Analysis and Design of Marine Structures – Guedes Soares & Das (eds)
© 2009 Taylor & Francis Group, London, ISBN 978-0-415-54934-9

Global strength analysis of ships with special focus on fatigue of hatch corners

H. von Selle, O. Doerk & M. Scharrer
Germanischer Lloyd AG, Hamburg, Germany

ABSTRACT: Global analysis of ships using the finite element method is a widespread technique. The importance of this type of analysis has grown in recent years due to the fact that ship sizes are increasing rapidly,especially container vessels. This paper gives an overview of global FE-analysis and evaluation. The main focus is the fatigue assessment of hatch corners. Due to the stress concentration hatch corners show a high degree of utilization, thus sound fatigue behaviour is essential. Germanischer Lloyd (GL) developed a technique allowing fatigue assessment of hatch corner radii in a very effective way by means of local detail model computation. The result assessment according to GL rules is being presented here. Finally the paper describes the extension of the tool on hatch corners without any radii which are found frequently in lower decks. Here the hotspot or structural stress approach is used. The assessment is based on latest fatigue recommendations published by the International Institute of Welding IIW.

1 INTRODUCTION

Nowadays it is common practice to perform global strength analyses of ships as a powerful tool to design a well-balanced and utilized vessel. This analysis technique is recommended especially in cases where new ship designs differ significantly from those ships which are proven and already operating for a long time. Increased ship sizes, unconventional designs, use of new materials or materials with new properties, e.g. steel with increased yield strength are reasons for global finite element calculations. It enables the engineer to detect areas of poor design and it also allows design optimisation.

From a class point of view it has to be emphasized that such an analysis does not replace the plan approval procedure. This is carried out in addition and will lead to a better design.

This paper is mainly based on analysis performed by Germanischer Lloyd (GL) as engineering services.

2 OVERVIEW OF GLOBAL FE-ANALYSIS

Despite many efforts in the development of global analyses, this technique is still very time consuming. The following steps have to be taken:

- Generation of a global finite element model
- Generation of loading condition and design wave load cases
- FE-calculation
- Calculation evaluation
- Drawing conclusions (proposal of reinforcements if overstressed areas have been detected)

A more detailed description can be found in Payer & Fricke (1994).

2.1 *Finite element model*

Many software packages are available for generating finite element models. As well as others Patran, Ansys, Hypermesh and Poseidon are well known in the shipbuilding industries. GL is using GL Ship-Model, a Patran based tool, Poseidon as well as an in-house developed program ISG, which is an internal GL program. Not only the capabilities of a tool are of importance but also the support by the developer, the acceptance by the users as well as the in-house experience, especially in the case of trouble shooting.

Global FE-models consist of a big amount of input data and therefore it is important to keep an overview of the model. A well grouped model structure and proper model documentation is essential for checking the FE model, e.g. element scantlings as well as material properties. Figure 1 shows a sample FE-model of a large container vessel.

2.2 *Load generation*

The load generation consists of the definition of relevant loading conditions, e.g. ballast and fully loaded condition for tankers and bulk carriers or representative loading conditions for container vessels and other ship types.

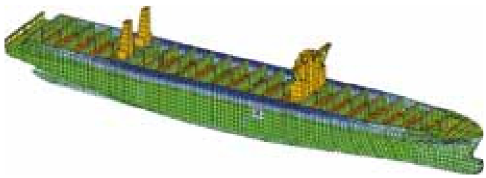

Figure 1. Sample Global FE-model.

For these loading conditions design wave load cases have to be created which need to meet the requirements given in rules or values coming from direct load calculation. For this purpose the software package GL ShipLoad was developed (Roerup et al., 2008). A graphical user interface facilitates the convenient application of ship and cargo masses to the finite element model and helps the selection of the relevant design wave situation. User defined selection criteria, such as the maximum values of sectional forces and moments, specify which waves have to be chosen for the global analysis. Scanning some thousands of wave parameter combinations leads to about 30 to 60 load cases which are taken as design load cases for the finite element calculation. The load cases are well balanced, which means ship acceleration forces are in equilibrium with forces from water pressure. For information on underlying theory see Hachmann (1991). Figure 2 shows a vessel in a typical wave sagging condition.

Figure 2. Container vessel in wave sagging condition.

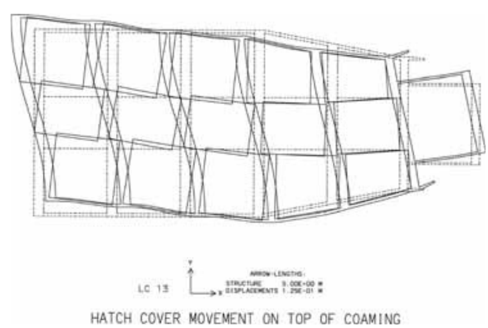

Figure 3. Hatch cover movements.

2.3 *Calculation*

During the last decades the demands on strength analyses have been increased rapidly but at the same time the computation capacity has been increased too. Therefore computation restrictions no longer exist in most cases. Most software packages include pre-processing tools, solvers as well as post processing tools.

2.4 *Evaluation*

Calculation evaluation according to the rules and standards should cover the following items:

- Deformations
- Stresses
- Buckling
- Ultimate strength
- Fatigue

Fatigue as the major topic of this paper is described in the next chapter separately.

2.4.1 *Deformation*

The checking of deformation is a precondition to gain confidence in calculated results. In general deformations do not influence strength in a negative way, but the functionality of structures must be ensured, e.g. ramps, door openings, clearance of car decks and hatch cover movement. The latter are demonstrated in Figure 3.

2.4.2 *Stresses*

To get a first impression of stress behaviour, equivalent stress plots are helpful. Principal stresses as well as shear stresses should be checked for further assessment. To keep the output as small as possible maximum stresses from all load cases can be stored for each element. This is a special GL-feature. Each stress type has to be checked separately against allowed values.

Figure 4 is a sample demonstration of equivalent stresses for a container vessel.

2.4.3 *Buckling*

Normally, a plate field buckling evaluation is one of the most time consuming tasks. This is due to the fact that the plate field and stiffener scantling information are not stored in FE-models, even though they are needed for the evaluation. However, the Poseidon software does store these information needed for dimensioning.

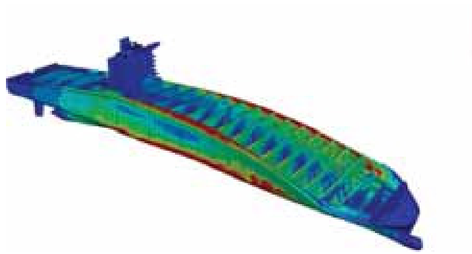

Figure 4. Equivalent stresses for a container vessel.

2.4.4 *Ultimate strength*

The Ultimate strength analyses by means of the finite element method are occasionally carried out for investigation of collision and grounding. The latest GL Rules cover also the ultimate checks but they are not FE-based.

3 FATIGUE

The fatigue of ship structures has become more and more important during the last decades. Reasons are trends to light weight structures, use of new materials as well as structural optimisation to a large extent.

Potential fatigue crack initiation points are welded components or free plate edges. In both cases the local design is the crucial factor. For the assessment of these, local design methods can be used, as described below. For typical cracks see Figure 5. The cracked welded detail (left) shows impressively the smooth surface of the fatigue crack propagation area and the rough surface of the final crack. The right Figure shows a crack starting from a plate edge. For fatigue assessment fine mesh calculations are usually needed.

3.1 *Local strength analysis*

The use of local strength analyses is a common practice to overcome the failure of global analyses with coarse meshes. The following methods exist:

- Stress concentration factors SCFs
- Sub-model technique
- Sub-structure technique
- Locally refined global FE-models

The use of stress concentration factors SCFs is a very fast and effective method but it works only if SCFs are available and if a well defined nominal stress state can be found.

Sub-models represent local details modelled with a fine mesh. The models are to be solved separately by applying the boundary displacements taken from the global analysis.

The sub-structure technique requires also a local fine mesh model but the internal degrees of freedom are condensed to boundary nodes and the resulting stiffness matrix is incorporated into the global finite element model.

Figure 5. Fatigue cracks.

For the last method the global FE-model has to be refined locally. If there is a lot of details, this method results in a large FE-system and corresponding computation time.

GL prefers the sub-model technique as it is a very simple post-processing method. Besides it does not require a re-calculation of the global model as would be necessary for the last two procedures. From a practical point of view it allows generation of the global model as well as the definition of details in parallel.

3.2 *Fatigue of hatch corners with corner radii (free plate edge)*

The sub-model procedure described here is an in-house development. Despite the fact that commercial programs such as ANSYS offer also the opportunity for local mesh refinement, the in-house development has been preferred. This is due to the fact that beside simple mesh refinement components have to be incorporated into the local model which are not part of the global model such as hatch corner radii and insert plates. Another reason is that the procedure fits well into GL's pre- and post-processing environment.

Steps are:

- Definition of details after global calculation run
- Set up of locally refined detail model by GL software
- Fatigue evaluation according to GL Rules

The definition of the details which are to be investigated can be done either interactively using the global model or by using an editor. In both cases the following data has to be defined:

- Geometry
  1. Location
  2. Size of radius (or ellipse)

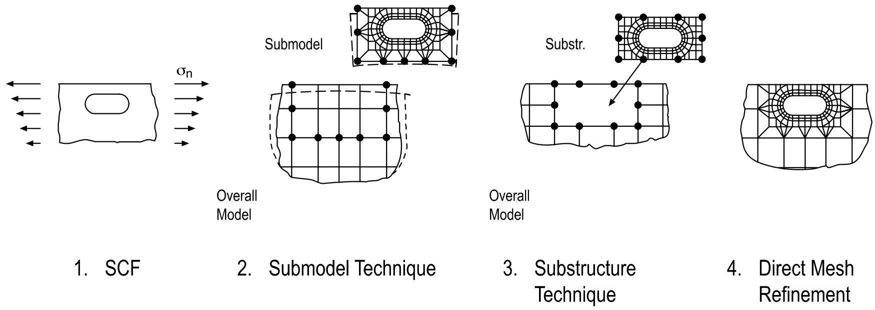

Figure 6. Methods for local strength analyses.

3. Plate thickness
4. Size of insert plate (if arranged)

- Fatigue parameters
  1. Material yield strength
  2. Fat class or detail category (quality of cut surface)
  3. Slope of SN-curve
  4. Shape of load spectrum
  5. Number of cycles (design life time)
  6. Load cases to be considerd.

One additional parameter defines the size of the detail model, i.e. how many elements of the global model adjacent to the corner are included in the detail model.

Bottom of Figure 7 shows a typical local model. As can be seen, the mesh is not ideal. The transition gradient from small elements to large sized elements is very hard, but comparison calculations showed that the stresses along the corner radius are not affected by this. Top of Figure 7 shows all local models for the fore part of a container vessel. For each hatch corner a separate model is established. The models penetrate each other but they are not connected physically. A special feature can be used to shift the model so that it can be checked better.

Calculation results are tangential stresses along the corner radius which is subdivided into 10 elements (evaluation positions). For each position the maximum stress range from all load cases is listed. In case of symmetric ship structures it is sufficient to consider waves coming from one ship side only. In these cases stress results from port side and starboard have to be combined. In the end the acting stress ranges are compared with permissible stress ranges taking into consideration the mean stress effect.

The permissible stress ranges can easily be determined by using the GL Rules (Germanischer Lloyd 2008).

From the load side a straight line spectrum can be assumed (spectrum A acc. Figure 8) in combination with 50 million load cycles for 20 years design life, as is usual for seaway induced loads.

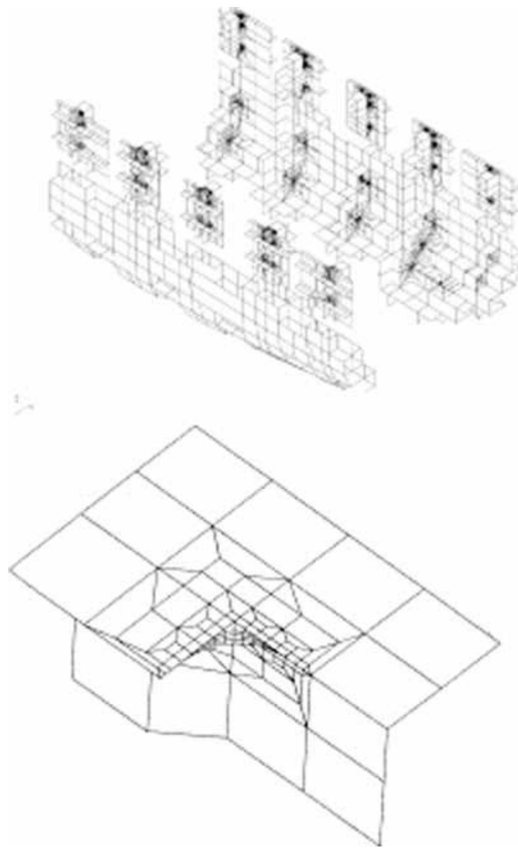

Figure 7. Detail models of hatch corners radius.

The load carrying capacity is reflected by an appropriate SN-curve (Figure 9). The different curves are valid according to the surface quality.

Using these data a linear damage calculation according to Miner's Rule can be performed resulting in a damage sum D. Instead of the damage sum D the usage factor U is used frequently, as it is related to

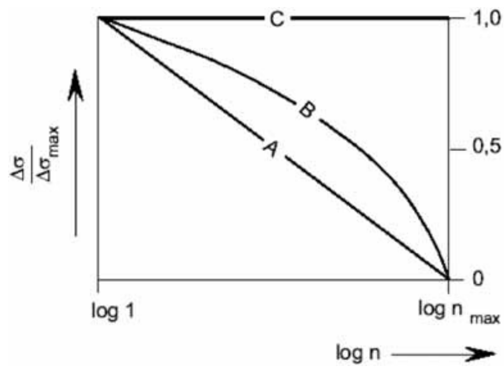

Figure 8. Standard stress spectra.

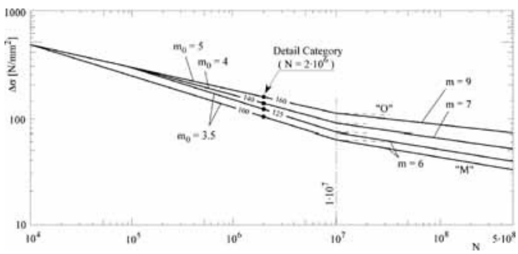

Figure 9. SN-curve for cut edges of different quality.

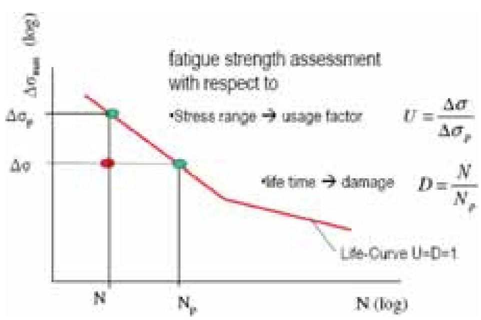

Figure 10. Definition of damage D and usage factor U.

stresses and therefore more helpful for engineers. The difference is illustrated in Figure 10.

In case of a detection of overstressed hatch corners an Excel-sheet is provided to find appropriate countermeasures. It is based on regression curves which reflect the influence of:

- Increase of corner radius
- Arrangement of insert plate with increased thickness
- Use of higher tensile steel
- Improvement of surface quality by grinding

The best solution should be fined for together with the shipyard.

It should be emphasised that this procedure is not restricted to hatch corners but it can also be used for opening corners in general, e.g. doors and windows.

3.3 *Fatigue of hatch corners without corner radii*

The work flow for hatch corners without radii is similar to that with radii but the concept of assessment has to be changed as the potential crack initiation point is now a weld.

Differences are:

- Assessment of welds instead of plate edges
- No fatigue bonus for higher tensile steel
- Special requirement on meshing
- Different SN-curves

The method implemented at GL is the so-called hot-spot or structural stress concept (Hobbacher, 2007, Niemi & Fricke & Maddox 2006). The notch stress approach (Fricke, 2008) would be suitable too, but it is much more complicated from a modelling point of view and the results are not always reliable.

The hot-spot concept requires a pre-defined mesh arrangement of the FE-model close to the weld, e.g. element sizes equal to plate thickness for welds on a plate surface. The method works with shell elements as well as with solid elements (Figure 11). The hot-spot stress is taken as the linear extrapolated stress from the two elements adjacent to the weld. A sample local FE-model is shown in Figure 12.

Again a stress spectrum using the maximum hot-spot stress range has to be set up (e.g. straight line spectrum A acc. to Germanischer Lloyd 2007, see Figure 8). As the hot-spot stress includes all stress concentrations towards the weld, unique SN-curves with appropriate Fat classes are used (Figure 13). The reference stress range values or Fat-classes are 90 and 100 for load carrying and non-load carrying welds respectively.

As described for hatch corners with radii Damages or Usage factors have to be calculated. Countermeasures in case of a detection of overstressed corners are a local re-design or the arrangement of a radius bracket.

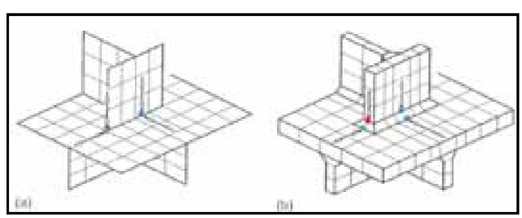

Figure 11. FE-mesh according to hot-spot concept.

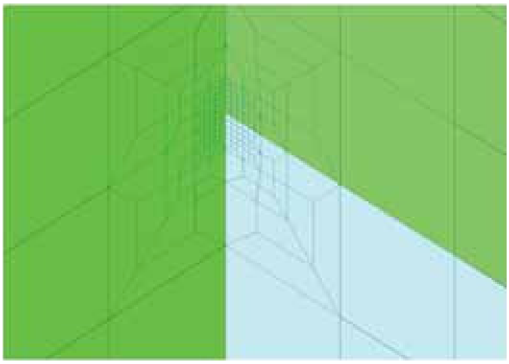

Figure 12. Sample FE-model for hot-spot concept.

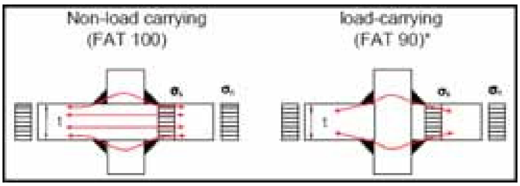

Figure 13. Unique fat classes for hot-spot concept.

4 CONCLUSIONS

With the fatigue assessment for hatch corners as described above, a powerful tool has been developed. It enables engineers to assess all hatch corners of a large container vessel in one day. The method is not restricted to hatch corners but is also suitable for other opening corners such as windows and door openings.

ACKNOWLEDGMENTS

This paper has been partly compiled within the Network of Excellence on Marine Structures (MARSTRUCT), which has been founded by the European Union through the Growth programme under contract TNE3-CT-2003-506141.

REFERENCES

Cabos, C., Eisen, H. & Krömer, M., 2006, GL ShipLoad: An integrated load generation tool for FE analysis. *Proc. 5th Int. Conf. on Computer Application and Information Technology in the Maritime Industries (COMPIT),* Grimmelius, H.T. (ed.), Delft University of Technology, Oegstgeest, The Netherlands, pp. 199–210.

Fricke, W., 2008, Guideline for the Fatigue Assessment by Notch Stress Analysis for Welded Structures, *International Institute of Welding,* IIW-Doc. XII-WG3–03r7.

Germanischer Lloyd, 1997, *GL-Technology*, Fatigue Strength of Ship Structures, part I: Basic Principles.

Germanischer Lloyd, 1998, *GL-Technology*, Fatigue Strength of Ship Structures, part II: Examples.

Germanischer Lloyd, 2008, *Rules for Classification and Construction*, I—Ship Technology, Part 1—Sea-going Ships, Chapter 1—Hull Structures.

Germanischer Lloyd, 2007, *Rules for Classification and Construction*, V—Analysis Techniques, Part 1—Hull Structural Design Analyses, Chapter 1—Guidelines for Global Strength Analyses of Container Ships.

Germanischer Lloyd, 2009, *Tutorial* Poseidon Software.

Hachmann, D., 1991, Calculation of Pressures on a Ship's Hull in Waves. *J. Ship Tech. Res.,* Vol. 38, pp. 11–132.

Payer, H.G. & Fricke, W., 1994, Rational Dimensioning and Analysis of Complex Ship Structures, *SNAME Trans.* Vol. 102.

Roerup, J., Schellin, T.E. & Rathje, H., 2008.

Load Generation for Structural Strength Analysis of Large Containerships, *ASME 27th International Conference on Offshore Mechanics and Arctic Engineering*.