Contemporary Engineering Sciences, Vol. 8, 2015, no. 9, 387 - 392
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2015.5243

Finite Element Analysis for Structural Evaluation of Marine Loading Arm

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Abstract

This paper describes a structural safety analysis of a marine loading arm that transfers liquids or gases to and from tank ships or cargo vessels. The structural design of the marine loading arm was performed in accordance with OCIMF. Stresses for ten load conditions considered in this study were drawn by finite element analysis, and were compared with the allowable stresses required by OCIMF in order to determine the design appropriateness of the marine loading arm.

Keywords: Marine loading arm, Load conditions, Finite element analysis

1 Introduction

A marine loading arm is a very useful pipe system for the fluid transfer of a liquid cargo from a ship or offshore plant. In order to load or unload liquid cargo such as crude oil, liquefied natural gas (LNG), chemical products, and so forth, the marine loading arms are usually installed not only on board of ships and cargo vessel but also on the loading yards. Marine loading arms have several configurations [1] due to various purposes of offshore production process, and are either manually or hydraulically controlled. Once the loading arm is connected to the flange of the ship, the arm is free to follow the normal movement of a properly moored ship at berth. A platform based marine loading arm are made of aluminum or carbon steel, and typically comprises base riser, inboard arm, outboard arm, swivel joints, upper/lower sheaves, locking devices, counterweights, etc. For the operation of marine loading arm, there are some studies on the automated real time monitoring and controlling system [2] and control strategy [3]. With accelerated development of marine resources, a fluid transfer has been consistently increasing in the marine industry. For transferring crude oil or natural gas from seabed to plant or ship, the safety of the marine loading arm is very important. Therefore, it is important to design the marine loading arm with safety purpose. For safe design and construction of marine loading arm, the structural design of the marine loading arm is obliged to comply with the design and construction specifications regulated by the oil companies and international marine forum (OCIMF) [4]. In this paper, the structural safety of the marine loading arm is analytically evaluated and checked for the design load conditions and modes required by OCIMF. For structural analysis of the marine loading arm, midasFX and NastranFX softwares were used as pre- and post-processors, respectively. The stress results based on the finite element analysis (FEA) are compared with the allowable stresses required by OCIMF specifications.

2 Analysis procedure

According to the OCIMF, the basic allowable design stress (S_d) for pressure containing and non-pressure containing structural components shall be the lower of either yield stress/1.5 or ultimate tensile stress/2.35. The allowable stress of SM45C used in the marine loading arm is 230 MPa. The OCIMF provides the allowable stress factors for design load conditions as listed in Table 1.

Table 1. Design load cases in OCIMF [1]

Case no.	Mode	Loading combination	Allowable stress (σ) K x S_d
1	Stored	DL + WLs	1.2 S_d
2	Stored	DL + EL	1.2 S_d
3	Maneuvering	DL + WLo	0.9 S_d

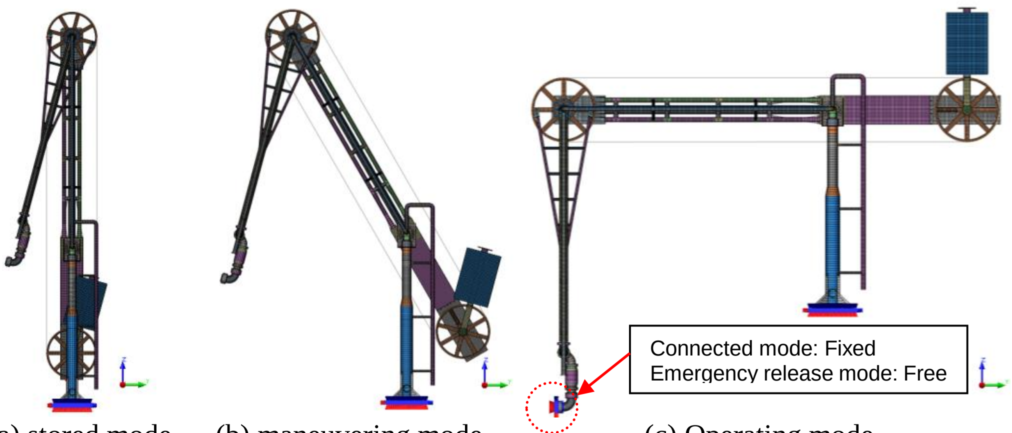
Table 1. (Continued): Design load cases in OCIMF [1]

4	Connected	DL + WLo	0.8 S_d
5	Connected	DL + FL + PL + WLo	0.8 S_d
6	Connected	DL + FL + PL + WLo + TL	1.5 S_d
7	Emergency Release	DL + WLo	1.1 S_d
8	Emergency Release	DL + FL + PL + WL_O	1.1 S_d
9	Maintenance	DL + WL_M	0.9 S_d
10	Hydrostatic Test	DL + FL + PL_T+WL_O	1.3 S_d

* DL is dead load; PL is design pressure load; WL_S is wind load in stored mode; EL is earthquake load; PL_T is test pressure load; WL_O is wind load in operating mode; FL is fluid load; TL is thermal load; WL_M is wind load in maintenance mode

For the structural evaluation of the marine loading arm, three modes have been considered in this paper. Boundaries of the base support are all-fixed for each mode, and boundary condition at the nozzle connector part is released in case of Emergency Release in Operating mode. Overall 3D views of the loading arm are presented in Figure 1.

For dead load (DL), a density of material used in the marine loading arm was input as a gravity parameter of analysis.



(a) stored mode (b) maneuvering mode (c) Operating mode

Figure 1. 3D views of finite element model

The structure loads are the self-weight of the loading arm structure including counterweight plates. These loads were considered as constants and were included in all design load conditions. Wind load (WL, 45 m/s of wind velocity) was applied as a form of pressure to the structural member, and pressure load (PL) due to fluid in feed pipe was input at the element in the direction of outside of the pipe. Seismic load (EL) was calculated as per UBC97 [5], and the total design lateral seismic force (F_p) was determined from the following formula;

$$F_p = 4.0\, C_a\, I_p\, W_p = 0.64\, W_p \quad (1)$$

where, seismic zone factor, Z = 0.2 (Table 16-I, ZONE 2B)
seismic importance factor, I_p = 1.00 (Table 16-K, Misc. structures)
seismic coefficient, C_a = 0.16 (Table 16-Q, S_A soil)

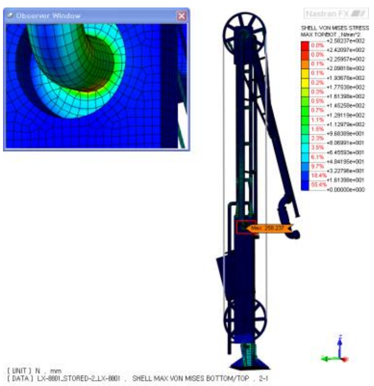
The seismic load was assumed as accelerations in horizontal and vertical directions. For connecting mode, a heat transfer analysis (case no. 6) was conducted, considering severe environmental condition (-40~87℃). The thermal loads (TL) were input at the nodes of the feed pipe; where, initial temperature was assumed to 20℃. The loading values for analysis is more conservative than real condition when the marine loading arm is in operating condition. For fluid load (FL), 672.7 kg/m^3 of ammonia fluid density was used. For design pressure load (PL), 20 and 10 barg of design pressure were input for ammonia and vapor, respectively. 30 and 15 barg of design pressure were respectively input for test pressure loads (PL_T) of ammonia (12 inch pipe) and vapor (6 inch pipe).

3 Analysis results for marine loading arm

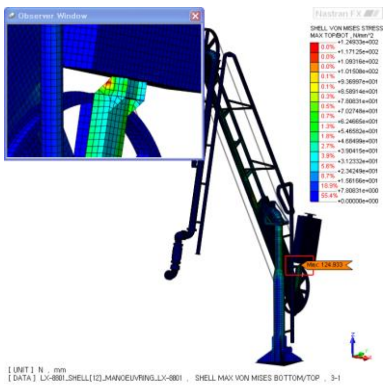
Figure 2 shows contours for Von-mises stresses of the analysis results.

As shown in Figures 2(a) and 2(d), for the stored and emergency release modes, the maximum stresses are observed at the connection between outboard arm and swivel joint. These stress concentration results were observed previously [6]. It can be inferred that the stress concentration is attributed by the conservative wind velocity assumed in the design. For the maneuvering and maintenance modes, the stress at the support of counterweights is the highest as seen in Figures 2(b) and 2(e). For connected and hydrostatic test modes, as expected, the maximum stress was observed at the nozzle connection as seen in Figures 2(c) and 2(f). It is noted that the utmost care for structural safety is required when the marine loading arm is in operation, and furthermore, the utilization of material that has higher strength characteristics could be recommended for the safety of human and equipment.

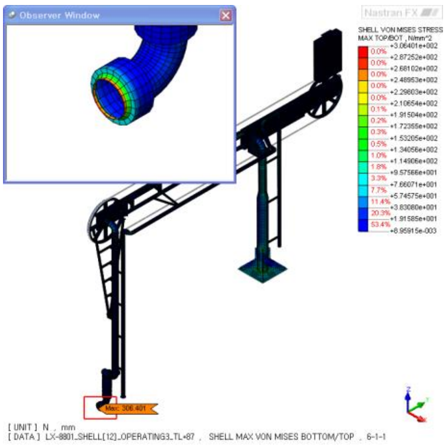
The stress check results of analysis for loading arm are compared with the allowable stresses by OCIMF and the detailed stress values are presented in Table 2. As listed in the table, for all design load conditions, there is no stress over the allowable stress. This indicates that the marine loading arm in this study meets the structural requirements for the fluid transfer of a liquid cargo from a ship or offshore plant.



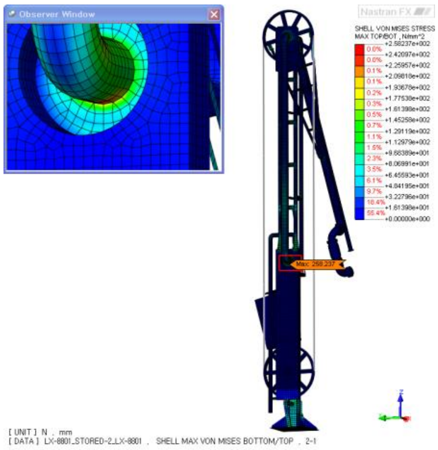
(a) stored mode



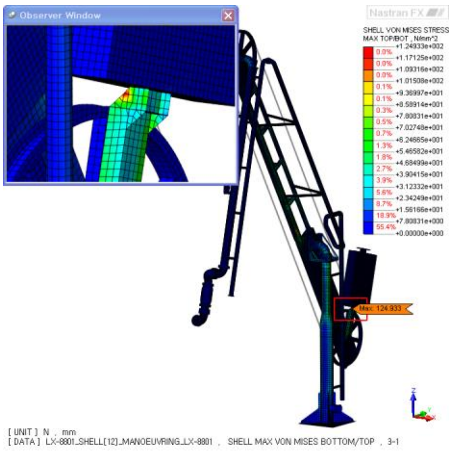
(b) maneuvering mode



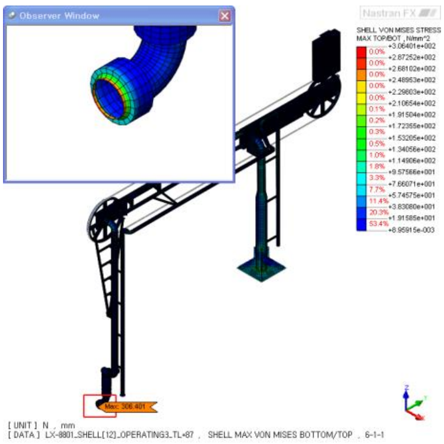
(c) connected mode



(d) emergency release mode



(e) maintenance mode



(f) hydrostatic test mode

Figure 2. Stress contour results

Table 2. Maximum stress of the marine loading arm

Case no.	Mode	Maximum stress (MPa)	Allowable stress (MPa)
1	Stored	121.62	276
2	Stored	258.24	276
3	Maneuvering	124.93	207
4	Connected	139.45	184
5	Connected	138.18	184
6	Connected	306.50	345
7	Emergency Release	171.77	253
8	Emergency Release	241.85	253
9	Maintenance	121.61	207
10	Hydrostatic Test	154.61	299

4 Conclusion

In this study, the structural safety of the marine loading arm was analytically evaluated and checked for the design load conditions and modes required by OCIMF. The results of the analyses demonstrate that the marine loading arm can withstand the applied loads and that all members are within requirements for the design conditions in accordance with OCIMF.

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Received: February 26, 2015; Published: March 24, 2015