CRACKING IN R.N. SURFACE SHIPS

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There has in recent months been an upsurge of interest in structural cracks in R.N. ships, particularly following problems suffered by the Type 12 and Type 21 Frigates. It must be stated that all steel ships of all navies suffer structural cracking in some degree, indeed all large steel structures will crack at some stage. Steel is a very tolerant material but as fabricated it always has a finite fatigue life and this life depends on local stresses and the number of cycles of stress seen by the structure. Theoretically it also depends on whether a defect acting as a crack initiator is present but it is safe to assume that such defects will always be present in a welded steel structure whatever the level of quality control and non-destructive examination applied during construction.

Cracks in steel structures are of two types, fatigue and brittle. Brittle cracks run rapidly following initiation, which is normally due to very rapid loading such as an explosion or collision; a brittle crack can only run in brittle material and generally the steel used for warships is ductile in normal operating conditions. Consequently the vast majority of cracks are due to fatigue loading, that is a cyclical load which need not be particularly high, although the higher the load, the shorter the life. Fatigue cracks are therefore most likely to occur after many years of service and, in ductile materials, will start at a point in the surface and gradually propagate through the thickness and then spread. Until the crack becomes very large it is so fine as to be invisible to the naked eye and there is no obvious plastic deformation. Consequently, unless a surveyor knows exactly where to look, or is lucky, many fatigue cracks will escape detection until significant damage has occurred.

Historically, although cracks occurred in riveted ships they were less frequent and potentially less dangerous as they could not normally continue beyond the plate in which they started. Since the 1950s, however, R.N. ships have been predominately welded. Cracks that occur in ships are generally propagated by fatigue action which, except in rare cases of very poor design, have taken many years to become apparent as noted above. It is only therefore in recent years that fatigue failures have become a matter of concern. The purpose of this note is to draw the incidence of cracks to the notice of naval engineers and to discuss their significance. At the same time, common cracks in some current ship classes will be listed and explained, and the action being taken to improve matters for the future will also be outlined.

Current Problems

Type 12

One WHITBY Class (H.M.S. *Torquay*) and seven ROTHESAY Class are still in service with the R.N.; all are over 20 years old and it is 28 years since *Torquay* first commissioned. The structure of these ships is very light, the ROTHESAYS being slightly heavier than WHITBYS. They were designed and built in the late 1940s and early 1950s to provide quick replacements for some of the many wartime ships reaching the end of their useful lives. Because of the very light structure, and especially the lack of plating reinforcement around the boiler uptakes and downtakes in 1 deck, they have always suffered some cracking and indeed were strengthened by adding deep girders under 1 deck either side of the funnel. Unfortunately, because it was a common problem, cracks were repaired as they occurred by welding (FIGS. 1 to 3) or by fitting doublers, and the significance of the accumulating fatigue damage was not appreciated at the time. The severe cracking at sea which occurred in *Lowestoft* in November 1982 brought the problem to the fore but after consideration the discovery of similar incipient cracking in almost all ships of the class was only to be expected. Repairs consist of renewing fatigue-damaged plate and this is being done as rapidly as possible. The problem is exacerbated by the extensive corrosion in the machinery spaces of some of the class which causes an increase in stresses and a speeding up of the rate of fatigue damage. These ships are therefore nearing the end of their fatigue lives but the state of their structure is being continuously monitored and assessed.

FIG. 1—'ROTHESAY' CLASS: TYPICAL FATIGUE CRACK IN 1 DECK GIRDER (H.M.S. 'PLYMOUTH')

FIG. 2—'ROTHESAY' CLASS: ATTEMPT AT WELD REPAIR IN 1 DECK GIRDER (H.M.S. 'LONDONDERRY')

FIG. 3—'ROTHESAY' CLASS: FAILURE OF WELD REPAIR IN 1 DECK GIRDER (H.M.S. 'PLYMOUTH')

Type 21

The structure of these frigates was designed by Vosper-Thornycroft without input from the Ministry of Defence. They have an aluminium superstructure which is intended to contribute to the longitudinal strength of the ship, and in fact as designed the strength of the steel hull is inadequate without a contribution from the superstructure. Aluminium has a very low tolerance to fatigue damage, and the superstructure has a large number of discontinuities leading to high stresses, and in consequence it has a very low fatigue life. Cracking actually commenced in *Amazon* at 02 deck level before commissioning and the builder fitted an expansion joint to relieve the stresses. The effect of the joint was to move the high stresses down to 01 deck where fatigue cracking commenced and was of much greater importance. After attempting weld repairs for some years, it has recently been decided to strengthen the steel hull to reduce its reliance on the aluminium, and thick strips of strong NQ1 steel are being bolted to the ships' sides to increase the section inertia; this will not completely stop the aluminium cracking but it will reduce the signficance of it to the level of a nuisance, which can be dealt with at normal refit or repair periods.

'Leander' Class

These are a much stronger derivative of the Type 12s with a continuous superstructure, and measured strains in strength deck and outer bottom are of the order of half those measured in similar sea conditions in ROTHESAYS. The only significant cracking is in the region of the bridge front resulting from poor alignment of the front with the bulkhead below, compounded by too many penetrations of the bulkhead. Cracks in this area are not endangering the ship in any way as they are self-relieving but are a considerable nuisance due to leaks. An A&A has been developed but will only be completed on the five Batch 3A ships as part of the Sea-Wolf conversion, the other ships being repaired progressively as the opportunity arises.

Type 22

Two of the Batch I ships have suffered a minor crack in a girder in 01 deck (FIG. 4). This crack is due to a poor design detail in a complex arrangement of structure around the many penetrations for machinery access and removal. The structure was assumed by the designers not to contribute to the overall strength. The crack is of little importance and will not extend to be dangerous. The design has been changed to eliminate the detail in later ships. Type 22s have also suffered cracking around the ends of bilge keels; this is due to poor alignment of structure and is being cured by fitting thick plate inserts in the hull in way of bilge keel ends.

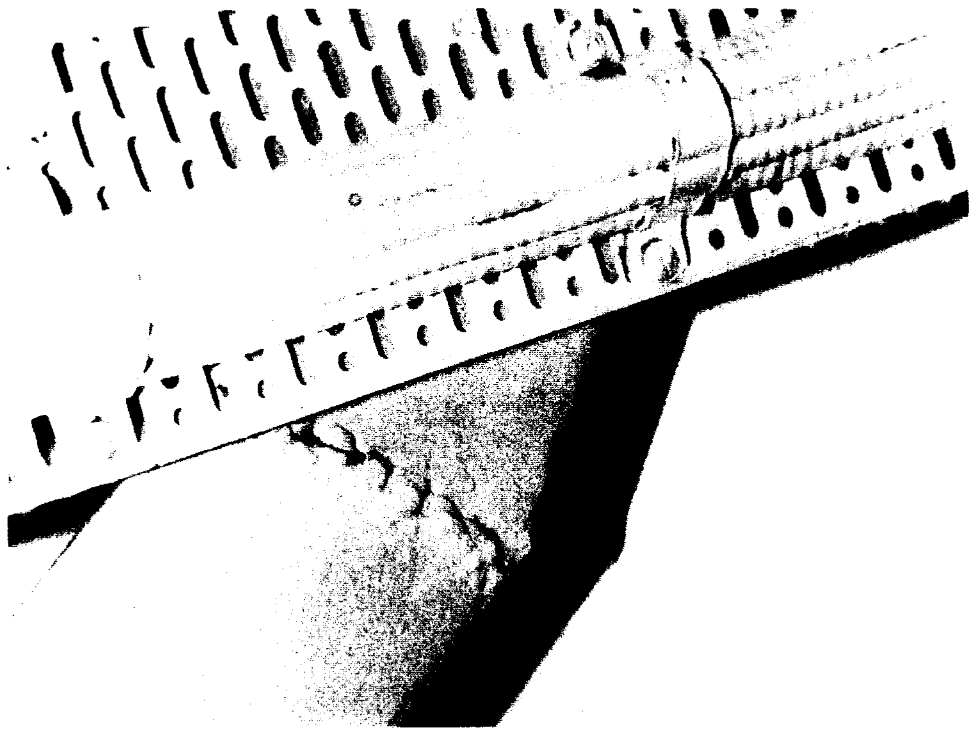

FIG. 4—H.M.S. 'BRILLIANT': FATIGUE CRACK IN 01 DECK GIRDER AT CRANKED CONNECTION (LOOKING UP AT DECKHEAD)

Type 42

Ships of this class have a bilge keel problem similar to that in the Type 22s which is being cured in the same way. The other main area of cracking is in way of the after generator shipping opening. The area is poorly detailed and minor cracks are likely to continue, although welding up the shipping access hatch may make some improvement; the cracks are a nuisance but are not critical.

There are other examples in other ships but the ones of recent interest are described above. TABLE I (page 307) gives a more comprehensive list of class cracks.

Reasons for Cracks

Fatigue cracks will occur if a local stress is too high for the number of cycles of stress required of the structure. Because the number of cycles is directly related to the life of a ship (it is actually assumed to average 1·2 million/year although the majority will be low stress cycles) the designer can only minimize cracking by keeping stresses low. In most structure this is not a problem but stresses will be high at local concentrations, such as holes, and at discontinuities such as welds. However, it is clear that it is precisely these areas where constructional defects are likely to exist, for example roughness in a flame cut edge to a hole, or a small weld defect, and therefore to grow as fatigue cracks over a period of time. All the ships' cracks described above started at a point of high stress, even the ones of the Type 12s where a favourite point for start of a crack was the shore steam connection in the upper deck to port of the funnel. It is therefore most important that the designer, builder and maintainer of ships should adopt the following code of practice:

(*a*) longitudinal structure in hull and strength decks should be continuous and not intercostal and have the minimum of discontinuities or sudden changes of stiffness;

(*b*) the number of holes cut in the structure should be a minimum;

(*c*) where holes are essential they must have well-rounded corners (corner radii should be $\frac{1}{8}$ breadth of the opening or 75 mm whichever is the greater) with thicker plate inserts to reduce stress concentrations;

(*d*) edges of holes should be ground smooth;

(*e*) welds whenever possible should not be sited at edges of holes or other discontinuities.

Generally the designer has control only over the first three; the remainder, and to some extent (*b*) and (*c*) also, are under the control of the shipbuilder, or the maintainer in the case of modifications or repair.

For those parts of ships designed by the Sea Systems Controllerate the above rules are well known and every effort is made to apply them. Guidance is then passed to the shipbuilder in an attempt to ensure that problems are avoided during construction, but inevitably in a structure as complex as a warship some local areas of potential cracking will slip through the net. Much of the skill of the designer lies in ensuring that areas where cracks are most likely to occur will not have any serious operational effect on the ship at a later date. Experience with existing classes has been taken note of, including strain gauge information gleaned by AMTE (Structures). Resulting rules have been written into relevant Naval Engineering Standards[1,2] and all the lessons learned have been applied, for example, to the Type 23 frigate. It is expected that the Type 23 will be less susceptible to cracking in service; nevertheless there can never be any guarantee that a structure will not crack any more than there can be a guarantee that the shipbuilder will not inadvertently create a discontinuity or defect in an area of high stress. However, every effort is being made to improve the assurance in critical areas by the diligent application of quality control standards.

The Maintainer's Position

The maintainer includes both ship and base staff, dockyards, and shipyards. It is important that they recognize the rules above and do not make matters worse by cutting unauthorized holes or changing the shape of holes. Additionally, where any repair is carried out every effort should be made to avoid notches and other discontinuities, and quality of welds should be up to standard[3]. Where a crack does occur the immediate reaction is to weld it up, but it will be clear from the foregoing that such can only be a temporary repair as the cause of the fatigue failure will still be there, possibly made worse by the presence of the new weld. A correct repair must involve tracing the source of the crack and removing it and then replacing fatigue-damaged material. It is appreciated that this is a counsel of perfection and removing the source will often require advice from the design authority, nevertheless that should be the aim, although temporary palliatives such as drilling a crack tip[4] are also worthwhile. It is such thoughts that are behind the current requirement[5] for all ships to report incidence of cracking with as much supporting detail as possible. This information is being used by the Chief Naval Architect, advised by AMTE (Structures), to improve designs in the future, at the same time as getting a feel for the pattern of cracks in each class of ship so as to avoid a repetition of such unexpected failures as those in the Type 12s.

TABLE I—*Some Common Class Cracks in Major Warships*

Class	*Crack*	*Reason*
Type 12 (WHITBY & ROTHESAY)	Bridge Screen to 1 Deck 1 deck abreast funnel, including longitudinal stiffeners 1 deck abreast boiler downtakes including longitudinal stiffeners Junction between 2 deck and 27 bulkhead Dieso tank bulkheads	Poor structural continuity Discontinuities near holes without adequate compensation Welds in corner of downtakes and lack of adequate compensation Poor detailing at local stress concentration Not known—may be due to occasional overpressurization
LEANDER	Side plating and bulkheads of forward trim tank Bulkheads around forward fresh water tank Bridge screen and 27 bulkhead area Dieso tank bulkheads	Local stress concentrations and poor detailing — ditto — Misalignment of bridge screen with 27 bulkhead, and too many penetrations of 27 bulkhead Possibly occasional overpressurization of tanks
COUNTY	Heel of pillar at 41 station 3 deck Between gas turbine downtakes and hangar and magazines Bridge screen to deck connection	Poor detailed design at pillar support Welds at points of stress concentration Lack of structural continuity
Type 21	01 deck passageway centreline, 41-42 station 01 deck around generator shipping opening, 37-40 station 01 deck outboard and ships side, 37-41 station Bridge screen to 01 deck connection	Overstressed aluminium at base of expansion joint Poor detailed design in aluminium around large hole Overstressing following above failures Lack of structural continuity
Type 42	In region of after generator shipping opening and after superstructure Shell in way of bilge keel ends	Poor detailing with welds at points of high stress Stiff structure ending an unsupported plate panel
Type 22	Shell in way of bilge keel ends Cracked longitudinal under 01 deck, 58 station	Stiff structure ending an unsupported plate panel Bad detail exacerbated by poor welding
BRISTOL	No significant cracking	
INVINCIBLE	Around sea inlet boxes in double bottom	Poor design leading to hard spots on cyclically stressed structure

Note: Repairs to cracks have generally been undertaken.

Conclusions

Because of the impossibility of building a steel structure as large and complex as a warship without a few defects in local stress concentrations, ships will always suffer some cracking. Every effort is being made by the Sea Systems Controllerate to design structures in such a way that potential areas of cracking are minimized and will not affect operations, at the same time as trying to require shipbuilders to improve constructional details and apply approved quality control standards. Maintainers must avoid creating new problems by carrying out unauthorized modifications, or by building in bad detail when changes are essential. Ships' staff can greatly assist the designers by providing feedback from sea on the incidence of cracking, both to enable corrective measures to existing ships to be prepared in good time and to improve design procedures for the future.

References

1. Naval Engineering Standard 110: 'The Structures Manual'
2. Naval Engineering Standard 155: 'Structural Arrangements'
3. Naval Engineering Standard 706: 'Welding Ships Structure'
4. 'Temporary Repairs to Hull Cracks', S2022a Z7598/5.T of 27 September 1983
5. 'Structural Cracks or Failure of Structure', S2022a Z7530/6.T of 14 July 1983