Fatigue Design of a Shuttle Tanker for the North Atlantic Operation

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Abstract

In general, structural design of a shuttle tanker operating in a harsh environment such as the North Atlantic and the North Sea needs the special requirements of winterization for the cold climate and the enhanced fatigue lives due to the severer wave loadings than the benign conditions.
HHI has completed design of a shuttle tanker which will be operated in a harsh environment with special equipments such as twin schilling rudder system, DP system, the latest bow loading system and helicopter deck. She is winterized and has a WINTERIZED COLD(-15^{o}C, -35^{o}C) and ICE-1C notation from DNV. The deck trunk structure from the accommodation to the forecastle is installed on the upper deck in order to protect all the pump heads and pipelines by an enclosed shelter and to be utilized as a sheltered passageway for the crews.
To meet requirements for the enhanced fatigue lives and the special notation of PLUS & CSA-FLS2, the direct analysis is carried out. The very fine-meshed F. E. calculations for verification of fatigue strength of the stiffener & frame connection are performed according to the procedure specified by the PLUS notation based on the Rule loadings and 3-holds cargo model.
Spectral fatigue calculation is applied to assess the fatigue strengths of the longitudinal connections, bottom and side shell plating connections and critical details in cargo hold area such as hopper knuckles, stringer/bracket ends and etc.. The inertia loads and external and internal pressure calculated in the hydrodynamic analysis are directly transferred to the structural model to calculate the fatigue damages at the hot-spot locations.
According to the results of spectral fatigue calculation, the higher values of the hull girder loadings than CSR requirement are applied and the scantlings were reinforced and the details of the weld attachments, deck openings and penetrations in the deck trunk and the upper deck area were designed with care to improve the fatigue strength.
This study introduces the overall results of fatigue design of a shuttle tanker with special notation for operating in the North Atlantic and also some technical issues related to the direct calculations of hydrodynamic analysis and spectral analysis.

1 Introduction

As development of the oil field moves to deeper and harsher environment, the needs for the stricter requirementsincrease for the hull structural design. In general, structural design of the general type of tanker would be done based on Common Structure Rule(CSR) and all the requirements for fatigue strength is also fulfilled with ease if we follow the procedure of CSR.
Even though CSR guaranteesthe minimum design life of 25 years in North Atlantic operation, the ship owner still insists the stricter reinforcement of the hull structures of the ship operating on the harsh environment.
The paper describes the CSA-FLS2 analysis of a 123K shuttle tanker and focuses on direct calculation procedures and the corresponding results obtained during verification of fatigue design of hull structures. This includes hydrodynamic analysis, global and local structural analysis and FLS(Fatigue Limit State) post processing.
These additionalnotations of CSA-FLS2 and PLUS are especially relevant for shuttle tankers which

should fulfill the operating in harsh environment like the North Atlantic or the North Sea.
All calculations are based on direct calculated wave loads using a 3D hydrodynamic program, includingeffect of forward speed. The pressures and inertia loads from the hydrodynamic analysis are transferred tothe FE-models.
The DNV classification notation CSA-FLS2 is based on direct calculation procedures. Compared to the traditional approach of using simplified rule formulas, direct wave load calculations improves the accuracy and reliability of the calculated loads and is tailored for intended wave environment.
Customized in-house programs were developed and used to reduce the time spent in carrying out a lot of calculation under the limited designing time instead of SESAM package. Verification of each module used in calculation was done to confirm equivalency of the in-house program to SESAM package and all the intermittent results were verified to be applicable for calculation.
The paper shows the results of structural design of the target ship which has a special notation for operating in the harsh environment and summarizes some technical issues arisen during verification of in-house programs used for calculations.
For reference, the principal dimensions and characteristics of the shuttle tankers are as follows and this vessel will call at Goliat on a weekly basis to collect about 850,000 barrels of crude oil from the Goliat FPSO.The vessel is designed for 30 years in North Atlantic operation even though she is actually scheduled to be operated in the Barents Sea.

Length between perpendiculars , L_{PP}	256	m
Breadth moulded, B	46.0	m
Depth moulded, D	22.7	m
Draught moulded, T (Design)	15	m
Design speed	16.71	knots

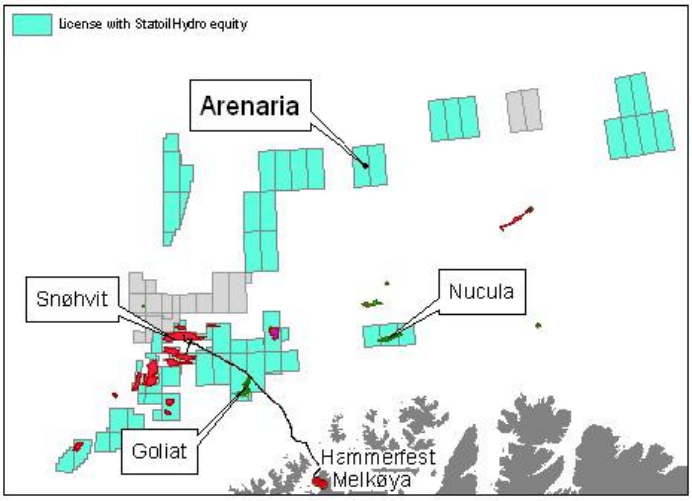


Fig. 1 Goliat field and operating route of 123K shuttle tanker

2 General procedure of CSA-FLS2

The CSA(Computational Ship Analysis, CSA hereafter) is the structural assessment method using wave load analysis to obtain the loading condition applied on the ship structure directly. It is needed because the ship rule of the Classification Societies does not cover the noble ship and the special ship completely. Hence, in the CSA, the loadings such as pressure distribution, inertia force and etc. are calculated by 3D potential code.General procedure of the CSA is shown in Fig.

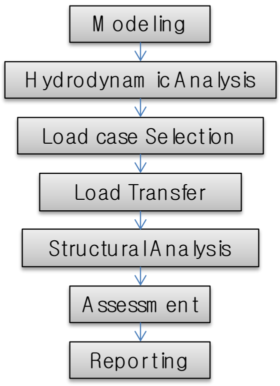


Fig. 2 General Procedure of CSA

The object of assessment is verification of the capacity of the structural strength or the estimation of the fatigue life as necessary. The CSA is mainly used to design the purpose of additional reinforcement.
Even though CSA-FLS2 calculation can be used for reasonable numerical calculation of the ship structure,the calculation process is very complicated and it is very difficult to fulfill without any human errors.
For example, the 3D panel code uses the hydrodynamic panels representing the hull form below the water line for calculation of the wave forces and it requires, in general, the coarser panel than F.E. model. The load transfer from hydrodynamic panel model to FEM fine mesh model is also needed. In this case, the mesh size of these models is not same with each other. Therefore the approximate interpolation is indispensible and its accuracy is dependent on the interpolation methods.
Furthermore, the ship motion analysis should be performed for each sea state, wave encounter frequency, phase and heading angle. This calculation needs very large amount of computational calculation. If we take into account 12 heading angles, 32 frequencies and real/imaginary phase, then the total number of calculation is 769 including the static load case. Hereafter the number of calculation is same at the load transfer, FE analysis, assessment of the FE result and etc. in the whole calculation process. If the loading conditions are added, the number of calculation is to be increased as the same multiples of the loading condition accordingly.As a result, if local analyses are considered, the total number of calculations increases exponentially.
In some cases, the softwares provided by Classification Societies commercially have much inconvenient environment to be adopted in the design process. In case of the DNV, the SESAM package provides the whole DLA procedure such as ship motion analysis, load transfer, FE analysis and so on. Using this package, it is difficult to carry out DLA for general cargo ships as well as offshore structure. Fig. 3 shows overall construction of the SESAM package.
Basically, SESAM packages provide users with a variety of numerical analysis tools to be adopted in CSA calculation. However, it is not easy to use each tool with ease for carrying out the whole calculations especially involved in the F.E. analysis(solving), load transfer and fatigue calculation. In addition, there are some unnecessary options not used for a general procedure of CSA.
In case of SESTRA, the F. E. solver, this module was developed in 1980s and it is difficult to handle the large F. E. model. Therefore, it is spend large amount of time and it is not easy to validate the result of analysis within limited time.

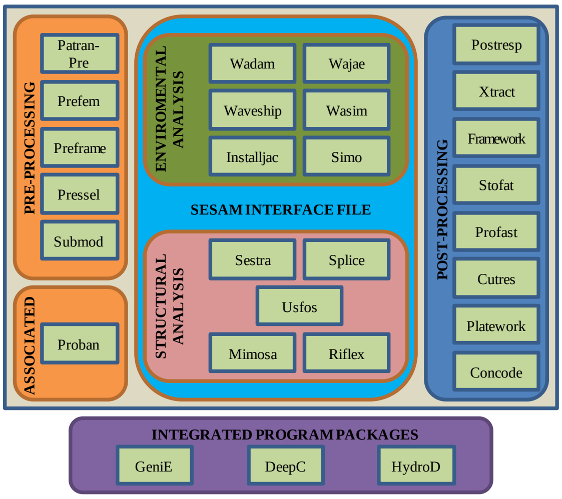


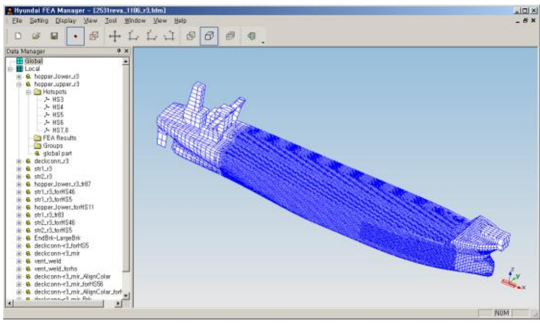
Fig. 3 The Organization of the SESAM package

There are such as the application of the swell, the type of wave spectrum, the function type of spreading effect and so on. These features give the advantage to the experienced person or the designer of the various types of vessels. But in practical point of view, it is not necessary to take into account all the parameters to be used.In case of ship structure, for example, the Pierson–Moskowitzwave spectrum is used only for calculation of the stress spectrum and the other spectrum types are not necessary.

In that sense, an in-house program is required to carry out spectral fatigue analysis within the limited times for actual ship design and also to reduce the possibility of human errors met during a number of the numerical calculations by automatic data flow into each module.

The HDSAFE (Hyundai Direct Strength Assessment system FEA based) is composed of two modules, HFM (FEA Manager) and HSM (Spectral Manager). HFM is used for handling of FE model and load transfer such as load mapping of global to local model, management of local models and etc. HSM is basically used for calculation of fatigue damage and also provide some useful tools for managing the stress spectrum of local hotspot and short term & long term statistical characteristics.

The typical screen shot of these modules are shown in Figs. 4 & 5.



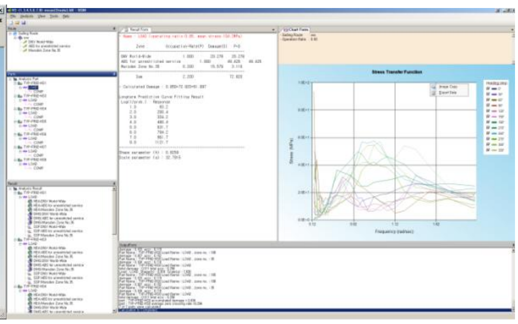


Fig. 4 The Screen Shot of the HFMFig. 5 The Screen Shot of the HSM

3 CSA-FLS2 calculation for 123K shuttle tanker

The fatigue calculations are carried out according to the CSA-FLS2 requirements based on the following assumptions.

- The calculations are based on a fatigue design life of 30 years based on the North Atlantic wave environment.
- The calculations are based on 42.5% on the design life in full load condition and 42.5% in ballast condition.

All fatigue calculations are based on direct calculated loads and stochastic (spectral) analysis procedures.

According to the calculated location, two type of spectral fatigue methodology are applied- CSA (component stochastic approach) and FSA (full stochastic approach).In this paper, only the FSA results will be introduced.

For fatigue strength calculations linear wave load analyses are performed for the two loading conditions based on a 2/3 of design speed. The hydrodynamic loads have been calculated using a seakeeping computation program WASIM in the SESAM package. Fig. shows a hydrodynamic model with free surface.

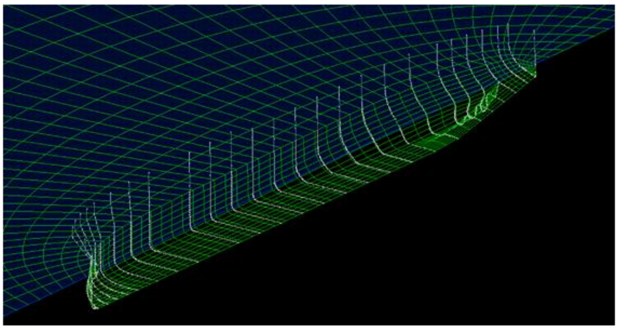


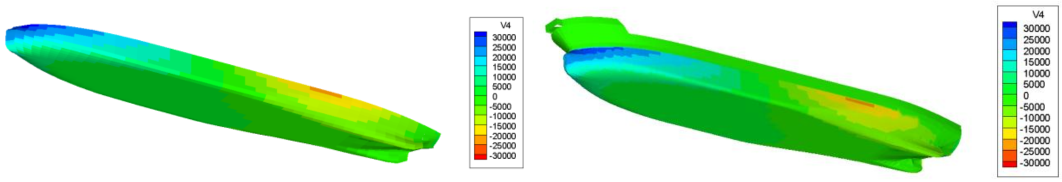
Fig. 6: Hydrodynamic Panel Model including the Free Surface for WASIM

The wave load analysis is carried out for speeds corresponding to 2/3 of the design speed for the fatigue analysis.

Design fatigue life of hull structure to be 30 years based on North Atlantic conditions. Fatigue strength analysis is to be performed in accordance with the Classification Society's standard procedure. The IACS North Atlantic scatter diagram is used.

For accurate prediction of roll motion, viscous roll damping should be considered in calculation. In this project, linearized viscous roll damping was used of 5% critical damping for conservative analysis.

To perform the FE analysis, loading conditions which generated by the WASIM is to be converted to the purpose of FE analysis based on FE model. It is performed by'WASIMpress' module which is developed in HHI. Fig. shows the comparison of external pressure between panel model for ship motion analysis and finite element model for structural analysis using the Nastran.



(a) Hydrodynamic panel model (b) Finite element model

Fig. 7: Comparison of the Pressure Distribution

Global structure model is meshed with the whole structure of the vessel using combination of stiffener spacing and girder spacing mesh. The model consists of 3 and 4-node elements for plating and 2-node beam elements for stiffeners. Fig. shows the global structural model for analysis.Local structure model is also modeled similar to global model but the mesh size of hotspot region is t x t and local detail shapes are applied. Fig. shows an example of local model with hot spot points. 6 hotspot locations are investigated in upper hopper corner.

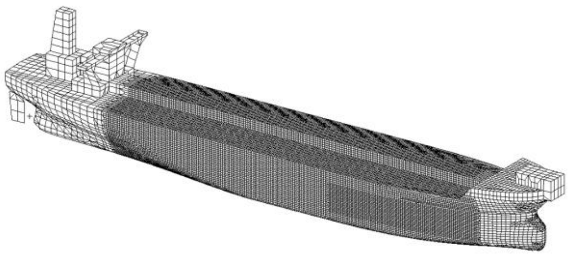


Fig. 8 Global FE Model for Analysis

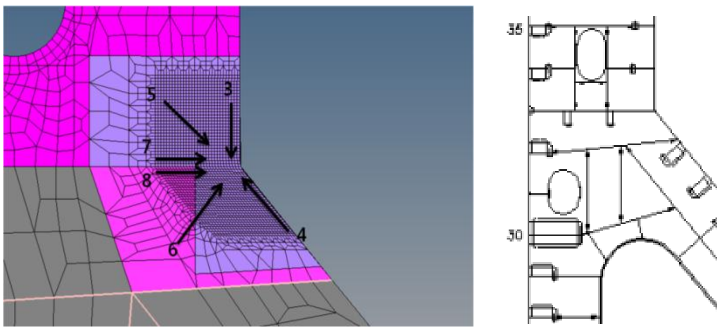


Fig. 9 Hotspot locations of the upper hopper corner

Fig. shows stress distributions global model and local model on large bracket. In this figure, the adequacy of global local mapping can be verified.

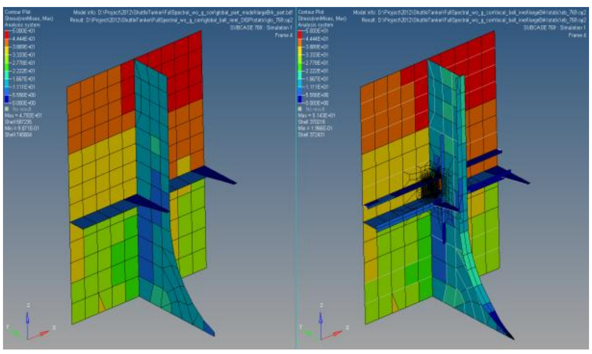
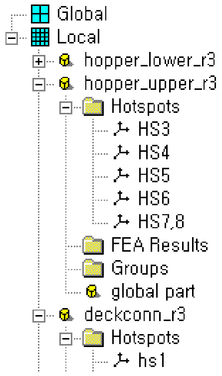


Fig. 10 Stress Distribution of Large Bracket(global model vs. local model)

The fatigue evaluation base on global mesh size is performed for the purpose of finding the location having the lowest fatigue capacity and the estimation of fatigue strength along the longitudinal direction with same detail structure.
The allowable SCF for deck attachment can be estimated. It is performed to check the fatigue capacity of welded connection. If it was not satisfied the allowable fatigue damage ratio, the local detail of weld shall

be reinforced to avoid the fatigue damage.
Hotspot locations are defined to extract the stress transfer function such as. In HFM, hotspots in the local model are managed as tree structure as shown in Fig. and Fig. shows the stress spectrum of the hotspot location.



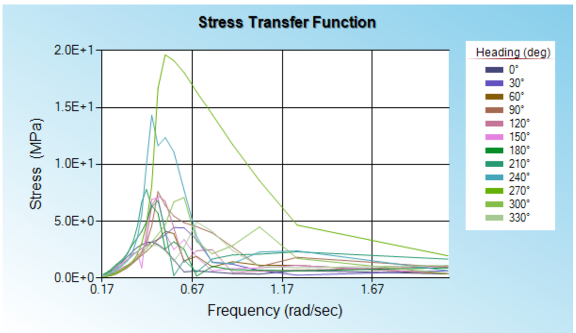


Fig. 11 Local Models and Hotspots in HFMFig. 12 STF on Hotspot 3 of Upp. Hopper Corner

Fig. shows the damage ratio of the hotspots in lower hopper corner along the longitudinal direction. The calculated local hotspot is located at frame number 80. Using global screening results, the damage ratio is estimated along longitudinal direction.

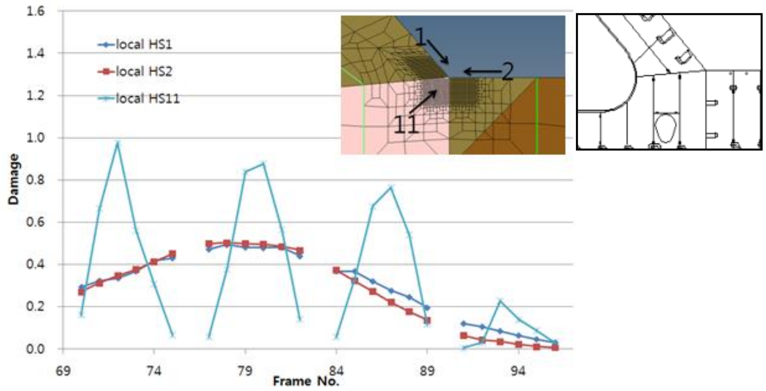


Fig. 13 Damage Estimation along the Longitudinal Direction

Damages are shown with some different ways.Fig. shows the fatigue damage ratio distribution of each wave heading, it provides information for directional influences of wave headings. Fig. shows the short-term damage histogram each sea state.

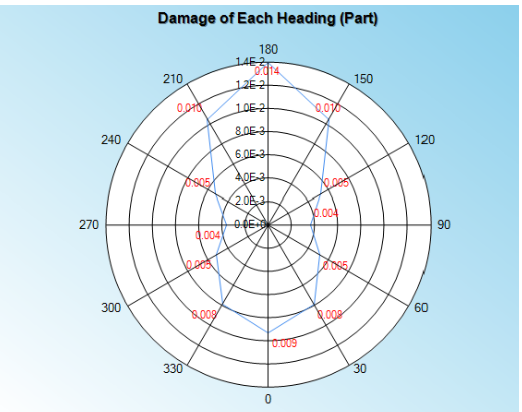


Fig. 14 PolarPlot of Fatigue Damage for Each Heading (equal probability for all heading)

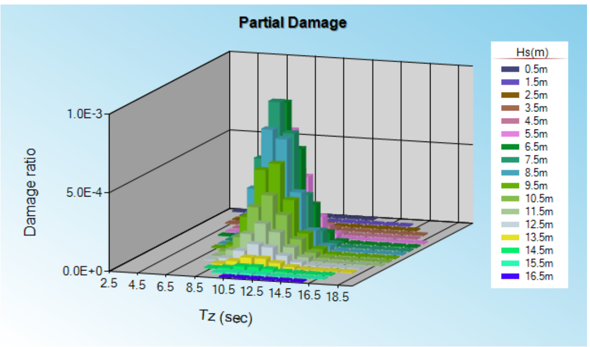


Fig. 15 Damage Histogram on Sea State

4 Conclusions

CSA-FLS2 needs many numerical calculations and quite a number of parameters. Therefore, it is easy to occur the human error and the calculation procedure is difficult to understand.
Using developed system, HDSAFE, the process for CSA-FLS2 is standardized and automated. Afterwards it is carried out to spectral fatigue analysis for a shuttle tanker.
Through the comparison with DNV software, the suitability of the HDSAFE is verified.
From this study, the calculation time is reduced and the probability of human error is reduced.

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