Fatigue Analysis and Condition Assessment of FPSO Structures

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Abstract

The paper describes the procedures applicable for the strength analysis and condition assessment of FPSO structures.

The determination of the hull girder loads and the local loads will be carried out by using the spectral analysis taking the intended operating area into account. An example demonstrates the influence of two different wave spectra of two operating areas on the hull girder response. The quality of the hydrodynamic algorithms will be demonstrated by a comparison of calculation results and measurement data collected from an existing structure.

The fatigue assessment of selected structural details will be done by superposition of global and local loads where the main focus of this assessment is to avoid any docking within the intended service time.

Finally the paper presents an example of a refit of an existing FPSO structure which has already reached its design life time. After inspection and assessment a concept has been developed to carry out the necessary structural repairs taking into account the limited budget and time schedule.

1 Loads and Spectral Analysis

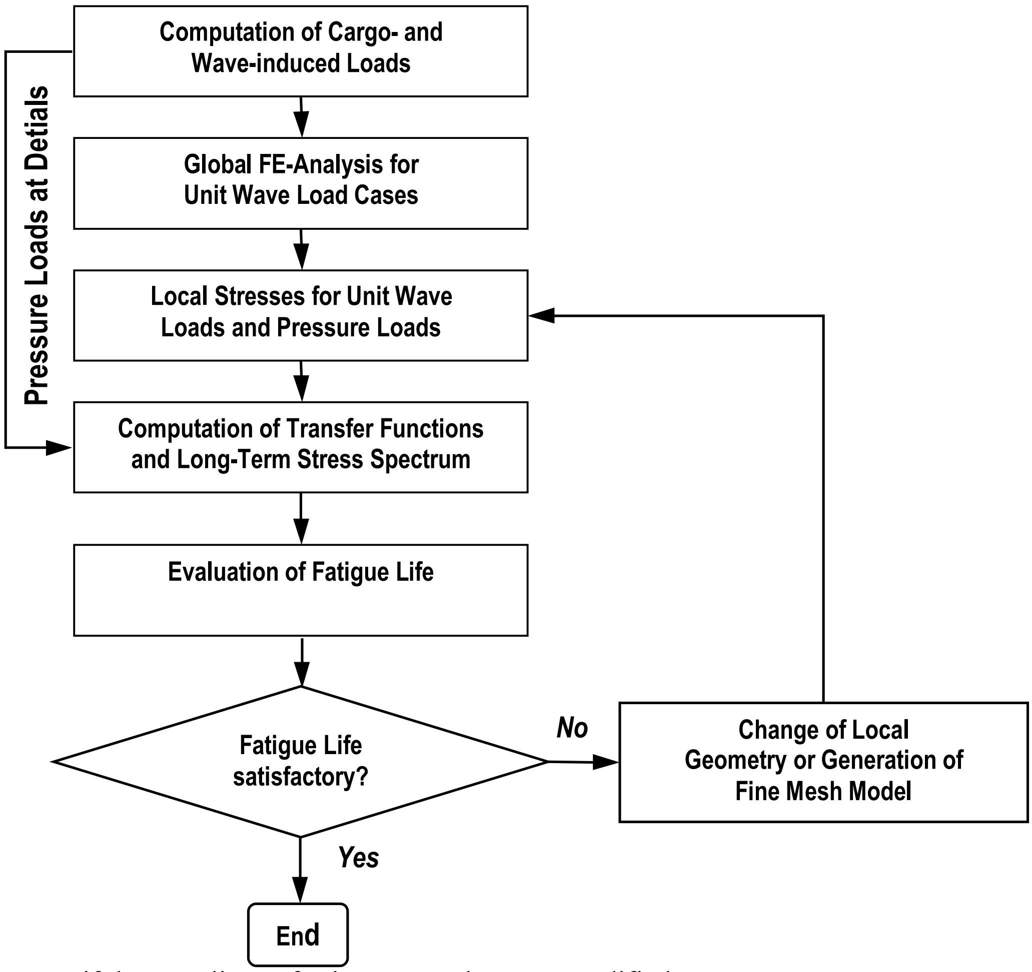
Floating structures are affected to a large extend by loads varying over time. Main influences are the operational area as well as the local weather condition. The combination of both leads to well known uncertainties of the load spectrum.

Within IACS, design values for e.g. vertical wave bending moments for the strength analysis of ship structures have been agreed on. For FPSO's the situation differs significantly as on the one hand the operational area is fixed and on the other hand the angle of wave encounter is more or less 180° (head seas). To account for these effects, spectral analysis can be used as a powerful tool. At Germanischer Lloyd this technique was developed for fatigue assessment from 1990 (Fricke et al. 1994). It couples the loads with the structural response (transfer functions), resulting in an individual stress spectrum and a related usage factor (fatigue life) by means of finite element calculation.

2 Procedure of the Integrated Fatigue Analysis

An overview of the spectral analysis is given in Fig. 1. The method was chosen for consideration of wave loads and acceleration forces. After generation of the stillwater and wave-induced loads (unit load cases), the global finite element analysis is performed, yielding global deformations and stresses. The next step is the computation of local stresses for unit load cases as well as for a unit pressure acting in the neighborhood of the details under consideration. Taking into account the relationship between global loads and local pressure at the details, the combined effect of both components and corresponding transfer functions for local stresses can be derived. In this step relevant nonlinearities are accounted for.

Transfer functions are used to commutate short-term and long-term stress spectra based on wave statistics of the North Atlantic in general cases. However, for FPSO's the wave climate of the actual operational area is considered. The design life is finally determined using the Palmgren – Miner rule for damage accumulation together with design S-N curves defined in relevant Rules, e.g., Germanischer Lloyd (2007). If the design life is not satisfactory or if there is room for optimization, the procedure is repeated starting from the computation of local stresses for the modified details. The global analysis has to repeated only if major changes are



made, e.g., if the scantlings of primary members are modified.

Fig. 1: Procedure of Integrated Fatigue Analysis

3 Fatigue Response

To determine structural response of loads global finite element models are commonly used.

As an example, Fig. 2 shows a global FE-model of a FPSO with an integrated turret. Global stresses can be derived directly from the FE model, as shown in Fig. 3, for stresses in deck longitudinals.

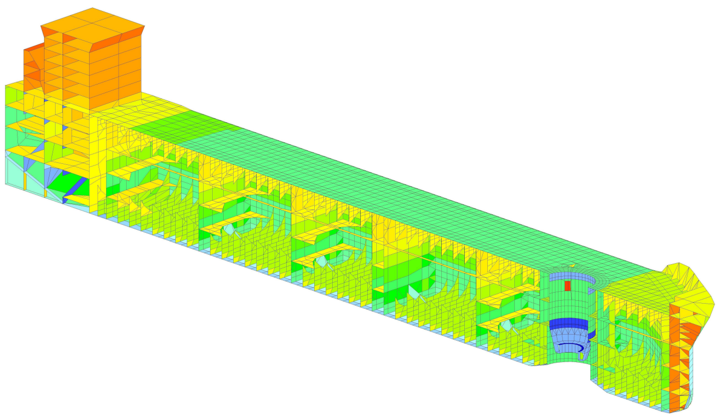


Fig. 2: Global FE-Model of a FPSO

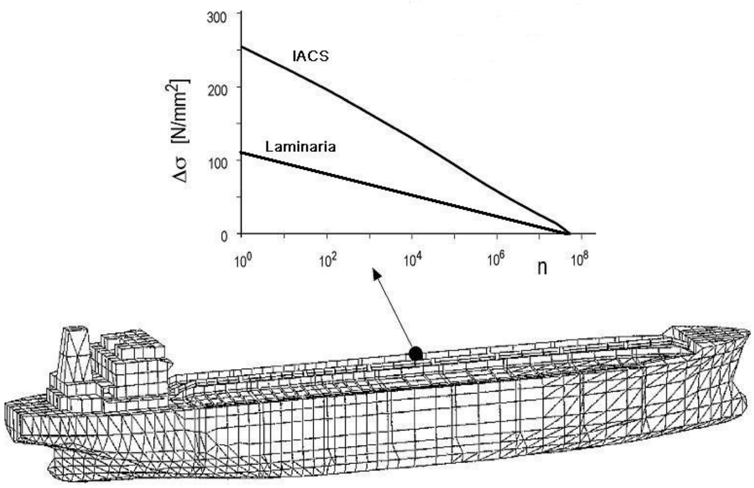


Fig. 3: Stress spectrum for a deck longitudinal

Results were derived from the IACS scatter diagram, representing the North Atlantic area. Investigations of FPSOs operating in Laminaria field, which is a much calmer environment, showed that the stress response can decrease significantly. Vertical bending moments and resulting stresses differ by a factor of more than two. In both cases a straight line spectrum, as given in GL Rules, has been verified (see above figure). In the past it was found that spectral analysis results lead to increased stresses in comparison to Rule values. Therefore an appropriate reduction factor might be necessary to apply to the results. In cases where local pressure loads act additionally, these have to be considered by either locally refined FE models or by superimposing the effects as indicated in Fig. 4.

In the example of side longitudinals, not only global loads and local pressure are important, but also relative deflections of webs influence the stress response due to additional stiffener bending.

As side shell longitudinals are mainly prone to fatigue some additional results will be presented. Due to the large amount of intersection details of longitudinal and transverse webs or with bulkheads respectively and due to high repair costs in case of damage, a sound design is essential.

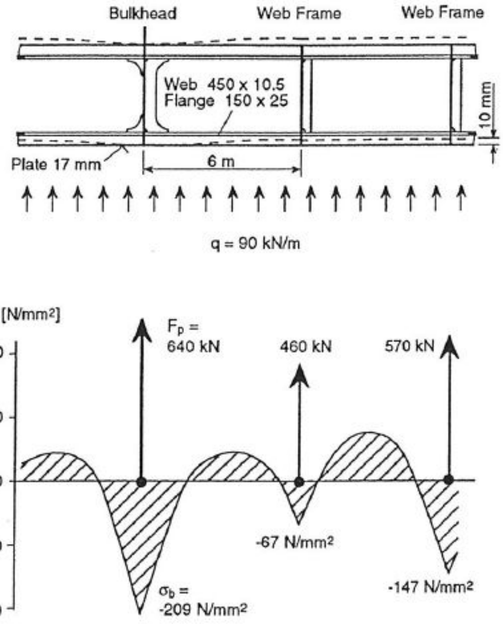


Fig. 4: Bending stress and supporting forces in side longitudinals of a FPSO

Fatigue results can generally be given as cumulative damage sum D, which is the ratio of expected life time to design lifetime. This number is of high interest for the ship-owner, but not very helpful for designers. A better number is the so-called usage factor U, which is the ratio of acting stress range to permissible stress range. Using this, it is easier for the designer to look for countermeasures in case of overstressing.

Fig. 5 shows the distribution of stress range usage factors U obtained for all intersections in the side area of two adjacent cargo tanks. Peak values can be observed at the bulkheads as well as below the sillwater line. Causative effects are relative deflections of webs and local pressure fluctuation, respectively. This is in agreement with the fatigue failures recorded by Yoneya (Yoneya, 1993). Based on the results, modifications can be defined in certain areas which reduce the local notch effects, for instance, by arranging brackets with soft toes at all critical points (see Sect. 0).

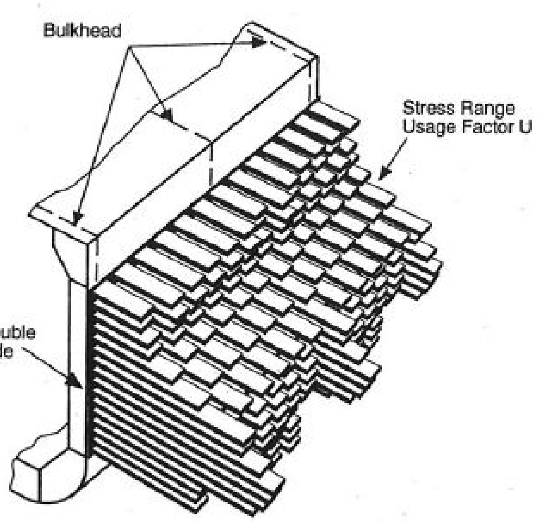


Fig. 5: Usage factors of intersections between side longitudinals and transverses

Results obtained for the intersections at one of the bulkheads are used in the following to illustrate the influence of some factors. Considering only the local bending stress due to the side pressure reveals the effect of global stresses and deflections on the total stress. Fig. 6 shows the resulting stress range usage factors U in comparison with the results including all load effects. It becomes obvious that the fatigue life is considerably affected by the additional stress components, especially by the bending stress due to the relative deflection of primary members, which increase the stresses mostly in the critical area below the stillwater line.

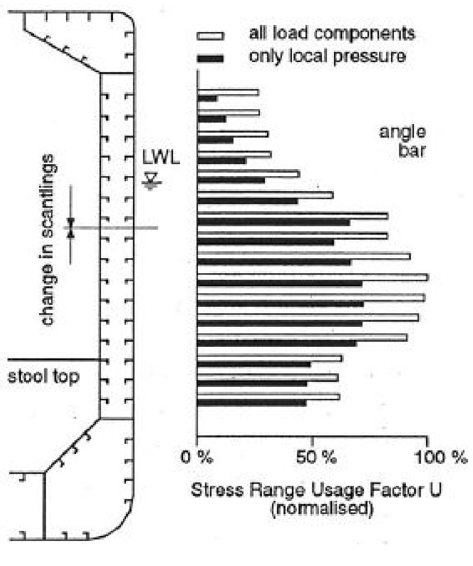


Fig. 6: Effect of load components on the usage factor of side longitudinals

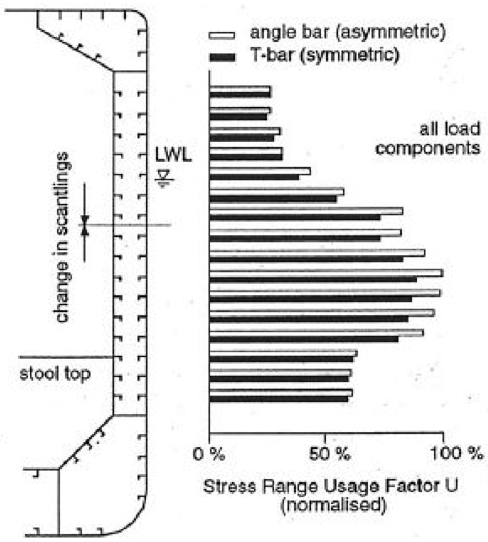


Fig. 7: Effect of the sectional shape on the usage factor of side longitudinals

Another important factor for local stresses is the sectional shape of the longitudinals. Fig. 7 shows the effect of the existing asymmetric section in comparison with symmetric T-bars. The difference is again mostly pronounced below the stillwater line, being in the order of 15%, which means a factor of about two with respect to the expected life time. An L-shaped section, where the flange is arranged at the side of the web and not at the top, would be even more critical because a buckling stiffener or bracket welded to the plate edge (i.e., the top of the web) belongs to the lower detail category "50" acc. to Germanischer Lloyd and International Institute of Welding (Hobbacher, 2007).

The effect of high fluctuating pressures close to or below the waterline has been investigated by Witmer (Witmer, 1994). Fig. 8 impressively shows the damages observed on tankers operating from Alaska to US west coast. Wave direction was mainly from one side, resulting in damages on the starboard side below the fully loaded line and on the opposite ship side below the ballast waterline. This damage scheme was verified by recalculation, using spectral analysis.

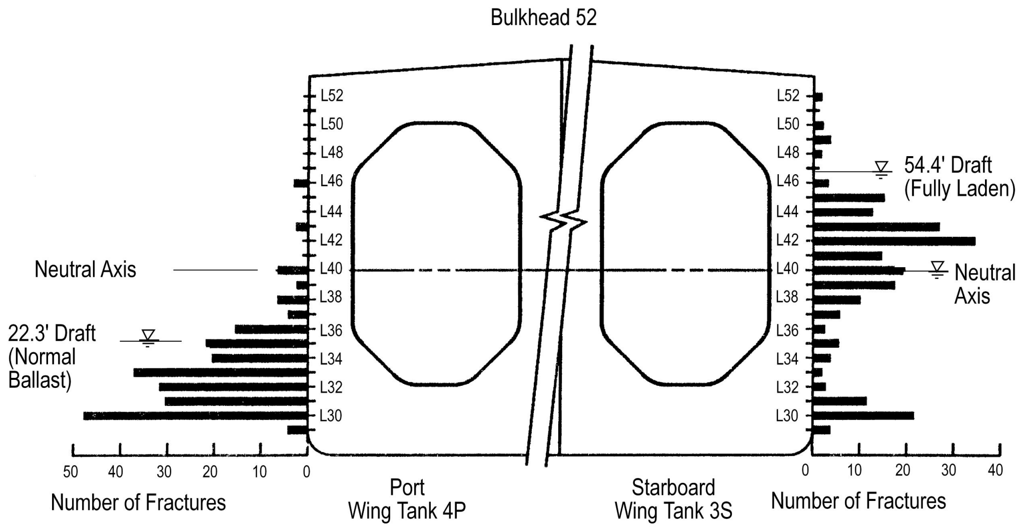


Fig. 8: Vertical distribution of side shell longitudinal fractures of the Atigum Pass Tankers

In context of research activities on strength aspects of tanker structures (Fricke, 1998) fatigue analyses of double hull designs confirmed the described observations made by applying spectral analysis.

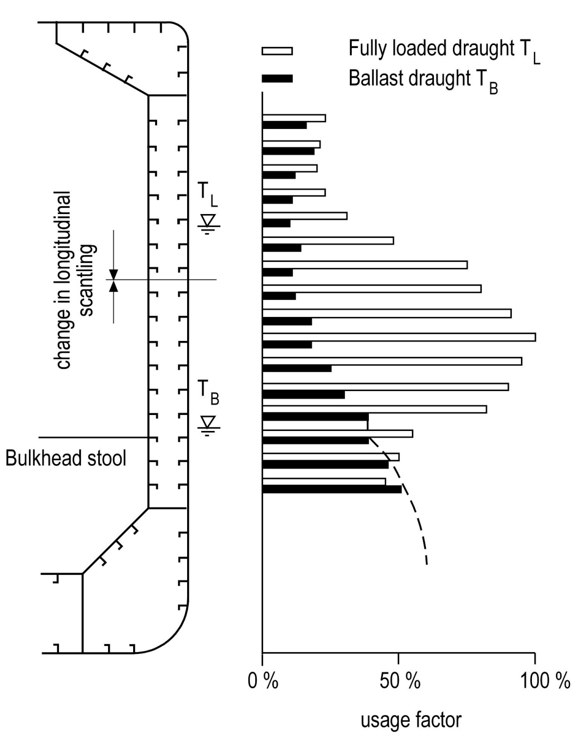


Fig. 9: Effect of draught on usage factors of longitudnals at intersections with web frames

Fig. 9 shows the effect of ballast draught and draught at full load condition on the fatigue life of the intersection of longitudinals with webframes. The bending stresses in the longitudinals caused by wave loads at each draft are the dominating effect on the fatigue life.

4 Repair of Fatigue cracks in side shell longitudnals of an FSO offshore Vietnam

4.1 Initial Situation

In context of an intended extension of the operating time for an existing FSO, an inspection of the structure with a subsequent fatigue analysis has been carried out. Based on the results a repair was conducted without docking the hull. The Hull in question was a 150,000 tdw single hull tanker, built in Sweden around 1975 and converted to an FSO twenty years later, now operating offshore Vietnam.

During the insprection from outside, in close vicinity of a tank bulkhead located approximately at mid ship a vertical crack about 300 mm long in the side shell was reported. The crack was crossing a longitudinal at about half height of the hull.

During the internal inspection it was observed that the L-shape longitudinal frame was fully ruptured. The crack has obviously started at a bracket attached to the frame at an end connection with a bulkhead. The photograph Fig. 10 and the drawing shown in The damage pattern is in excellent accordance to calculation results presented in Sect. 0.

Fig. 11 give an impression of the damage and of the structural design

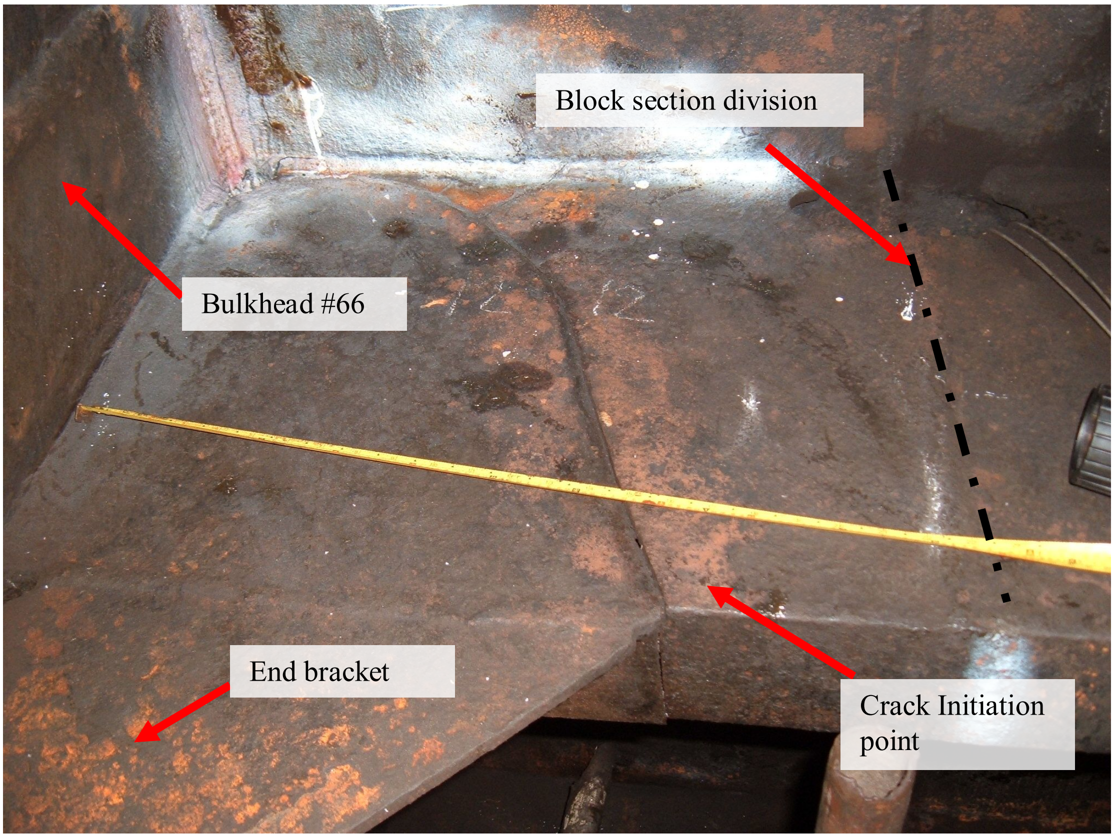


Fig. 10: Longitudinal frame, fully ruptured

Further internal inspection showed that about 75% of the frames had cracks of different lengths, most of them visible to the naked eye. The cracks were all similar, starting at the end bracket where the frame is connected to the transverse tank bulkhead.

The longest cracks were found at about half height of the hull. This is a very clear indication that the dominating loads for the fatigue cracks are local wave loads rather than global hull girder bending loads.

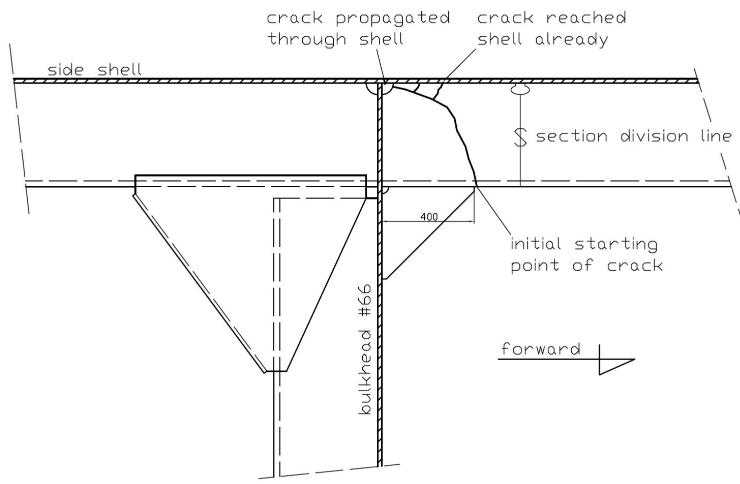


Fig. 11: Original details of the longitudinal framing system in way of the tank bulkheads

The inspection also showed that several repairs have been tried in the past with insufficient success. At some locations the cracks have been re-welded and an extension of the bracket has been installed previously. Although the shape of the extension of the extension was somehow rounded, but this did not provide a sufficiently soft transition to the frame. Consequently the crack re-occurred at the end of the bracket extension. The damage pattern is in excellent accordance to calculation results presented in Sect. 0.

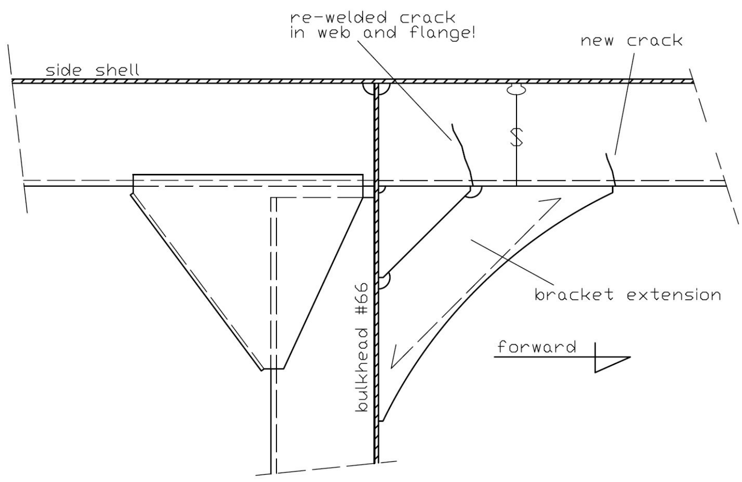


Fig. 12: Intermediate unsuccessful repair of unknown date

It is interesting to note that at the overlapped bracket at the opposite side of the bulkhead no cracks have been found. The welding around the bracket edge of an overlapped bracket obviously creates a smooth detail that improved the fatigue strength. This is also reflected in GL Rules and in IIW recommendations given by Hobbacher (Hobbacher, 2007), where overlapped bracket arrangements have a higher detail category than butt weld connected brackets.

4.2 Repair proposal

Based on the findings on board and a subsequent analysis a repair methodology was proposed. One of the preconditions was that the hull should be taken out of operation for the shortest possible time preferably without docking.

Several calculations for different ballast conditions have been carried out to achieve the least possible vertical still water bending moment in way of the locations to be repaired. The repair sequence limited the number of frames repaired at the same time to only one frame per tank. Further calculations were made to determine the maximum allowable significant wave height during repair, which then was limited to 1 m.

Apart from the environmental conditions under which the repairs should be carried out a technical solution for an improved end connection of the longitudinals has been worked out. The objective was to achieve an increased fatigue life compared with the previous solution. Two significant modifications were proposed, see Fig. 13.

The shape of the newly inserted bracket, replacing the original small one and the previously added extension, shows soft toes at each leg end. Further it was intended to allow sufficient distance between the weld seams around the bracket and the edge of the L-profile. For the latter reason as well as to account for the effect shown in Fig. 7, the shape of the original profile was changed from a L-profile to an asymmetric T-profile, by cutting off the original flange and inserting a flatbar.

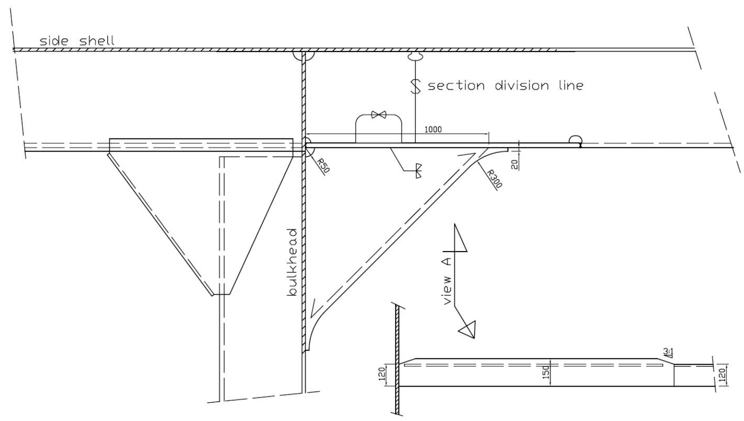


Fig. 13: Proposed repair, bracket with smooth end toes

5 Conclusion

The application of spectral analysis allows identifying the effect of different environmental conditions on the fatigue life of structural components in ship structures. Long term experience and observation of existing structures have confirmed the findings of the previous research work and are basis for the recent refurbishments of FSO structures.

6 REFRENCES

Fricke, W., Scharrer, M., Selle, H. von (1994) Integrated Fatigue Analysis of Ship Structures, Proceedings of 5th IMDC and Summer Meeting of STG, Delft 1994.

Fricke, W., Scharrer, M., Selle, H. von (1995) Integrated Fatigue Analysis of Tanker Structures, 6th International Symposium on Practical Design of Ships and Mobile Units, Seoul 1995.

Fricke, W., Rathje, H., Selle, H. von (1998) Strength Aspects of Tanker Structures (in German), Jahrbuch der Schiffbautechnischen Gesellschaft 1998

Germanischer Lloyd (2007), Rules for Classification and Construction, Ship Technology, Hull Structures, Sect. 20 Fatigue

Guedes Soares, C., Gorbatov, Y., Selle, H. von (2003) Fatigue Damage of Ship Structural Components Based on the Long-term Distribution of Local Stresses, International Shipbuilding Progress, Vol. 50, No. 1, pp. 35-56

Payer, H. G., Fricke, W. (1994) Rational Dimesioning and Anlaysis of Complex Ship Structures, Transactions SNAME

Witmer, D.J., Lewis J.W. (1994), Operational and Scientific Hull Structure Monitoring on TAPS Trade Tankers, Transactions SNAME, Vol. 102

Yoneya, T., Kumano, A., Yamamoto, N., Shigemi, T. (1993), Hull Cracking of Very Large Ship Structures, Proc. Of 5th International Conference on Integrity of Offshore Structures, Glasgow

Hobbacher, A. (2007), Recommendations for Fatigue Design of Welded Joints and Components, International Institute of Welding, Document XIII-1965-03 / XV-1127-03