traditional and perhaps slightly heavier structures which will be more reliable and durable in service. To enable this to be done in a cost-effective manner, design procedures need to be tightened up and some further research undertaken.

Introduction

Since World War II with the advent of fully welded hulls and with the availability of faster and more powerful computing capability, ships' structures have become progressively lighter and more complex. In the process they have also become expensive to build, very susceptible to degradation in service due to fatigue and corrosion and, with low safety margins, open to greater risk from analytical errors.

This article explores the evolution of surface ship structural design in the U.K. with special reference to current ships and those of the recent past. The success of the designs is identified in terms of incidence of defects in service and suggestions are made as to why hull structures might seem to be less reliable than in the past. Conclusions are drawn and proposals are made both for improving design procedures and for further research.

PRINCIPAL DESIGN CRITERIA

Loading

All the important design problems of the structure of surface ships derive from wave loading, which, over the period of a ship life, depends only on operational sea area and patterns of usage. R.N. Ships are traditionally designed for world-wide operation but with a significant proportion of their life spent in the North Atlantic. This pattern of operation has been matched in design by probabilities of exceeding different speeds and headings in different sea states. Currently, no advantage is taken of the possibility of reducing loading by better seakeeping and less slamming and green sea loading. It is however likely that if seakeeping were improved, ships would be driven harder in a particular sea state and so loading would not be reduced.

Secondary loads are those due to heavy equipment, but even here the inertial effects of ship motion predominate. Significant inputs not associated with the sea are due to vibration excitation from machinery and impulsive effects of weapon firing, but the latter are very local in extent.

Failure Mechanisms

Principal failure mechanisms of ship structure are two-fold:

(*a*) Elasto-plastic collapse where some material has reached its yield stress and shed load so as to precipitate overall buckling. (Rarely, in an inefficiently designed structure, pure elastic buckling can occur).

(*b*) Fatigue cracking due to local high stresses at a design or construction deficiency.

(Brittle failure following a local very high or rapidly applied load, or extending from a fatigue crack tip when critical conditions exist is also possible, but should be excluded in warship design by ensuring all hull steel has adequate toughness.)

The collapse failure process will only be caused by severe wave loading, probably exacerbated by slamming. Fatigue failure is cumulative and will depend on the intensity of stress concentrations and the length of time the ship has been at sea. Vibration due to slamming (whipping) can use up fatigue life rapidly due to the resulting high hull girder bending stresses; in some cases fatigue life can also be affected by machinery-induced vibration.

If a ship's structure is designed to withstand wave loading with an adequate margin against collapse then it should remain acceptable through life. The margin, however, must allow for corrosion and possibly fatigue cracking reducing the effective cross-section of material and also for changes in load distribution changing the still water bending moment. Damage leading to distortion of structure will reduce resistance to buckling but is not important unless very severe or unless machinery or weapon alignment is affected.

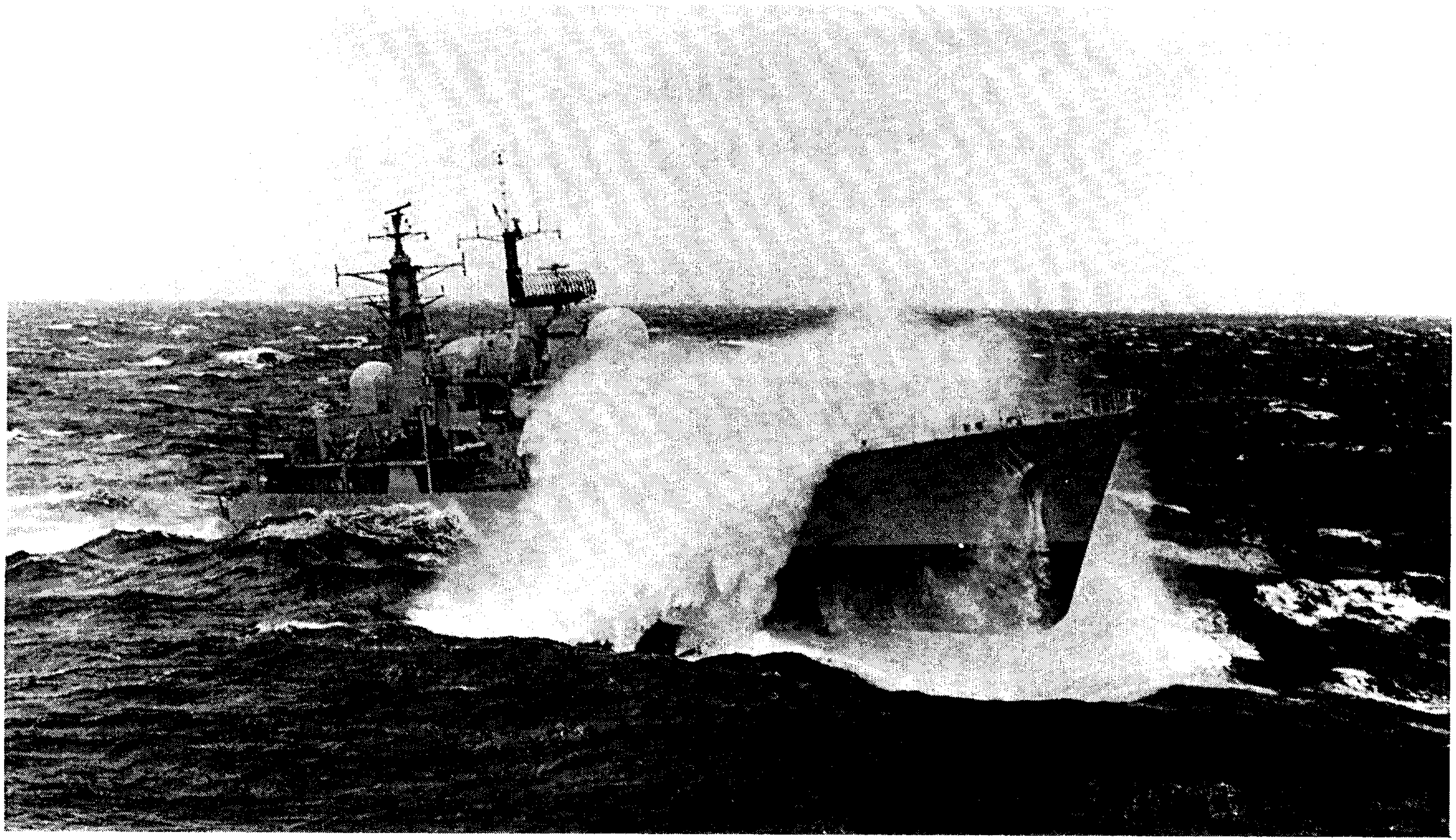

FIG. 1—TYPICAL HEAVY SLAMMING. H.M.S. 'MANCHESTER'
Photograph by CPO Les Warr

Fatigue life begins to be used up as soon as a ship goes to sea. There is no stress level below which welded steel or aluminium structures do not suffer fatigue damage so even the smallest wave encountered will have some cumulative effect. Over-enthusiastic driving at high speeds in high sea states, which is not recommended[1] especially if the ship is slamming (FIG. 1), can so consume fatigue life that a ship's operational effectiveness may have to be restricted as she gets older. Stress concentrations leading to fatigue failure, such as holes in highly stressed areas or discontinuities around deckhouses, are inevitable in any complex steel structure and, while the designer will always try to keep stress levels as low as is feasible, matters can then be made worse by poor construction or by badly carried out or unauthorized modifications during service.

Machinery-induced vibration is usually more of an irritation than a danger, but it can cause local fatigue problems such as at the base of a mast or in hull plate due to pressure fluctuations close to the propeller. Whole hull modes will always be excited by the propulsion train, but only rarely will the amplitudes and associated strains have an effect on ship operation and even then they are unlikely to increase the risk of hull failure.

DESIGN METHODS

Traditional Processes

For the whole of this century up to the mid 1970s the method of assessing the wave bending moment on a ship was to carry out a quasi-static balance on a wave (FIG. 2). The wave height for R.N. ships was L/20, (L = ship length) but elsewhere in the world and for merchant ships, a height (in metres) of $0.6\sqrt{L}$ (with L in metres) or $1.1\sqrt{L}$ (for L in feet) was more common. The use of L/20 might have led to some conservatism in larger ships (more than about 150 m long) as the likelihood of meeting the larger wave progressively reduces with size. However, this was compensated for by higher stresses being allowed in larger ships. Because the L/20 wave was a severe but not an extreme one and could be met fairly frequently, the bending moment so derived was compared with previous successful designs, and associated with a stress factor generally not less than 2 between yield stress and the average stress distribution. Some buckling checks on single stiffeners and plating were also undertaken at amidships and at the quarter length points.

In the 1950s and 1960s methods were formalized for checking the buckling strength of components in warship structure, in particular column buckling of longitudinal stiffeners and associated plating with initial imperfections.

FIG. 2—TYPICAL 'STATIC' BALANCE CONDITION ON A WAVE. 'FLOWER' CLASS CORVETTE

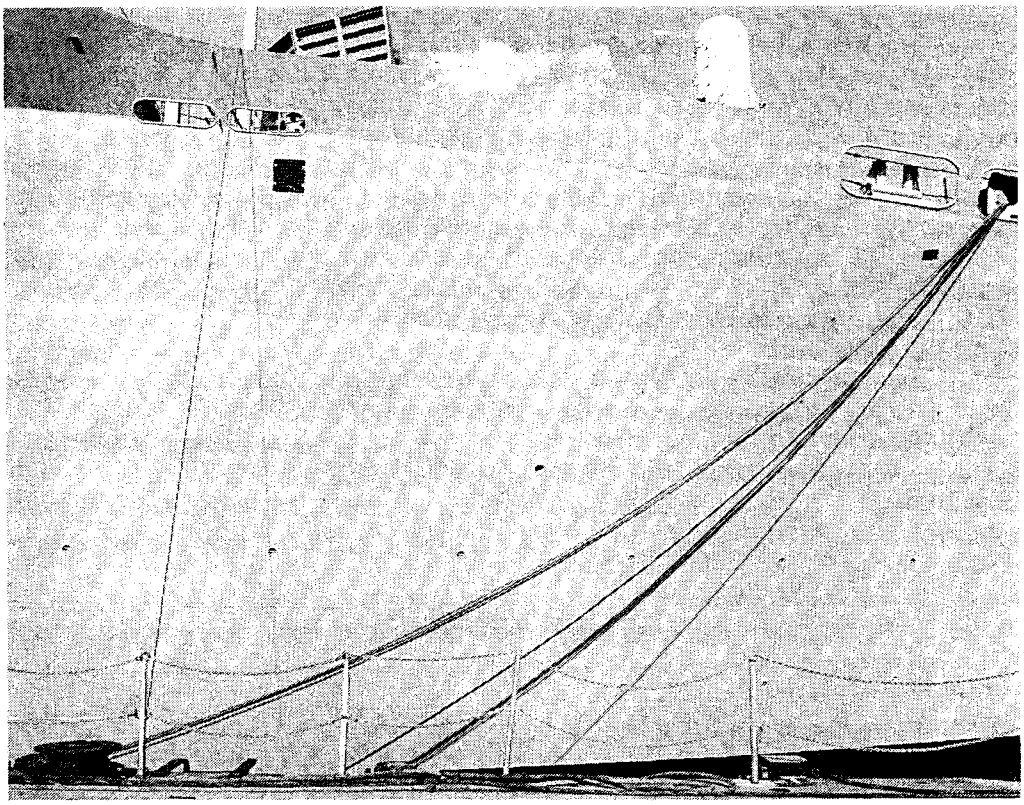

FIG. 3—PLATING IS INITIALLY BUCKLED. H.M.S. 'ILLUSTRIOUS'

Due to welding distortion, plating between stiffeners was effectively buckled in the unloaded condition (FIG. 3). Overall buckling of an orthogonal grillage could only be assessed in an ideal undeformed state. A large margin (around 5) was therefore applied to this latter condition, while a margin of at least 2 was required for the column buckling case against the L/20 wave bending stress.

There was no explicit means of allowing for fatigue in design during that period. Historically, for riveted ships, cracking was likely to occur in a single plate only and cracks were expected to be arrested at riveted joints. For the first all-welded ships designed in the late 1940s and 1950s, good attention to detail was deemed adequate, associated with relatively low field stresses which would then result in acceptable resistance to buckling. It is notable that,

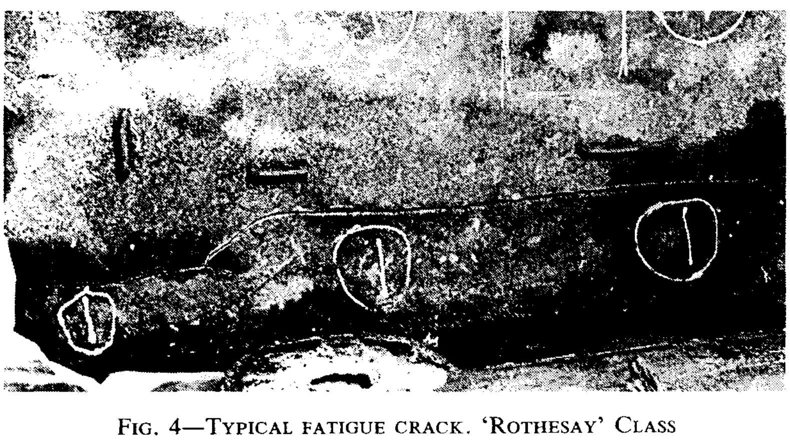

FIG. 4—TYPICAL FATIGUE CRACK. 'ROTHESAY' CLASS

except for areas of poor local detail which were attended to early in life, all ships designed at that time have achieved over 20 years of life and have only been operationally restricted by fatigue failure (FIG. 4) at around 23 to 25 years. Nevertheless, they have required some repair at every refit.

Brittle failure (FIG. 5) was known as a problem from World War II times and intruded into warship designs in the 1950s due to the relatively poor steel quality available and the transition to all-welded structure. This was solved by the introduction of notch tough steels into naval service, but the early all-welded vessel always had riveted crack arresting strakes in the hull.

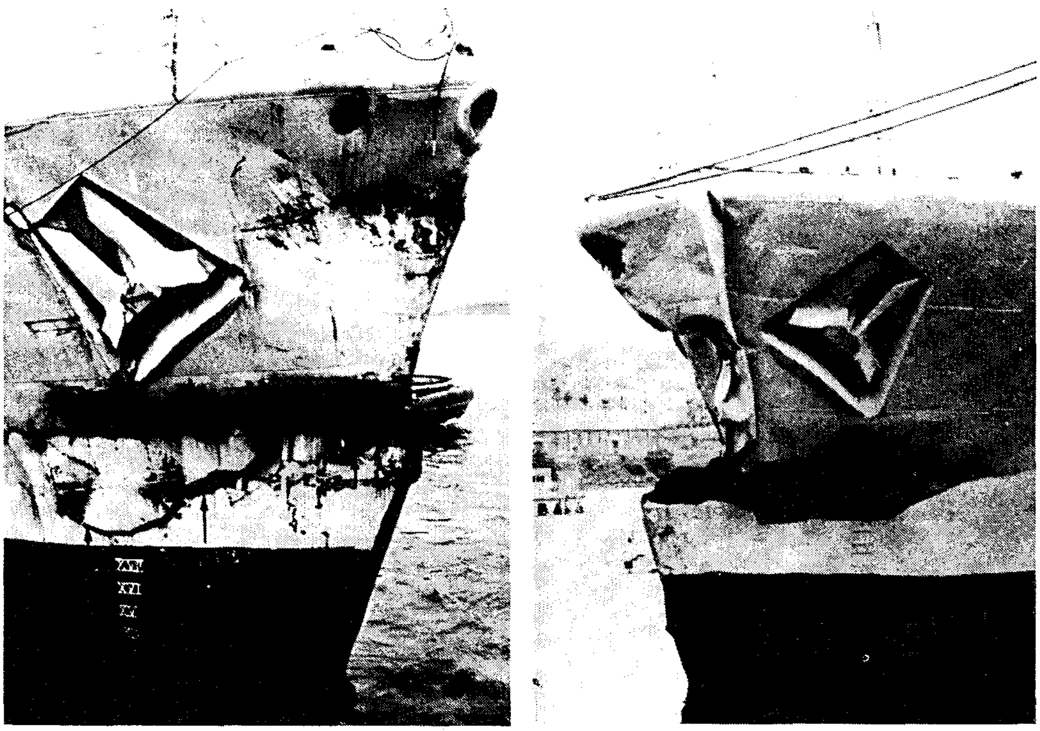

FIG. 5—LOW TEMPERATURE BRITTLE FRACTURE COLLISION DAMAGE. 'LEANDER' CLASS DURING THE COD WAR

Modern Developments

In the mid 1970s, following research over the previous 20 years, two significant developments took place. The first was intended as a more objective means for calculating wave bending moment using rigid body dynamics associated with the statistics of seas in which a ship was expected to operate. The second was a method of calculating the ultimate collapse strength of a hull as a complete entity rather than in a piecemeal manner, and allowing much more accurately for hull curvature and initial imperfections. Both these techniques took advantage of the increased electronic computing power becoming available to the designer.

The new method of estimating design bending moments involved assuming the ship to be a wall-sided non-uniform beam and, for a particular set of sinusoidal wave excitations, solving the equations of motion to find the shear forces and bending moments. Then, for an appropriate set of wave frequency spectra, linear superposition is used to estimate the mean square bending moments for each spectrum. Finally, from an assumed operational scenario in terms of probabilities of meeting particular wave heights at particular speeds and headings, a plot of bending moment against probability of exceedence in a specified time period is deduced. However, because this method takes no account of the non-linear ship shape or of non-linear wave effects under the extreme conditions appropriate to the design point, it over-estimates the bending moment compared with measurements from sea. It was therefore necessary to take a class of ship for which there was a large body of measured data (in fact the Type 12 WHITBY Class) and to derive an increased probability for entry to the bending moment/probability curve to yield the design moment. This was achieved by calculating the collapse bending moment for the WHITBY hull and using that figure in reverse to give a design probability of 0.33×10^{-7} per wave encounter. From stress measurements on the class it was also deduced that for 33% of a 25 year life spent at sea the probability per wave encounter was equivalent to an approximate 1.5% probability of exceedence in a ship life, which was deemed acceptable.

As this method yielded an 'extreme' load (instead of 'severe' load due to static balance) and with a lower probability of exceedence, it was also necessary to adjust all the safety margins downwards.

The complete method was first published[2] in 1976. At the same time a slightly better fatigue criterion was introduced, requiring the principal stress in any part of the hull structure to be below a certain value depending on the type of steel used.

Over the next few years, as ARE Dunfermline amassed further load data from sea, it became apparent that the difference between theoretical and measured bending moments, as exemplified by the WHITBY Class, was not being followed by other classes. Indeed some marked discrepancies came to light which could not be explained. For example, measured extreme values of bending moment did not consistently follow the assumed extrapolation from earlier lower measured values, and for the Type 21 frigate a high value of sag to hog strain ratio was discovered. ARE(D) was therefore given three tasks:

(*a*) To improve the method as laid down in the 1976 method to take better account of non-linearities, and to match data from measurements.

(*b*) As an interim method, to provide a wave height on which to undertake static balance to give the extreme load, so that the safety margins in the 1976 method could still be used.

(*c*) To provide a method for design against fatigue.

All three tasks are now completed and (*b*) and (*c*) have been validated. There are still questions of accuracy hanging over the probabilistic method and so for the immediate future the static balance method[3] will be specified for estimation of design bending moments. The method for estimating fatigue has been published[4].

CURRENT WARSHIP CLASSES

Design Methods Used

Warship classes at sea, with the method to which they were formally designed are as follows:

ROTHESAY	Quasi-static wave balance
TRIBAL	Quasi-static wave balance

LEANDER	Quasi-static wave balance
LPD	Quasi-static wave balance
COUNTY	Quasi-static wave balance
BRISTOL	Quasi-static wave balance
CVS	Quasi-static wave balance
Type 42 Batch I	Static balance followed by 1976 method
Tye 22 Batch I	1976 method cross-checked by static balance
Type 42 } later	
Type 22 } batches	1976 method only.

The CVS and Type 42 were both partly analysed using finite element techniques but there was insufficient effort available to analyse the results. MCM vessels and patrol craft are not included as their design requirements are somewhat different. The Type 21 was designed by Vosper Thornycroft (see p. 44).

When the 1976 method has been used in addition to the formal procedure, it has been common practice to carry out an unofficial static balance as well, ostensibly to provide more confidence, although the results are not usually reported in books of calculations. In practice, because design criteria and safety margins for the static balance method were never explicitly laid down, any feelings of confidence or unease generated by the results could not be used in support of or against the 1976 method. Official documentation simply recorded stresses achieved in earlier designs but did not draw any conclusions. Acceptance criteria in general terms for the results of static balance were taught to Naval Constructors by Naval Constructors at R.N. College Greenwich and successful designs were achieved by this continuity. The transfer to the much more theoretical course at University College London has resulted in a gradual loss of understanding of the shortcomings and pitfalls in static balance, while encouraging a belief in the results of more sophisticated analytical methods which may not always be justified and may be difficult to apply. (This is not intended as a criticism of the UCL course, but an illustration of the dangers implicit in changing established procedures and practices when many of the consequential effects may be far from obvious.) At the same time, increasing availability of computing power has led to more *ab initio* design and less reliance on the 'type ship' approach, with a consequent loss of the safety net of steady evolution.

With the design of the new Type 23 Class, these problems and uncertainties were becoming apparent; however, for lack of anything better, the 1976 method was used but with greater margins to allow intuitively for risks inherent in the method. A large bonus was the availability of the new fatigue design method[4], just completed by ARE(D) although not then validated, which has been used to provide objective guidance on fatigue life.

Experience in Service

No significant strength problems have been experienced in service by any of the larger vessels, that is CVS, LPD, BRISTOL and COUNTY Classes, although all have had minor fatigue problems at points of poor detail which are cured progressively. The CVS had problems during assembly due to very light internal structure buckling before it was fully supported, but the only problems that have arisen in service have been due to lack of torsional stiffness, not strength. In general, the length to depth ratios of these larger ships means that it is very easy to achieve acceptable stress levels, indeed stress levels tend to be lower than maximum acceptable because scantlings are dominated by secondary considerations such as aircraft landing loads on the CVS deck. Also, as has been stated earlier, static balance on the L/20 wave is conservative for ships over about 150 m length.

'County' Class

The COUNTY Class, was very different in both its weapon systems and machinery, and as such was almost an *ab initio* structural design. Traditional static balance methods were used, but it was decided for simplicity to use a constant frame spacing of 6 ft throughout, with $\frac{1}{2}$ and $\frac{1}{4}$ frames where loading demanded smaller panels. The Type 82 *Bristol*, was a direct derivation of the COUNTY and again used 6 ft frame spacing, but after an exhaustive investigation into whether layout could be improved by some variation on 6 ft. Great care was also taken to design structure in way of stress concentrations in the upper deck around gas turbine uptakes and downtakes and to ensure continuity of longitudinal stiffening. Although these efforts predated the use of finite element analysis, the very few problems *Bristol* has had show the design approach to have been successful.

Type 12

The ROTHESAY and LEANDER Classes (and the WHITBYS and Type 41/61 before them) have light structure and the WHITBYS and ROTHESAYS in particular were designed to the limits of high stress and light scantlings. The purpose of their structural arrangement of light plate and closely spaced small stiffeners (FIG. 6), which has been likened to 'watchmaking', was not however to save weight but to provide an explosion-resistant structure following the lessons learned from World War II experience and the subsequent ship target trials. Weight saving was a bonus and could possibly have been achieved from a less labour-intensive but more discontinuous structure.

The effectiveness of the structure in resisting underwater explosion damage has never been proved either experimentally or in service. However, the high stresses in normal service have led to continuing problems of fatigue cracking, getting worse as the ships have aged and exacerbated by significant increases in displacement, while the thin, complex structure has suffered severely from

FIG. 6—TYPICAL LIGHT PLATE, CLOSELY STIFFENED STRUCTURE. FRAME SPACING IS 1 METRE

corrosion both because loss of material has a greater proportional effect on thin plate, and because the many stiffeners provide more pockets for water to lie and corrosion to progress.

The LEANDER Class have a similar hull to the ROTHESAYS but with a structurally effective superstructure resulting in a significant reduction in stresses compared with the earlier Type 12s. The earlier LEANDERS have had as much corrosion as ROTHESAYS but because of the lower stresses it is of less importance. Both ROTHESAYS and LEANDERS incorporated numerous structural improvements based on WHITBY experience. However, even LEANDERS, especially those operating with towed arrays, are now showing an increased incidence of fatigue cracking.

'Tribal' Class

The Type 81 TRIBAL Class was designed concurrently with the LEANDERS, not as a direct derivative of the ROTHESAYS but with the knowledge that the lightweight structure had proved very difficult to build. Consequently they had heavier scantlings and somewhat lower stresses, while a conscious effort was made to simplify the structure with wide frame spacing and make it easier to build with less susceptibility to corrosion (where structure was susceptible it was zinc sprayed). Longitudinal framing was changed to transverse in the bow area, putting stiffeners in the direction of the shortest span to provide greater resistance to slamming. The reason why this was not as successful as had been intended only became apparent when much later research showed maximum slamming pressures occurring further aft on ships with low prismatic coefficient. Local slamming damage on the TRIBALS was cured by the insertion of a few half frames, and the hulls have proved very robust, being in sufficiently good condition for three of them to be renovated and sold to Indonesia after 20 years in R.N. service.

Type 42

The Type 42 Batch I was derived as a hull form from the much earlier Type 41/61 design, but its structure has its ancestry in the LEANDER, COUNTY and BRISTOL. However, the wide frame spacing (7 ft)—even wider than BRISTOL though in a smaller hull—was taken from U.S.N. practice and, like the Type 81, was intended to reduce structural complexity and cost. Unlike the Type 81, weight was also kept to a minimum, the result being an inefficient structure with fairly low wave bending stresses, but also with low critical buckling stresses. Trying to follow two separate and inconsistent principles, those of low weight and simple widely stiffened 'cheap' structure, led to a design outside the previous evolutionary bounds with a significant increase in risk. At the same time a short timescale of 18 months from concept to ordering the first ship inhibited logical checking and development of the design.

Although the stress levels are fairly low on the Batch I and II Type 42s, there are still some awkward stress concentrations and some irritating fatigue cracks are now growing. These will cause problems through the lives of the ships, creating a permanent though so far minor maintenance load. Finite element analysis was undertaken for some stress concentration during design, but there was insufficient effort available to analyse the results.

It is unfortunate that the Type 42 design was used as the basis for the Structures Manual (NES 110)[2], as their design shortcomings have to some degree been written into Departmental design methods. However these deficiencies were realized before a new design was carried out solely to the requirements of NES 110; nevertheless the Structures Manual will now have to be rewritten to take account of the experiences noted in this article, and of more recent understanding of structural loading and response.

Type 22

The Type 22 frigate lies in a different evolutionary chain from the Type 42; indeed the original concept was scaled directly from LEANDER. However, a conscious attempt was made to make the structure easier to build and the hull was optimized on that basis with some thicker plate and wider spaced and larger longitudinals. The wide frame spacing of the Type 42s was deliberately avoided. Because there are more and larger deck penetrations for gas turbine downtakes and uptakes, finite element analysis was fully used for the first time to check on and reduce stress concentrations. The 1976 manual method was used to estimate loads and strength and has in this case been successful, although the apparent accuracy of the load prediction probably owes much to the evolution of the hull form from the WHITBY on which the prediction method is based (see above).

A difficulty that arose during the design was that, in evolving from LEANDER but increasing hull weight, the structural weight budget was too small. Consequently internal structure was sacrified and scantlings of internal decks and secondary bulkheads are very light. The result is a structure difficult to assemble with large distortions and consequent rework.

In service the Type 22s have given few problems and, except in a few isolated minor areas, have shown no fatigue failure so far. Their success must be due to an evolutionary design with adequate margins and careful use of the latest analysis methods to check adequacy of the structure.

Type 21

The Type 21s are a departure from the evolutionary progress, having been designed by Vosper-Thornycroft, albeit nominally to the same criteria as MOD designed vessels. There were two marked differences from previous MOD practice. The first was that the structure in the decks near amidships was in thick plate with small stiffeners, making it very sensitive to initial imperfections. This subsequently became clear using the 1976 ultimate collapse analysis, and was also apparent later from classical buckling analysis. The lack of strength was exacerbated by the final design being 500 tonnes overweight. The second difference was the use of aluminium for a highly stressed superstructure intended as part of the primary hull girder. Aluminium has poor fatigue properties and the superstructure cracked very early in life throwing even more load on the steel hull. All these ships have had to be strengthened with strips of Q1N steel bolted to the shear strake, but cracking will continue to occur in the aluminium for the rest of the ships' lives, without however resulting in unacceptable weakness.

Type 23

The Type 23 design represents something of a departure from the Type 12/Type 22 or Type 42 design development. A statement of technical requirements (STR), which included acceptance criteria, was prepared by MOD based on the 1976 manual method but with some margins increased reflecting knowledge gained from the Type 42 and 22 designs. Yarrow Shipbuilders then undertook the structural design to an agreed weight budget and with the aim of minimizing cost. The result has been a compromise hybrid structure with conventional tee bar longitudinal stiffening in the deck and bottom, but with transverse bulb plate stiffening in the sides. The scantlings are intentionally heavy with a structural weight proportion greater than all recent designs, although about 80 tonnes of structural weight is estimated to be due to the hybrid arrangement.

POTENTIAL CHANGES IN DESIGN PHILOSOPHY

Two particular current factors may lead to changes in design philosophy. These are changes in operating patterns and ship life, and advances in material technology.

Operating Patterns

The first of these changes is consequent on the increasing average age of the fleet. In the past a life of 20 to 24 years has been implicit, although until very recently it has not been possible to make any explicit estimate of fatigue life. As long as ships were spending significant time in dockyard hands where hull repairs could be carried out, this life was achievable and the cost was hidden. The Type 12s are an example of considerable resources having to be put into keeping going very light hulls, at the same time as the more robust hulls of the TRIBALS and COUNTYS have been fairly easy to maintain.

It is now a stated requirement for the Type 42s and 22s to achieve a 22 year life[5] and, while the Type 22s should not have much difficulty, particularly the Batch IIs and IIIs, the Type 42s are likely to be an increasing burden on maintenance resources as they get older.

The Type 23s have been designed for a relatively short life and high usage rate. In the future, much more thought will need to be given to the design life of ships, the possibility of future life extensions, mid-life modernizations, changes in usage pattern and the cost of maintenance. This, in effect, means applying a realistic margin over the stated minimum requirement on structure to provide some flexibility in life and rate of use. Over-emphasis on unit production cost (UPC), a minimum weight and minimum (or zero) margins represents a false economy, bearing in mind that hull structure (including labour) costs only about 10% of UPC and structural material only about 1%. More robust, longer life hulls could be built with not more than a 10% increase in structural weight, which is less than 3% increase in displacement and less than 1% increase in UPC.

Associated with the problem of life and usage is the increasing use of towed arrays in frigates. It is becoming apparent from the Batch IIA LEANDERS that the world-wide statistics for wave loading used currently in design are not sufficiently demanding for a ship that spends much of her time in the northern North Atlantic on fixed courses and speeds. It will be necessary to change the design criteria, and ARE(D) are carrying out strain measurements on a number of towed array ships to provide design guidance. It is possible that hulls of the next class of towed array vessel will have to be relatively heavier and costlier.

New Materials

The second current change, involving new materials, could show significant savings in weight or through-life cost. The U.K., with U.S.A. and Canada, is putting some effort into developing superstructure designs in composite materials. When this application has been proved, and design criteria and methods prepared, it will be possible to allow a much more flexible layout of superstructure, minimizing stress concentrations and consequent fatigue damage, and at the same time considerably reducing ship husbandry requirements as well as top weight. Other applications of composites, such as in mast structures, are also being investigated.

Higher strength steels are also now becoming available following research in the submarine area. These steels are stronger than 'B' quality while being about the same price and as easily welded. When the fatigue life of these steels has been established, it is possible they can be used to advantage to save weight or complexity in areas of high stress concentration, or for structure such as bulkheads for which infrequent bending and shear are the critical design loads.

Explosion Resistance

A design requirement which figured strongly in the WHITBY Class but seems to have been subsequently neglected is resistance to underwater explosion damage. The probability of a non-contact explosion is now more than it was in World War II due to the stand-off torpedo threat and it would be highly embarrassing for a ship to be put out of action due to hull rupture and flooding from a charge too small to cause severe equipment damage. The ship target trials carried out after World War II were mainly against riveted ships and so specific conclusions may not relate to modern welded structure, nevertheless the general conclusion of the need for a homogeneous structure with a minimum of stiffness discontinuities and strong bulkhead boundaries must still apply. Since the WHITBY, more or less effective attempts have been made to achieve the ideal but with progressively larger departures in the interest of cost reduction or production simplicity. This may be because explosion-resistant structure depends on judgment and experience and, without numerical acceptance criteria, is too difficult to write into a contract. It is desirable that a new series of model tests and full scale trials be initiated to enable new requirements to be laid down.

The forgetting of past experience is leading to proposals for merchant ship style structures, at least for large ships, on the assumption that they will be cheaper. There is no doubt that a merchant vessel designed to Lloyd's Rules with commercial sections would have very poor resistance to underwater explosion on account of the structural discontinuities, intercostal members and intermittent welding which are permitted and which are adequate for a relatively short and predictable life (most merchant ships are expected to have depreciated to zero value to the original owner after about 10 years). Additionally, although the materials used are marginally cheaper, a heavier hull would result with consequent loss of payload and performance. Noting that the cost of structural materials is only about 1% of UPC the saving is hardly worth the risk. The cost of structure is mainly in the man-hours needed to assemble it, and this is heavily dependent on the complexity of sub-division and equipment and services fitted. It is unlikely that such complexity will be changed by a move to a different structural style except to the limited extent due to a bigger hull. It would be more logical, and lead to a more durable and less risky design, to specify a larger and less congested hull to well proved warship practice.

CONCLUSIONS

The principal conclusion that can be drawn from the foregoing discussion is the importance of allowing evolutionary design, so as to avoid the risk of unexpected loss of operational capability. The most successful designs, for example the LEANDERS, TRIBALS and Type 22s, all follow logically from previous successful classes with due allowance being made for known deficiencies. In the case of the TRIBALS where a larger evolutionary step was taken, larger than usual margins were consciously required. The less successful designs are those where inconsistent sets of design data have been taken from different type ships resulting in a 'lowest common denominator' solution, or where something quite different has been attempted without a clear understanding of the implications, or at least a large margin for error. It is certainly a false economy to try to save cost by reducing margins and so increasing design risk.

Another important point is the need to design the ship for a realistic life. Whatever is intended at the time the staff requirements are written, it must be accepted that requirements change and, with the Navy always short of hulls, around 25 years is likely to be the minimum life for a ship. Furthermore, if the operational requirements in terms of usage rate, sea area, etc., for a ship differ from previous experience, for example with the introduction of towed arrays, the designer must take care that he is using adequate margins to cover the unknowns.

The use of commercial standards for warships is likely to increase the risk of loss of operational availability, particularly following underwater explosions of a severity which a warship would normally be expected to survive. Commercial standards of structure are unlikely of themselves to save much money, and that at the expense of considerably increased risk. A more logical way of saving money without risk would be to accept larger and less congested hulls using well proven warship technology. Nevertheless, it is highly desirable to initiate a trial to establish the real requirements for explosion-resistant structure.

The use of higher strength steels and composite materials, especially the latter, is likely to show potential for reducing weight and through-life maintenance costs at the expense of a small increase in UPC. The design of frigate superstructures in glass reinforced plastic is being pursued jointly by U.S.A., Canada and the U.K., and the data is likely to be available for the material to be considered as an option in NFR 90 and contemporary designs.

Provided the evolutionary approach is followed, and the designer starts with a consistent set of design assumptions, a valid concept design and adequate margins, there is every reason to suppose that a reliable and cost-effective solution will result. Whenever significant departures from established and proved structural styles and design methods are taken, risk increases significantly as the designer is unlikely to be able to comprehend many of the implications. Further, even where the level of risk is realized, it may be difficult to sustain the necessarily large margins in the light of the implicit initial assumption that there was no risk in such a departure. The desirable low cost/low risk design can only be achieved by departures from established practice being concentrated on reduction of construction man-hours, producing a simple structure which, under the conditions in which warships operate, will still have well-known characteristics and failure mechanisms.

Research and Development Requirements

A number of deficiencies in knowledge of structural loading and response have been highlighted in the foregoing discussion. To improve understanding of the phenomena a continuing programme of research and development is required which should include the following topics, some of which have also been mentioned in the conclusions above.

There is a need for trials and possibly mathematical analysis to investigate explosion-resistance of structures so that arrangements of material can be optimized. This should cover internal and external air blast and fragments as well as underwater shock. For the latter a better understanding of shock transmission through structure is also needed.

Work must continue into the use of new materials such as fibre reinforced plastics and high strength steels for use in conventional vessels. This will require study in particular of the most cost-effective applications for these materials in the marine environment.

To work towards cheaper structures, even though structural cost is a small proportion of total ship cost, a greater understanding of the cost of such aspects as complexity of layout or lightweight structure is needed. The designer must have cost figures to support the judgment that heavier, simpler structures are cheaper, before the broader ship implications of such arrangements will be accepted.

There is still insufficient knowledge of seaway loading on hulls, especially from slamming and green seas. The acquisition and analysis of data from sea must continue and is particularly important for novel vessels such as towed array ships, SWATHs, etc. The data and ship response should be formulated so that it can be presented in terms of mean values and standard deviations for the different uncertainties, so that the design point can be found at a known probability of exceedence.

In association with a design load derived statistically from measurements at sea, there is a need for an analysis of uncertainties in structural strength. This will include material variability and geometric imperfections, effects of production methods and structural tolerances. Again, means and standard deviations are needed so that a design strength with a known probability of achievement can be derived. Additionally there is a need for a better understanding of structural effectiveness where structural elements are discontinuous, and of the effects of local asymmetry, such as sponsons, on stress distribution.

The views expressed in this article are those of the author and do not necessarily reflect departmental policy.

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