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DESIGN METHODOLOGY OF STRENGTH VERIFICATION OF PLATFORM DURING LOAD OUT OF THE ARKUTUN DAGI SE-TOPSIDE 43.800 MT

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ABSTRACT

This paper presents the methodology of strength verification during load out of the heavy cargo, in this case Arkutun Dagi SE-Topside platform. General methodology of making calculation models and load algorithms has been presented. Paper shows results of verification of global shear forces and bending moments using self-developed algorithms to modify centre of gravity, fill tanks and hydrostatically balance a 3D finite element model with commercial hydrostatic code. The NAPA and ANSYS codes were used to calculate hydrostatic pressures and to apply to 3D-FE models and to carry out strength calculation of barge construction.

Keywords: Strength verification, transport of offshore structures, load out analysis, ANSYS automation

NOMENCLATURE

LC	Load case
ANSYS	FE strength analysis software
NAPA	Stability calculation software
DSF	Deck support frame
GD	Genfer Design
WDP	Westcon Design Poland
SE	South east
NE	North east
Fr	Frame
LBHd	Longitudinal bulkhead
TBHd	Transverse bulkhead
FE	Finite element
CoG	Centre of gravity
AD Topside	Arkutun Dagi Topside 43800 mT
PS	Portside
SB	Starboard
SWSF	Still water shear force
SWBM	Still water bending moment
SWTORSION	Still water torsion moment

INTRODUCTION

A large number of transport operations of offshore heavy structures and increased requirements for strength calculations during load out and transport, cause an increased demand for complex strength analyses [3, 12]. The barges used for those operations need strength analysis for each cargo separately [4, 7, 11]. Methodology for performing such analyses was successfully introduced by Genfer Design (currently Westcon Design Poland) for analysis of load out of heavy structures from quay to oceangoing barge. The same technique has also been applied in inland transport. This paper is based on one of the heaviest offshore cargo load out analysis which has been carried out by GD/WDP. Subject of this analysis was a strength verification of the barge under the AD Topside 43.800 mT during load out in the harbour and seagoing transport from the harbour to destination place. The paper focuses only on load out in the harbour.

Transport of AD Topside has been contracted by Heerema Marine Contractors on offshore barge H-851, one of the biggest offshore barges in the world [2, 9]. Main dimensions of the barge have been shown in table 1.1.

Tab. 1.1. Principal dimensions of H-851 barge

Length (moulded)	= 260.0 m
Breadth (moulded)	= 63.0 m (42.0 m narrow forward part)
Depth (moulded)	= 15.0 m
Maximum Summer Load Draft	= 10.674 m

The general view of 3D-FE model with cargo (DSF and Topside of offshore platform) has been shown on figure 1.1.

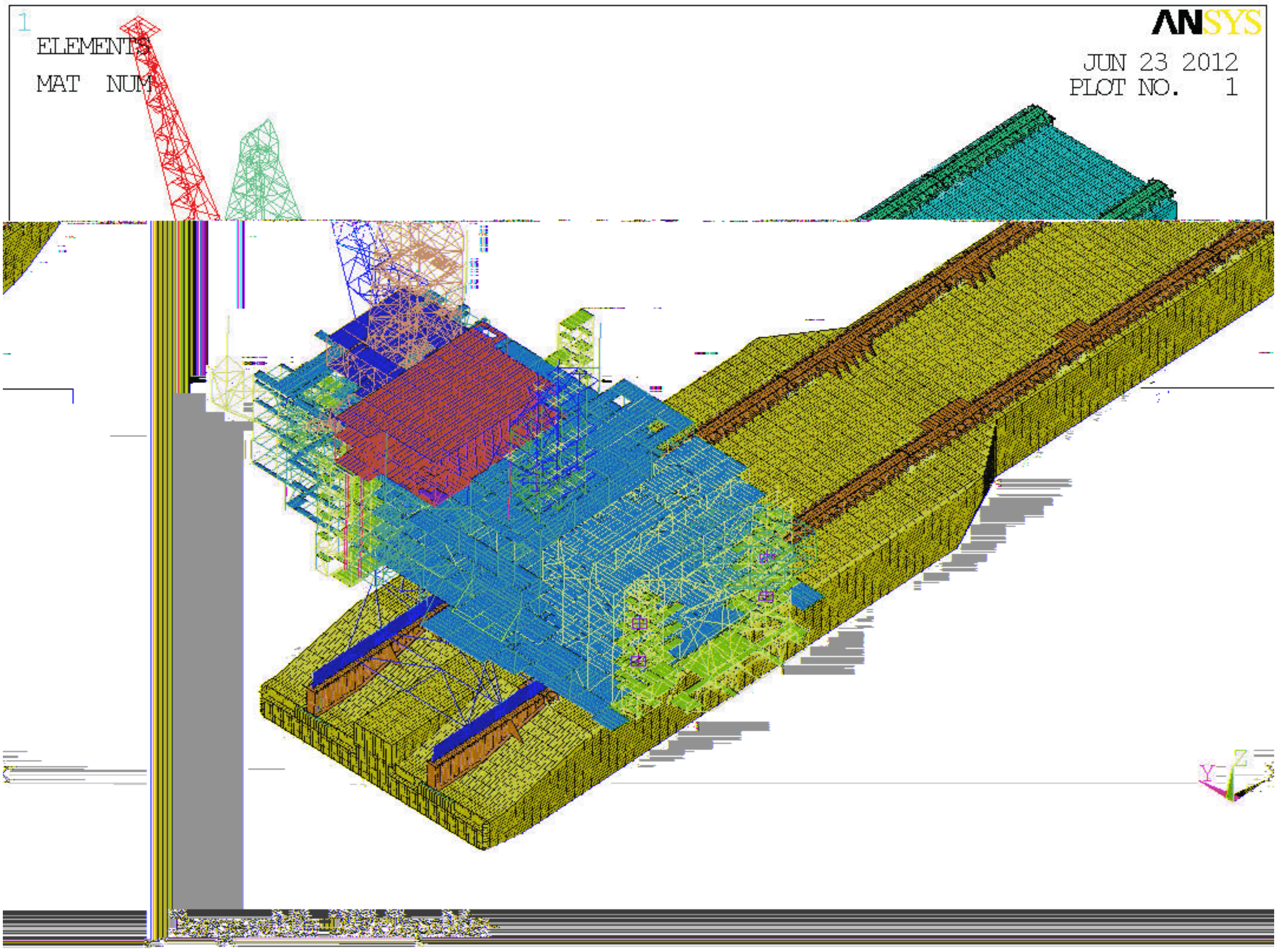


Fig. 1.1. 3D-FE model of H-851 barge, DSF with AD Topside, general view

Presented load out operation consisted of the transportation of the main cargo – AG Topside with deck supporting frame (DSF) on skid beam (steel part of the barge on deck used for cargo skidding) from quay onto barge. The load out operation has been shown on figure 1.2.

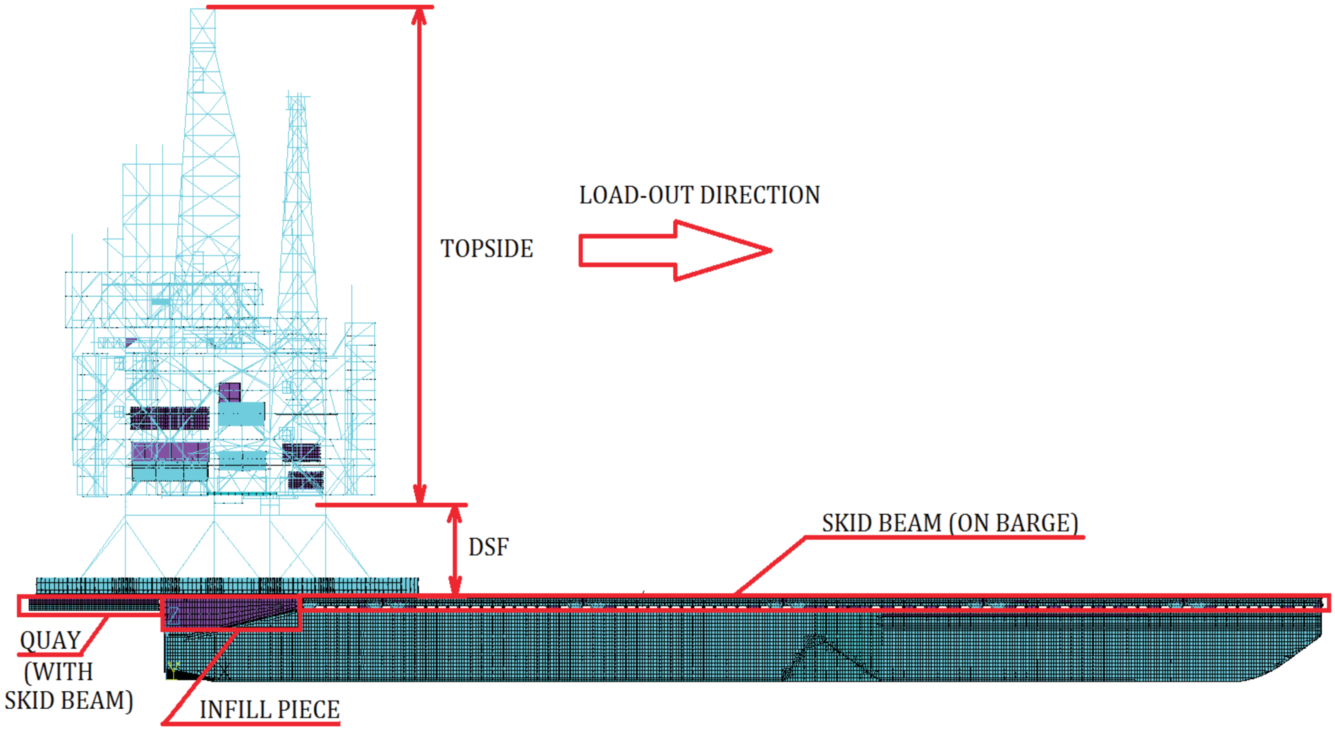
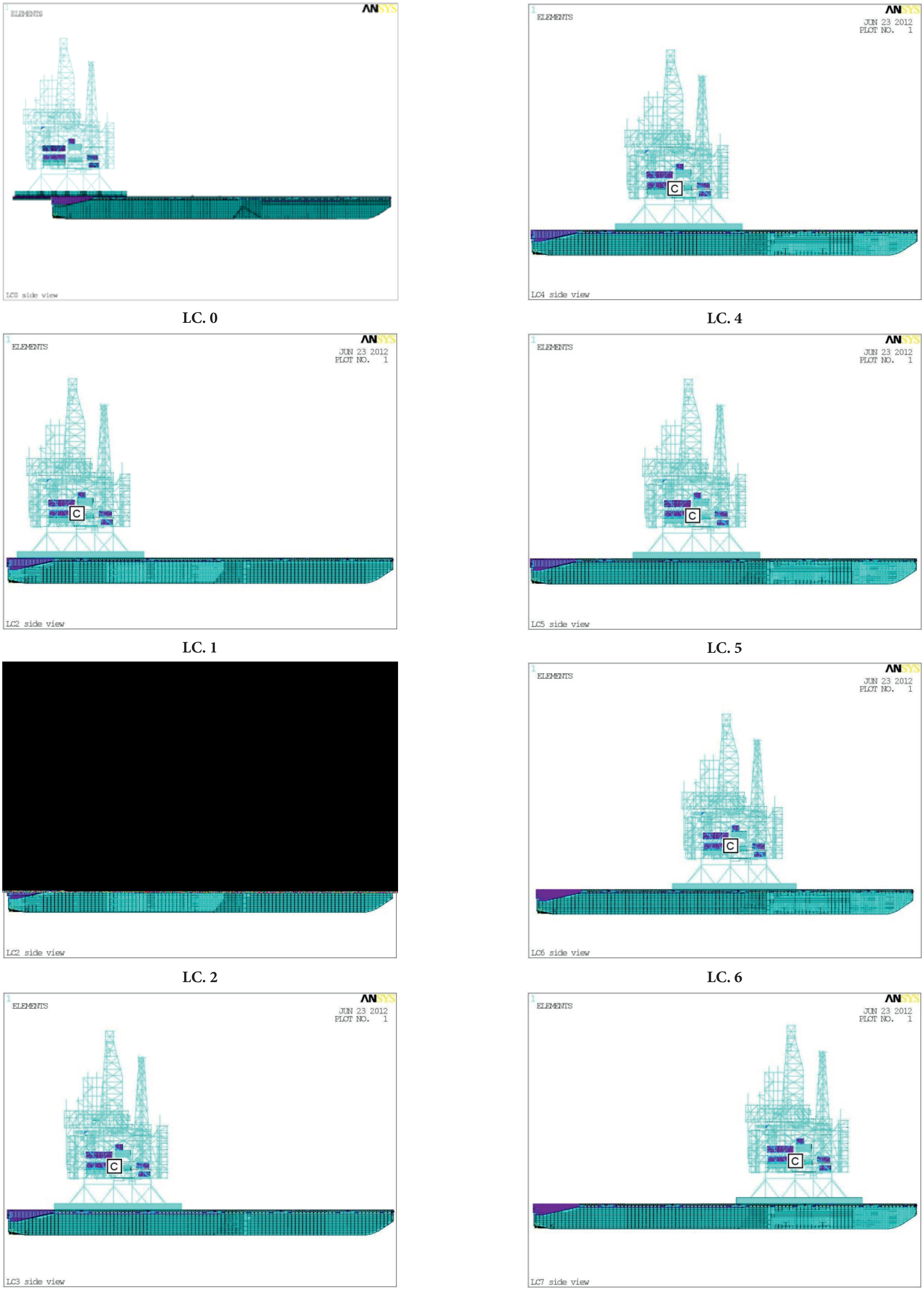


Fig. 1.2. Barge H-851 and DSF with AD Topside on skid beam during load-out operation

For the purpose of load out operation analysis, nine load cases were defined by position of Row C of DSF&AD Topside on barge (see table 1.2 and figure 1.3.):

Tab. 1.2. Load cases defined by the position of DSF Row C with respect to the barge

Load Case	Position Row C		Remarks
	Frame	X [m]*)	
LC0 fr5-NE_plus25 and LC0 fr5-NE_min25	5	11.5	Assumed 2/3 of DSF and topsides weight supported by barge (two LCs with +/-25mm differences between level of barge and quay). NE Topside
LC1 fr16-NE	16.5	40	NE topside & DSF fully on barge – most aft
LC2 fr19-NE	19	46.25	NE topside & DSF fully on barge – Row C on fr.19, i.e. on TBHd
LC3 fr29-NE	29	71.25	NE topside & DSF fully on barge – Row C on fr.29, i.e. on TBHd
LC4 fr39-NE	39	96.25	NE topside & DSF fully on barge – Row C on fr.39, i.e. on TBHd
LC5 fr44-NE	44	108.75	NE topside & DSF fully on barge – Row C on fr.44, i.e. between TBHds
LC6 fr54-NE	54	133.75	NE topside & DSF fully on barge – Row C on fr.54, i.e. between TBHds
LC7 fr71-SE	71.5	177.5	SE topside & DSF in transport position (harbour)
LC8 fr71-SE	71.5	177.5	SE topside & DSF in transport position (before sea voyage on calm water) – another draft and ballast distribution than in LC7



LC. 0

LC. 1

LC. 2

LC. 3

LC. 4

LC. 5

LC. 6

LC. 7 & LC. 8

Fig. 1.3. Graphical presentations of selected load cases defined by the position of DSF Row C with respect to the barge

CALCULATION METHODOLOGY

GENERAL ALGORITHM OF ANALYSIS

During load out operation the AD Topside with DSF was transported on skid beam by continuously pulling hydraulic cylinders. In analysis quasi-static move along step-by-step has been assumed, therefore as many 3D-FE models as load cases were required (each model for each analysed topside position). Topside FE model [8] has been delivered by the client (where beam and shell elements have been used) in transport position (LC7). Due to design modification during project, the model had different mass and centre of gravity than expected (and many constrain equation). 3D-FE model of barge has been made by GD/WDP. Because of idealization of the structure and neglected barge equipment this model also had different mass and centre of gravity than required.

The second part of the calculation (transport load cases) requires accurate mass and CoG position because of acting accelerations (directional and angular). DSF is lying on skid beam with layer of wood is mounted in-between (for reduction of local pressure due to barge stiffness distribution). There is no fixed connection between DSF and barge, therefore frictional contact connections between the wood and DSF as well as the wood and skid beam have to be defined in each position of Topside (see figures 2.1.1 and 2.1.2).

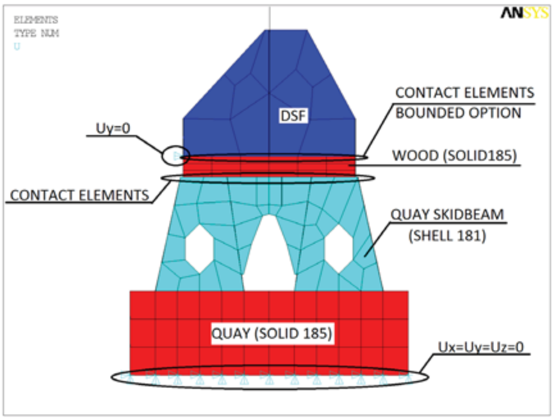


Fig. 2.1.1. Connection of quay with DSF by contact on skid beam

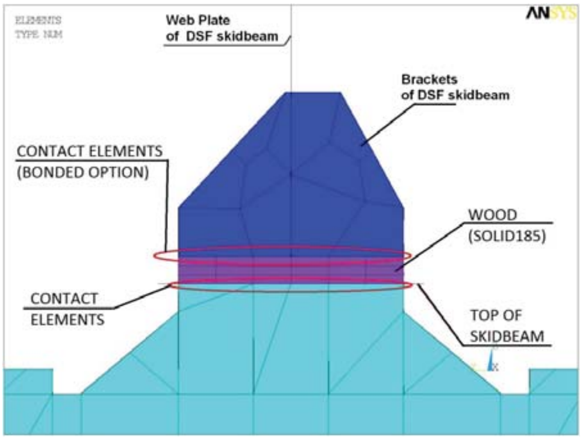


Fig. 2.1.2. Connection of barge with DSF by contact on skid beam

Due to required modification of existing structure, (after checking results of strength analysis) the process of complete calculation had to be repeated. For reducing the overall design time, calculation process had to be automated. General algorithm of analysis has been shown on figure 2.1.3.

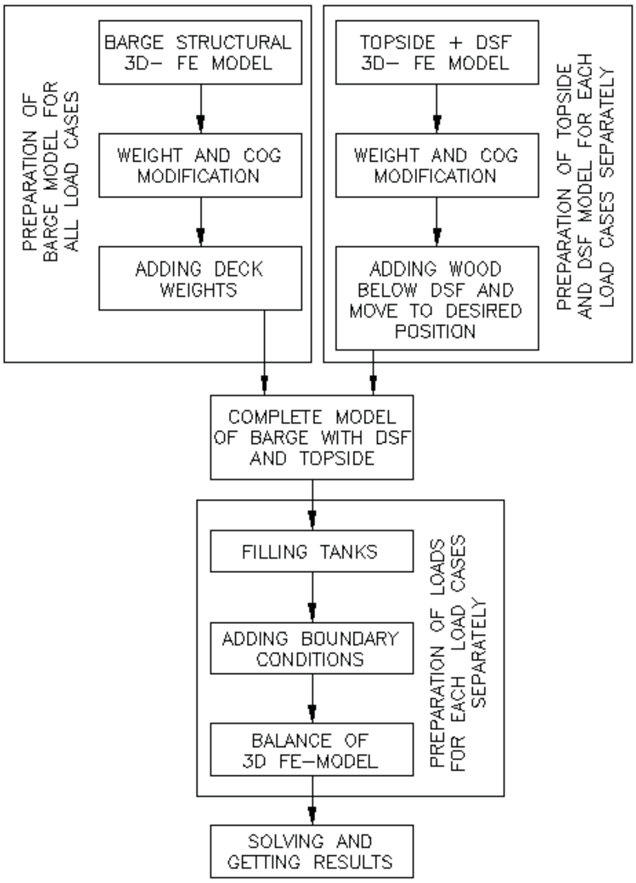


Fig. 2.1.3. General algorithm of analysis

Because of geometric complexity of barge structure and detailed modelling, barge has been divided into twelve parts. Geometry of each part has been modelled and meshed separately. In the next step the complete 3D-FE model of barge has been assembled from all the parts (without geometry, i.e. only finite elements). This approach is faster than operation on the complete model because it allows to use only partial geometry for modification. The other reason to use this approach is a fact, that ANSYS APDL (version 13) has problems with large, complex geometries (but problems not occur with FE models) [1].

The next difficulty was to achieve a required mass and CoG of barge, Topside and DSF. There are few known methods of solving such a problem. The easiest way is to change the density of material. This approach allows to achieve required mass easily, but introduces difficulties with achieving correct CoG in X, Y and Z direction.

To obtain required mass and CoG of 3D-FE model of the barge the other method has been used. The solution was to add the mass elements (Mass21 in ANSYS) on each node of FE web frame. Total required mass of those mass elements was computed as a difference between the mass required and the mass calculated from 3D-FE model (for each web frame separately). Using this method allows to achieve correct longitudinal mass distribution and to obtain shear forces and bending moments comparable with the results from hydrostatic software.

Next phase of making the barge model consists of adding concentrated masses on deck (as containers, outfit equipment, etc.). It has been done using mass elements in CoG of each concentrated mass and contact elements for connection of with relevant deck area.

In the same time the 3D-FE model of Topside with DSF has been modified, i.e. it's mass and CoG has been checked and corrected. The layer of wood below DSF has been added into 3D-FE model and it has been moved to required position (defined by analysed load case).

By connecting models of barge and Topside with DSF the complete 3D-FE model has been built. The next phase was to prepare applied loads such as tanks filling hydrostatic pressure, buoyancy hydrostatic pressure and residual loads for final balance. Each block of general algorithm (mass and CoG modification, filling tanks, and balance of model) has been described in more detailed manner in subsections below.

ALGORITHM OF MODIFICATION OF MASS AND CENTER OF GRAVITY

Algorithm used to modify mass and CoG for barge has been shown on figure 2.2.1 Algorithm of modification of the mass and CoG of AG Topside with DSF uses very similar procedure and has not been shown separately.

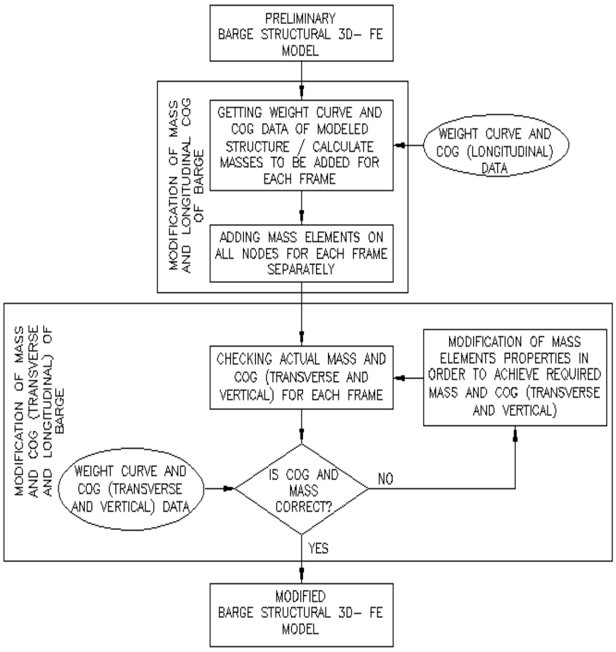


Fig. 2.2.1. Algorithm of weight and centre of gravity modification

Currently this procedure is semiautomatic, which means that modification of transverse and vertical CoG position requires an iterative process of changing the coefficients. The current version of the algorithm requires the expert to modify the coefficients, which is planned to be automated in the future.

ALGORITHM OF FILLING AND CHECKING MASS OF TANKS

Tanks' contents have been defined by client for each load case to achieve equilibrium position of barge (no heel and trim position). Because CoG of Topside is not in the centreline of barge, filling of tanks is not symmetrical. The example of tanks' filling for one load case has been presented on figure 2.3.1.

Fig. 2.3.1. Example of ballast tanks used in load cases LC0 fr05-NE

There are a few ways to add tank loads to 3D-FE model. The easiest way is to add mass element in CoG of liquid in each tank and connect this element's mass by contact with boundary walls of tank. This approach does not give correct distribution of pressure on tank's walls. It is better to use internal liquid tank pressure instead of equivalent mass element. In this way we can take into consideration the trim, heel and dynamic accelerations (sea-going cases are not described in this paper) without local peak stresses caused by numerical inaccuracy. Internal liquid pressures of filled tanks have been found using following algorithm (see figure 2.3.2).

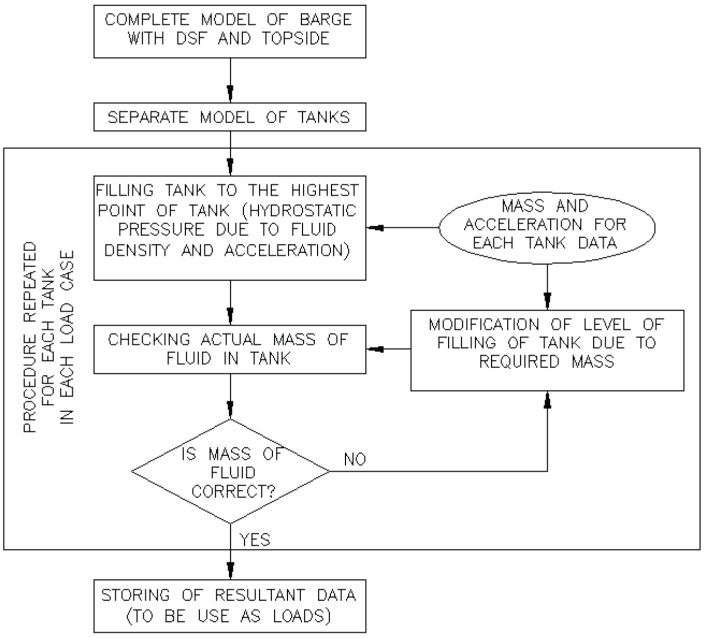


Fig. 2.3.2. Algorithm of filling of tanks

Internal liquid tank pressure application procedure adopted in 3D-FE model is based on ABS Guide for 'SAFEHULL-Dynamic Loading Approach' for Vessels [5].

Static and dynamic pressures exerted on completely filled and/or partially filled tanks are considered in analysis assuming that there is no relative motion between the tank and the contained liquid. No sloshing effects are considered, i.e. not included in the procedure.

The loads are calculated by applying a hydrostatic pressure distribution in the accelerated reference frame fixed with respect to the tank. The tanks are modelled by assigning the pressure load to those surfaces which are the walls of the tanks.

The filling of the tanks is controlled by assigning pressure load only to the wet part of the tank walls (see figure 2.3.3). Internal pressure head in direction of resultant acceleration vector is found iteratively in order to achieve user specified filled volume of tank with assumed accuracy.

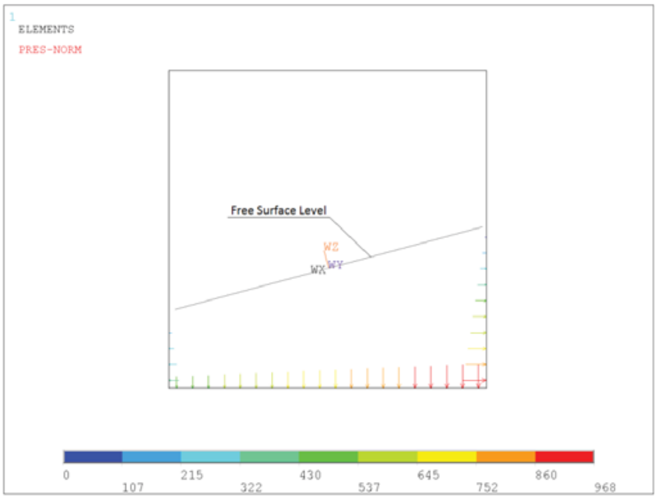


Fig. 2.3.3. Internal liquid tank pressure distribution

Procedure described above allows to find level, position (heel and trim) and pressure distribution taking into account relative acceleration vector.

ALGORITHM OF BALANCING THE COMPLETE 3D-FE MODEL

Last step of preparing of loads for particular load cases is to add buoyancy pressure on shell of barge. This pressure can be taken as hydrostatic pressure for waterline calculated in hydrostatic software, but it introduces significant reaction forces in places where boundary condition are added. It is because of numerical differences in definition of barge shell in NAPA [9] and finite element model in ANSYS [1]. Those high reactions forces cause peaks of stresses and inaccurate distribution of shear forces and non-zero bending moments on ends of barge. To avoid the difficulties with significant reaction forces described above it is important to make very accurate hydrostatic balance.

General algorithm of model balancing has been shown on figure 2.4.1. Separate model of shell has been extracted from complete 3D-FE model (i.e. barge, AD Topside and DSF) and has been used to calculate balance hydrostatic pressure due to smaller model size and faster calculation time.

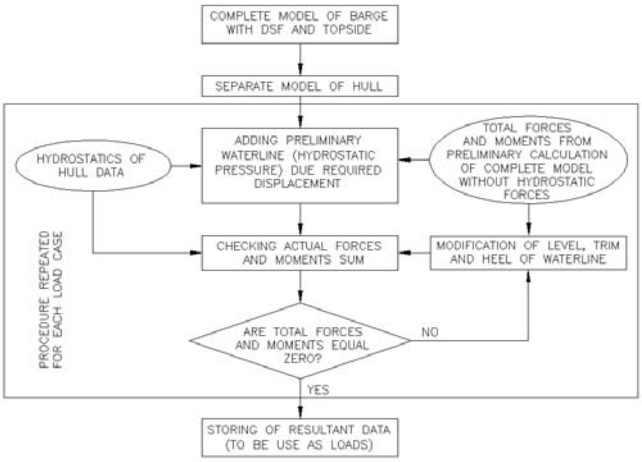


Fig. 2.4.1. Algorithm of balance of 3D-FE model

In the first step complete model has been calculated with all loads except buoyancy hydrostatic pressure. Loads and additional masses taken into consideration in those calculations are as follows:

a. structural weight of hull and skid beam,
b. DSF & Topside,
c. infill-piece,
d. mooring equipment and other deck masses,
e. fenders,
f. liquids in tanks,
g. gravity loads (in sea-going load cases also dynamic accelerations).

Reactions forces obtained from those calculations act as inputs to calculations with separate model of hull. The purpose of the above algorithm is to find correct waterline (balanced hydrostatic pressure).

In the case of ANSYS 3D-FE model, static trim is computed by iteratively adjusting the variables: draught, trim angle and heel angle until hydrostatic equilibrium is achieved, i.e. until the balance of buoyancy and lightweight distributions is met.

This approach gives very low unbalanced reactions forces which can be neglected from strength analysis point of view (below 0.1% of displacement).

RESULTS

COMPARISON OF SHEAR FORCES AND BENDING MOMENTS OBTAINED FROM ANSYS AND NAPA

On the basis of ballast and weight distribution (the AD Topside positions have been shown in chapter 1) for harbour LCs the static equilibrium of barge has been computed in NAPA and compared with ANSYS results. Distributions of bending moments in all harbour load cases obtained from ANSYS have been shown on figure 3.1.1.

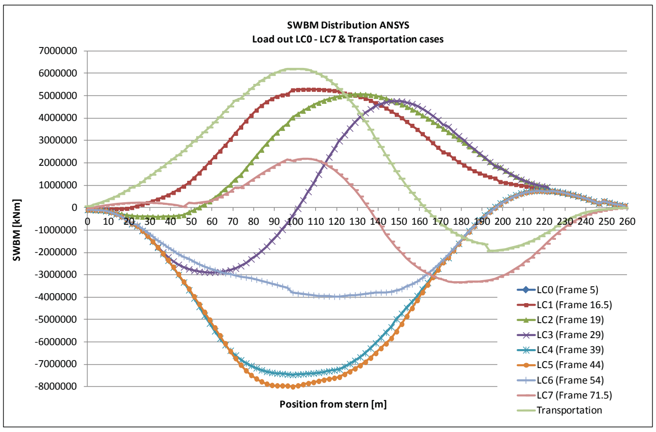


Fig. 3.1.1. Bending moments distribution in all harbour load cases

Analysis algorithm has been verified by checking the shear forces, bending moments and torsion moments acquired from NAPA and from ANSYS. Results of comparison for selected load cases (LC0, LC4 and LC8) have been shown on figures 3.1.2 to 3.1.10.

Values from ANSYS were captured only from structure of barge and skid beam (i.e. only from elements that are taken into consideration in longitudinal strength) but effect of DSF with AD Topside is included in the results. Because of this, maximum values of bending moments are equal or lower from those computed in NAPA. DSF is about 85m long and its stiffness has influence on whole structure (BARGE+DSF).

The next important thing is a construction of DSF. There are a few columns on each side of DSF. In hydrostatic software, weight of DSF with Topside is taken into account as triangle distributed load (to achieve required mass and centre of gravity). In ANSYS distribution of weight is resultant of DSF stiffness and barge condition (hogging or sagging) and stiffness. This situation is observed on figures 3.1.2 to 3.1.10. In place of DSF shear forces obtained from ANSYS are different from those obtained from NAPA. Outside of DSF the values and distributed curves are very close from both programs.

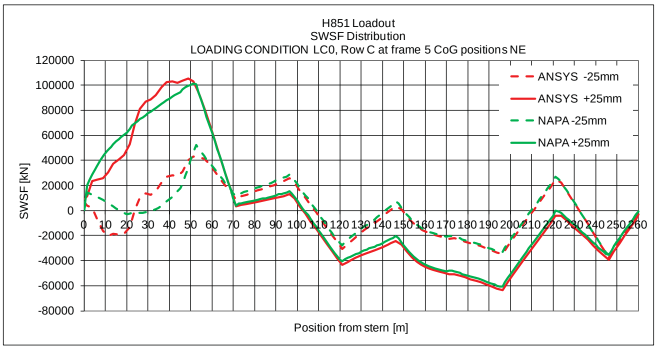


Fig. 3.1.2. LC0 – Comparison of shear forces obtained from ANSYS and NAPA

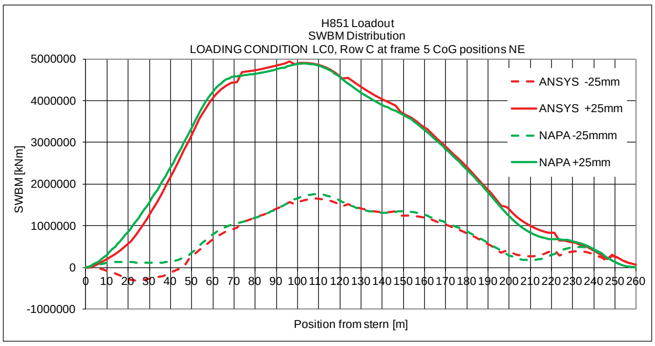


Fig. 3.1.3. LC0 – Comparison of bending moments obtained from ANSYS and NAPA

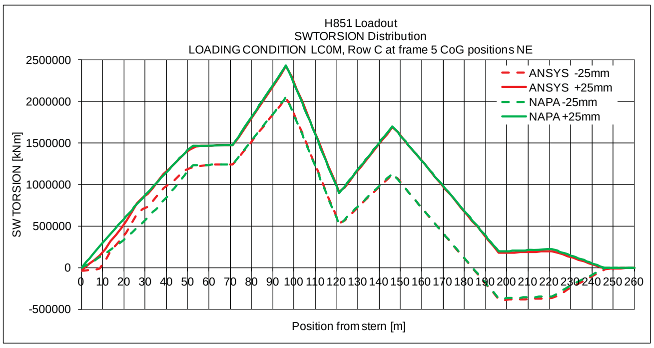


Fig. 3.1.4. LC0 – Comparison of torsional moments obtained from ANSYS and NAPA

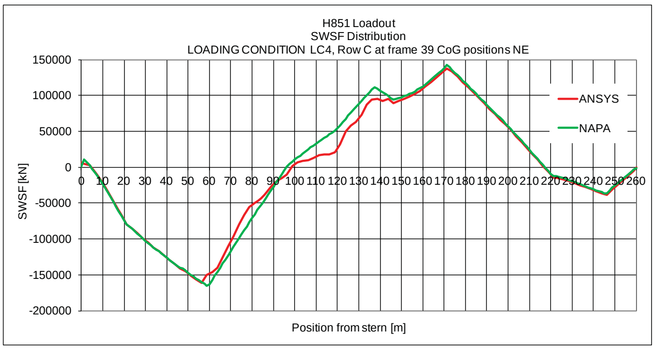


Fig. 3.1.5. LC4 – Comparison of shear forces obtained from ANSYS and NAPA

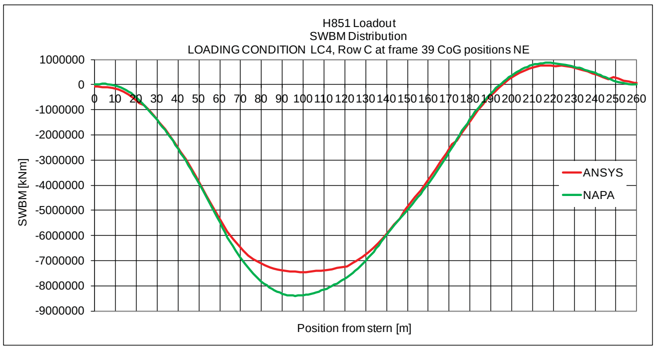


Fig. 3.1.6. LC4 – Comparison of bending moments obtained from ANSYS and NAPA

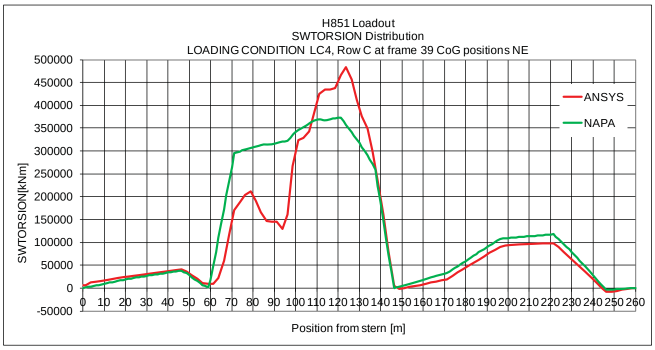


Fig. 3.1.7. LC4 – Comparison of torsion moments obtained from ANSYS and NAPA

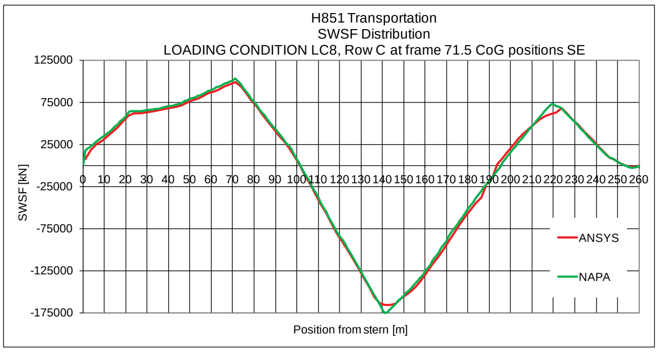


Fig. 3.1.8. LC8 – Comparison of shear forces obtained from ANSYS and NAPA

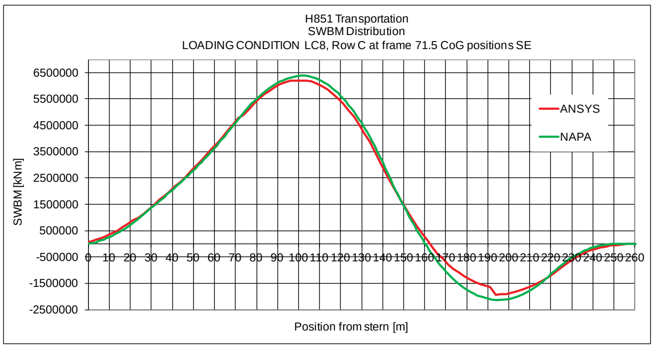


Fig. 3.1.9. LC8 – Comparison of bending moments obtained from ANSYS and NAPA

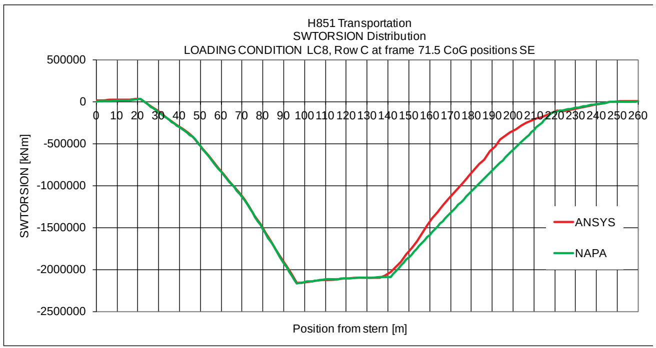


Fig. 3.1.10. LC8 – Comparison of torsion moments obtained from ANSYS and NAPA

SELECTED RESULTS OF ANALYSIS

Complex strength analysis of load out of AD Topside against Llloyd`s Register rules [10] has been performed. Complete stresses distribution images have been captured, but not presented in this paper. Only selected results have been shown. Because of wood installed below DSF it was important to know forces acting on skid beam. During load out from quay to barge in part of time DSF is partially on quay and barge (see figure 3.2.1).

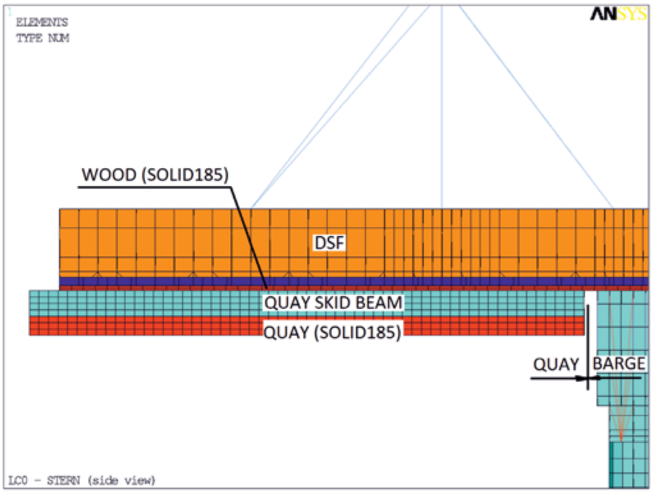


Fig. 3.2.1. LC0 – DSF partially on quay and barge
(vertical position of barge can be controlled in range of +/- 25 mm)

Vertical position of barge can be controlled in range +/- 25mm. This means that the edge end of the quay will have a peak of pressure when the top of skid beam of barge is 25 mm below the skid beam of quay. On the other hand if the top of skid beam of barge is above the top of skid beam of the quay, it will cause a peak of pressure on barge structure. Because a stiffness of the quay is significantly higher than stiffness of barge structure the peak of Z-forces on the quay (see figures 3.2.2 and 3.2.3) is higher than peak of Z-forces on barge (see figures 3.2.4 and 3.2.5) . The next thing that can be observed is the gap (no contact) between skid beam and DSF. The gap occurs on barge or quay due to barge position (+/- 25mm). Those figures have shown that contact elements allow for separation of the skid beam and DSF skid and interaction of transverse forces between barge and DSF by friction.

Reaction forces on skid beam have been also shown for LC4 and LC8. The maximum values of reaction forces, observed in this LCs, are lower than in LC0. The most uniform distribution of reaction forces is observed in LC8.

No symmetrical distribution of reaction forces and moments on skid beam gives bending and torsion of barge structure. Deflection in one of load cases (LC8) has been shown on figure 3.2.6. Deflections have occurred on top deck lines of longitudinal bulkheads (Y=0m, Y=10.5m, Y=18.75m and Y=21m, both sides PS and SB).

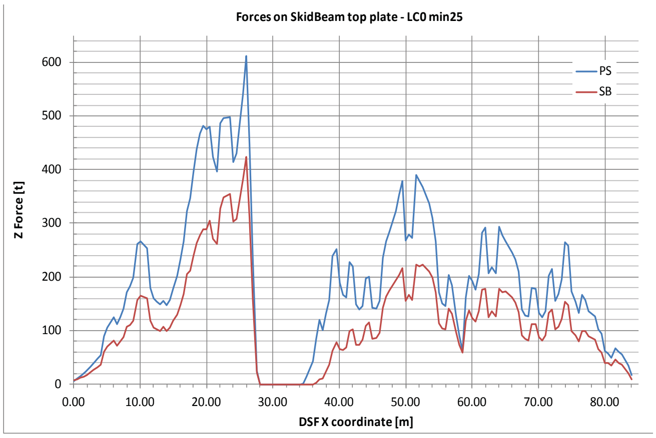


Fig. 3.2.2. LC0 (minus 25mm) – Reaction forces on PS/SB skid beams (top of skid beam on barge below top of skid beam on quay), peak of force on end of quay observed

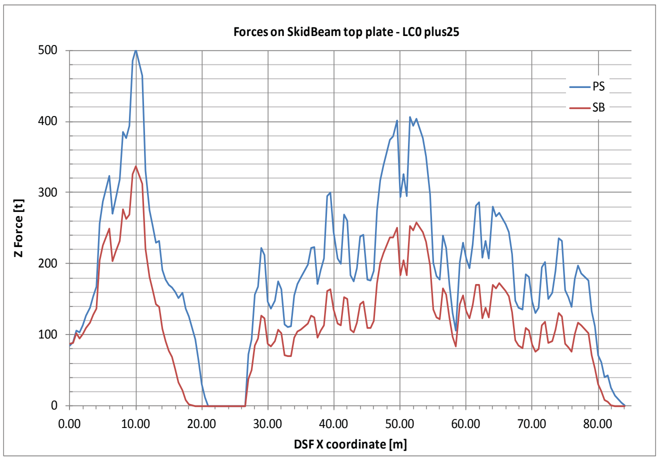


Fig. 3.2.3. LC0 (plus 25mm) – Reaction forces on PS/SB skid beams (top of skid beam on barge above top of skid beam on quay)

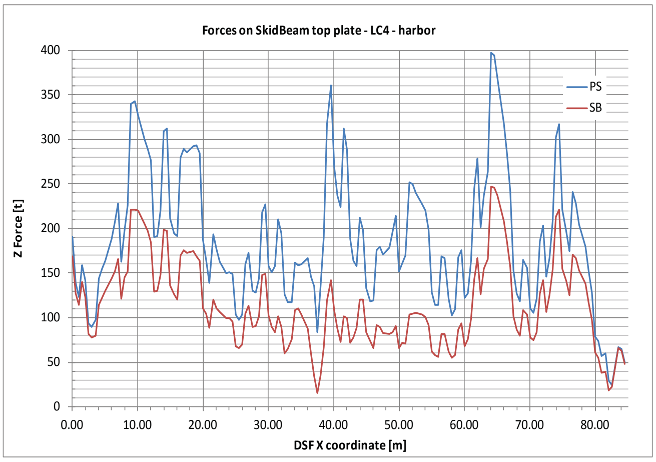


Fig. 3.2.4. LC4 – Reaction forces on PS/SB skid beams

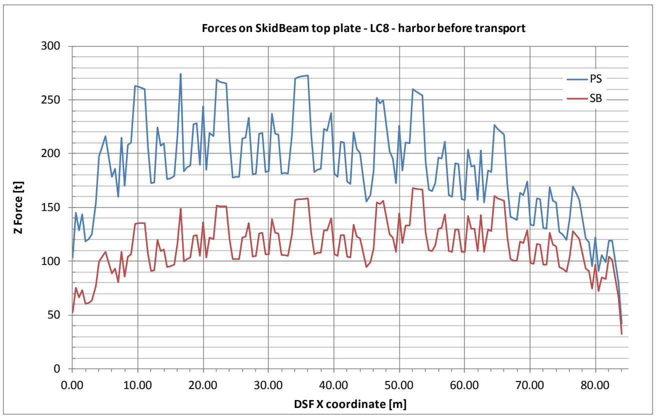


Fig. 3.2.5. LC8 – Reaction forces on PS/SB skid beams

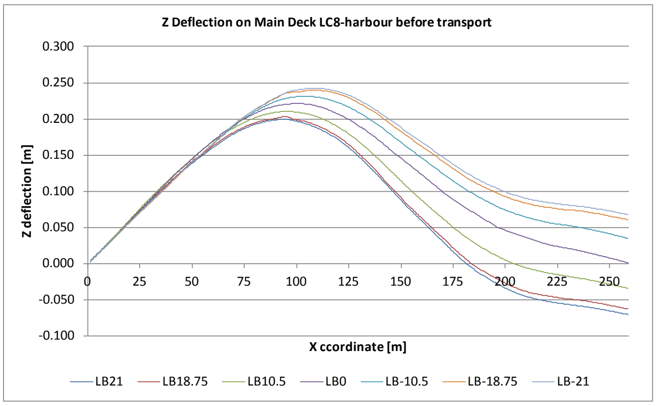


Fig. 3.2.6. LC8 – Deflections of deck lines on longitudinal sections (top of longitudinal bulkheads)

CONCLUSION

Design methodology of strength verification of platform during load out has been presented. The NAPA and ANSYS codes were used to calculate hydrostatic pressures and to apply them to 3D-FE models and to carry out strength calculation of barge structure. Presented results show a very good convergence of shear forces, bending and torsion moments with results obtained from NAPA. Due to a different definition of vertical loads used in codes of ANSYS and NAPA small differences in results has been observed. Hydrostatic software such as NAPA does not take into account influence of stiffness of deck load (AD topside with DSF). The use of 3D-FE model allowed to include that stiffness and therefore reduce stresses during load out of barge. More accurate results lead to reduction of a range of modification of skid beam and decrease the operation costs. Because time required to obtain accurate balance with self-developed algorithm in ANSYS is much longer than using NAPA, barge ballast procedure and balance were always prepared in NAPA. Only final hydrostatic balance was prepared in ANSYS.

Neither NAPA nor ANSYS currently takes into account changes of hydrostatics due to barge deflection. Implementation of this phenomenon in own algorithms is currently under consideration. Deflected waterline has a positive effect on hull deflection and stress level. This effect can reduce deflections and calculated stresses during similar harbour operations.

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