PORT-SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - port said university
Volume 22 No. 2 September 2018 pp: 32:39

Structural Safety Assessment of a Floating Dock during Docking Operation

M. El-Maadawy[1], M. M. Moustafa[2], H. S. El-Kilani[3] and Adel A. Tawfeek[4]

ABSTRACT

This paper focuses on the accuracy of the "load per meter run "criterion which is used as a simple assessment for the acceptance of a specific docking operation regarding the structural safety of an unrated caisson floating dry dock. A candidate floating dock system in Port Said Shipyard is modelled in order to illustrate the procedure followed to attain a proper decision. The development of the 3D finite element model acquires the availability of the full technical data of the floating dock. All major docking operation phases are taken into account. The adequacy parameter is a good measure to detect the suspicious locations within the dock's structure and identify the expected failure modes. The created 3D model is a useful tool that may be used in a trial and error process to attain a proper ballasting system to reduce stresses instead of rejecting the operation. The present case study had showed that the "load per meter run "criterion may be highly simplified and can be quite inaccurate specially in the critical docking operations.

Key Words: Port-Said Shipyard, Floating Docks, Structural Modelling, MAESTRO, FEA, Dock Strength

1. INTRODUCTION

All floating marine vessels such as ships, tugs, floating cranes and even floating docks need to be docked either periodically for survey or occasionally to inspect or repair a suspected damage to any underwater part. A common ship docking facility is the floating dry dock, as shown in fig.1; it consists mainly of pontoon and wing walls with proper dimensions, stability and strength to withstand the forces acting on the floating dock during docking operation.

The pontoon is the main supporting body that must displace the weight of the vessel and dry dock in order to lift marine floating vessels using buoyancy. The transverse strength of the pontoon should withstand the load of the ship concentrated along the dock's centreline, and the uniform buoyant support of the water pressure.

The presence of the wing walls is favourable for stability when the pontoon is submerged and for the longitudinal strength subjected to the non-uniform ship weight and the uniform buoyant support [1].

Dry dock accidents are not common, but they do happen. Overloaded dry docks may crack, buckle, flood, sink, damage the ships they are trying to lift - and sometimes even cause accidental deaths.

The structural safety of the dock is the main issue controlling the acceptance of the specific docking operation.

[1] *Design Section, Port Said Shipyard, Suez Canal Authority, Port Said, Egypt, E-mail: elmaadawy2002@yahoo.com*
[2] *Lecturer, Naval Architecture and Marine Engineering Department, Faculty of Engineering, Port Said University, Port Said, Egypt, E-mail: sasa3875@yahoo.com*
[3] *Professor, Naval Architecture and Marine Engineering Department, Faculty of Engineering, Port Said University, Port Said, Egypt, E-mail: hebaelkilani@eng.psu.edu.eg.*
[4] *Professor, Naval Architecture and Marine Engineering Department, Faculty of Engineering, Port Said University, Port Said, Egypt, E-mail: adil.tawfiq@gmail.com.*

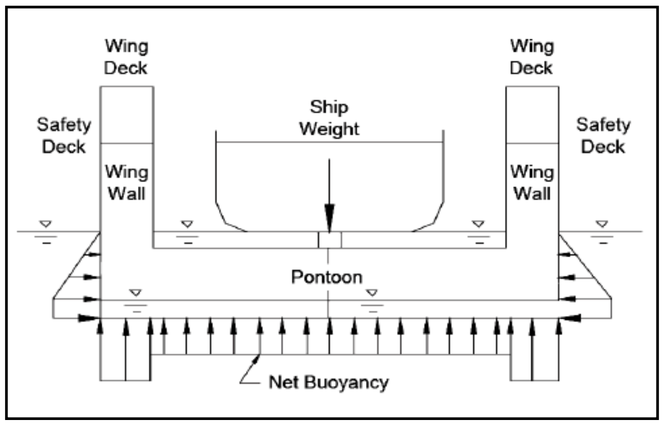

Fig.1: Floating dry dock components [1]

Prudent dry dock operators strive to avoid overloading, normally through a set of manual calculations, but in certain cases through more sophisticated methods. One of these methods had been the use of the finite element software MAESTRO. This is a design, analysis, and evaluation tool specifically tailored for floating structures which have four main capabilities: overall or global stress analysis, structural adequacy (limit-state) evaluation, structural design optimization, and local stress analysis [2]. It had been previously used for the analysis of stresses and buckling failure mode of floating dry-docks [3]; the work had been carried out for AFDL-23 ADEPT which is an existing rigid, one-piece welded steel, floating dry dock that had been renewed with plating and stiffeners that were not in accordance with the dock's plans. The main criterion adopted to certify the operation of the renewed dock had consisted of allowable longitudinal deflection limits during dry docking operation. Stone's MAESTRO model of ADEPT considered plate and stiffener corrosion of pontoon deck, bottom plate, side shell, and wing tanks. The analysis showed that the dock structure is satisfactory for the specific dockings considered, with longitudinal deflections adjusted to take into account the permanent sag observed. The model had been carried out to determine the maximum safe load for the dock [3]. Maxsurf software had also been used to perform the design and analysis of a ship floating dry-dock for two types of the hull namely the monohull and the twin hull types [4]. The innovation in that study had lied in separating the docking process from the maintenance platform and the ballast water displacement; this study had included details of the general arrangement and stability requirement [4].

The “load per meter run” is a simple assessment method that requires minimum information data [5].

The load per meter run of the docked vessel is calculated by dividing the docking weight by the keel bearing length while, the max. Load per meter run of the floating dry dock is calculated by dividing the dock carrying capacity by the pontoon length; in this method, if the load per meter run of the docked vessel is less than the maximum allowable load per meter run of the targeted floating dry dock, then the docking operation is accepted, otherwise it is rejected.

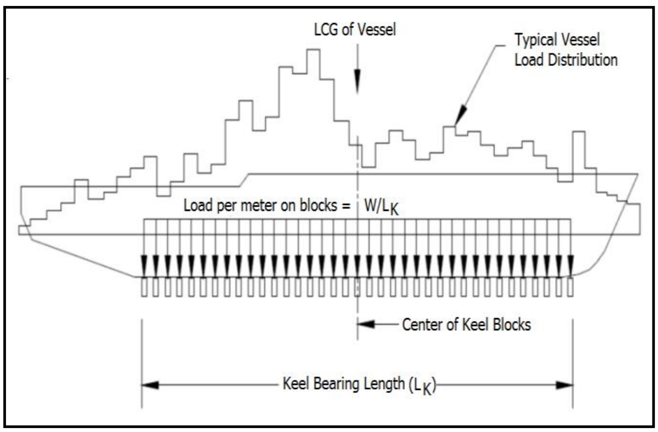

Fig. 2: Load per meter run of the docked vessel [3]

This criterion may ensure a good margin of structural safety but may lead to the rejection of many docking operations since the structural strength of the floating dock is not taken into account.

The major docking phases included in any docking operation and related to structural safety are as follow [3]:

First phase: It is the light weight condition. It includes the self-weight of the dock with its supporting blocks and weight of the rest water with a height of 50 mm in all ballast tanks. This height is the minimum height that can be achieved by dock pumps.

Second phase: It is the full submergence load condition. It includes the self-weight of the dock with its supporting blocks and weight of ballast water leading to the maximum draft required to receive the docked ship.

Third phase: It is the maintenance & repair condition. It includes self-weight of the dock with its supporting blocks, weight of the docked ship and weight of ballast water giving the required working draft.

The first and second phase are usually performed safely at each docking operation as there are no ship load on the dock structure.

In the present study, the sufficiency of the load per meter run criterion is investigated throughout the finite element analysis of a floating dry dock during major phases of a docking operation. The candidate floating dry dock is located in Egypt and is called "PORT SAID". The selected docking scenario presented in this paper consists hypothetically of the third docking phase of a previously rejected docking process of a 100-ton bollard pull anchor handling tug.

2. PROPOSED METHODOLOGY

Docking operation induced stresses and dock's structural behaviour during major phases of a docking operation of a previously rejected docking operations based on load per meter run criterion are studied and analysed using the developed finite element model of the dock.

In order to check the structural safety of the dock during a certain docking operation, the FE analysis aims to compare the actual stress QA to the failure stress QL for all members, load cases and for all relevant failure modes. For each scenario, the adequacy parameter “g(R)” given by equation (1) is generated;

$$g(R) = \frac{1-R}{1+R} \qquad (1)$$

Where $R = \frac{Q_A}{Q_L}$

The adequacy parameter ranges from –1 to +1, and each value of the parameter has a specified meaning as illustrated in Table 1. It is to be noted that the limit states for panels and frames embedded in the software cover 15 different modes of failure [2].

Table 1: Significance of adequacy parameter [2]

Adequacy Parameter	Meaning
Negative	The member has failed, or at least the safety margin is less than was specified
Zero	The member has exactly the required safety margin and no more
Positive	The safety margin is larger than the specified value

The main assumptions of the present analysis are summarized as follows:

– Floating dock works near shipyard at very calm sheltered area. Hence, no inertia or wave induced forces are included in the analysis.
– The dock building materials (plates and stiffeners) are considered new. Hence, corrosion and aging are not taken into account.

– Since the docking operation is a relatively slow process, the load on the dock structure is considered as static.
– Docked ship weight is distributed in a way that centreline blocks receive 70% of docked ship weight and side blocks receive the remaining 30% of docked ship weight 15% for each side

The proposed modelling and analysis carried out in this study is illustrated in the flowchart shown in Fig. 3.

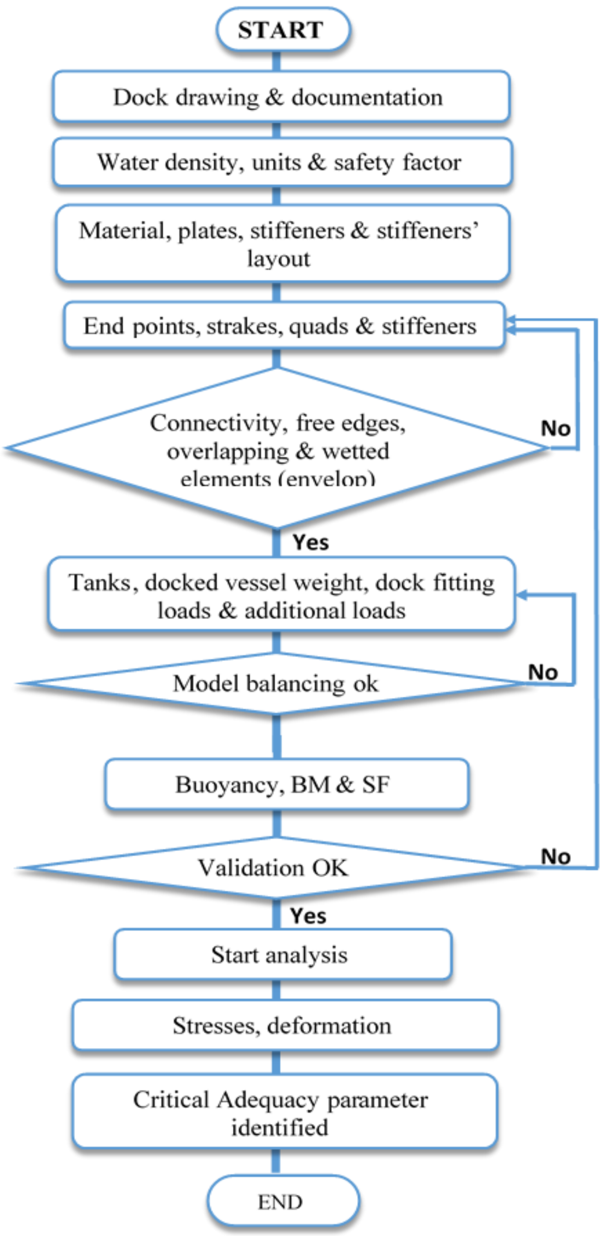

Fig. 3: Analysis flowchart

3. CANDIDATE FLOATING DRY-DOCK SYSTEM

The selection of a suitable case study was made among all the floating docks in Egyptian Shipyards that are reported in Table 2. According to authors' survey, it is common in Egyptian shipyards to use the "load per meter run" criterion as an assessment criterion to take a proper decision to accept the docking of a specific vessel.

Table 2: Floating Docks in Egyptian Shipyards

Name	Lifting Capacity (tons)	L (m)	B (m)	Load / Meter Run (tons/m)
EID ELNASR	25000	210	35	119
ELSALLAM	17000	171	36	99.4
ATTAKA	10000	169.4	28	59
PORT SAID	5000	106.4	21.8	46.99
SUEZ	55000	270	55	203.7
30th June	9000	153	26.8	58.8

"PORT SAID" is one of the Suez Canal Authority (SCA) floating dry docks with a lifting capacity of 5000 tons and located at Port Said shipyard, see Fig. 4. This dock is mainly used for docking the small vessels of SCA fleet for the purpose of scheduled hull maintenance and repair. Main particulars of "PORT SAID" floating dry dock are shown in Table 3 [7] and its midship section is almost similar to that shown in Fig. 5. It had been found convenient to choose this case study due to the availability of the data required, and due to the practical experience of the author.

Fig. 4: Floating dry dock - "PORT SAID"

Table 3: Particulars of PORT SAID Floating Dry dock

Length over pontoon	106.40 m
Breadth in /out	21.8 / 29.18 m
Max draft over keel blocks	5.40 m
Carrying capacity	5000 tons
Load per meter run	47 ton/m

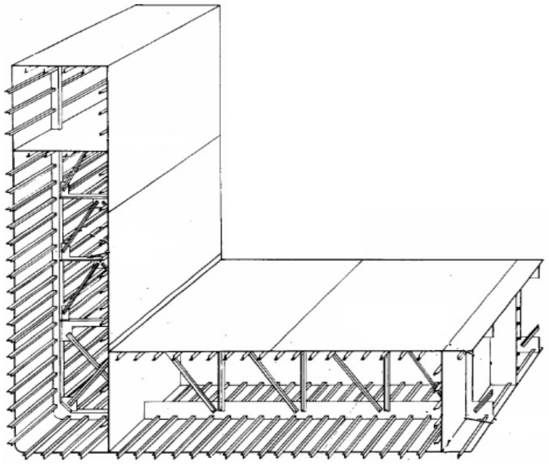

Fig. 5: Floating Dry Dock - "PORT SAID" Midship Section

In this paper, the previously rejected docking operation for the anchor handling 100 tons' tug boat "AHT 100 ton" is considered in the case study. "AHT 100 ton" is shown in Fig. 6 and its particulars are shown in Table 4.

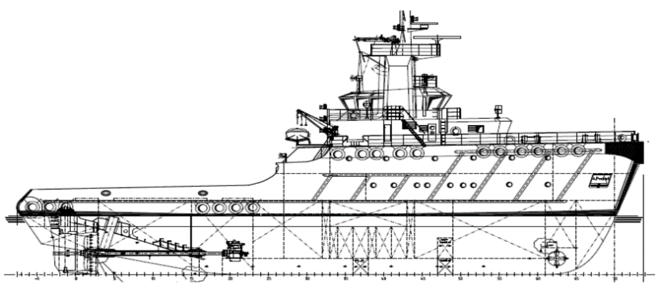

Fig. 6: Anchor Handling Tug Boat "AHT 100 ton"

Table 4: Main Particulars of the Docked Tugboat "AHT 100 ton"

Weight	1773 tons
Breadth	11.0 m
Draft	4.8 m
Keel bearing length	34.2 m
Load per meter run	51.84 tons/m

Using the load per meter run criteria, the decision made had been that the tug could not be docked using the floating dry dock "PORTSAID", although the dimensions and lifting capacity of the dock (PORT SAID, 5000 tons) are quite large to lift "AHT 100 ton". It had been recommended to use ATTAKA floating dry dock specified in Table 2 in spite of the low profitability of the operation and overall docking planning of the yard. This case is investigated in this research to check if the load per meter run is a reliable criterion for such a docking operation.

4. FINITE ELEMENT MODEL

The finite element (FE) model is created using all design and construction drawings of the dock. The material used is mild shipbuilding steel of 235 MPa yield strength. This model had been created by means of the commercial Software (MAESTRO) using a combination of shell/plate and beam elements; the total number of elements attained is 3866 elements. Dock's FE model is shown in Fig. 7 and the major structural elements of this model are presented in Table 5.

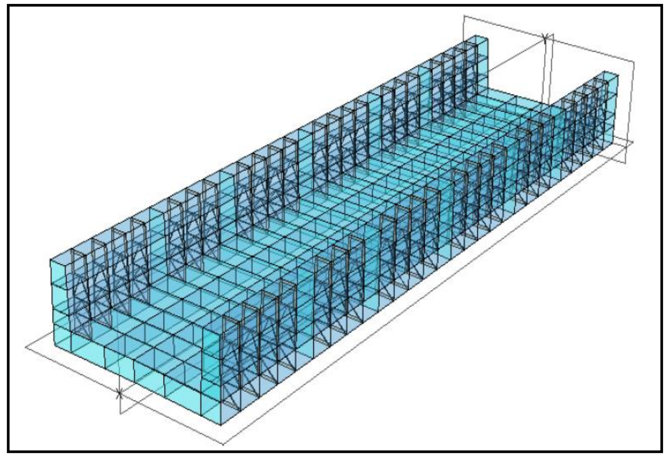

Fig. 7: Dock's FE Model

Table 5: The Major Structural Elements of Dock's FE Model

Structural Element	Element Type	Cross Section	Dim. (mm)
Deck	Shell / Plate	Plate	t = 13
Bottom	Shell / Plate	Plate	t = 14
Side	Shell / Plate	Plate	t = 10
Longitudinal / Transverse bulkheads	Shell / Plate	Plate	t = 11
Deck / Bottom stiffeners	Beam	Angle	120×80×12
Side stiffeners	Beam	Bulb	200×12
Centreline bulkhead stiffeners	Beam	Tee	300×10 / 100×12

The boundary conditions had been specified only to prevent rigid body motions. The fixation points had been set close to aft and fore ends away from areas of interest to avoid imbalance of the model due to the applied loads. The global model is supported in four positions; the aft end of the water plane had been set fixed for translation along all three axes while the fore end of the water plane had been set fixed in the vertical and the transverse directions.

The developed FEM is validated using the available data obtained from AVEVA software [8] that had been used to calculate ship's hydrostatical data, shearing forces and bending moments and to prepare stability reports approved by the classification society.

The values presented in Table 6 are obtained during the first phase of the docking operation. A good agreement is observed between the results of the developed FEM and those obtained by the validation tool.

Table 6: Validation of Applied FE Model

Items	MAESTRO	AVEVA	Deviation
Displacement (Δ)	2302.9 tons	2270.5tons	1.42%
Section Modulus (Z)	5.70 m^3	5.85 m^3	-2.57%
Max. Shear Force (SF_{max})	305.9 kN	290.6 kN	5.26 %
Max. Bending Moment (BM_{max})	6910.4 kN.m	6580.615 kN.m	4.77 %

The load case to be studied (LC3) simulates the third phase of the docking operation. The determination of the imposed ship load at each block is a difficult task since it is a function of the bending of the ship and the dock and the unequal compression or yielding of the interposed blocking system [9].

Due to the eccentricity between vessel longitudinal centre of gravity and midpoint of keel bearing length, the uniform load distribution of vessel load on keel blocks could not be adopted and trapezoidal load distribution should be used instead.

Assuming that a shorter vessel being docked is very rigid, the actual weight distribution of the vessel can be transformed into a trapezoidal load distribution as shown in Fig. 8 using equation 2, 3 and 4 [10].

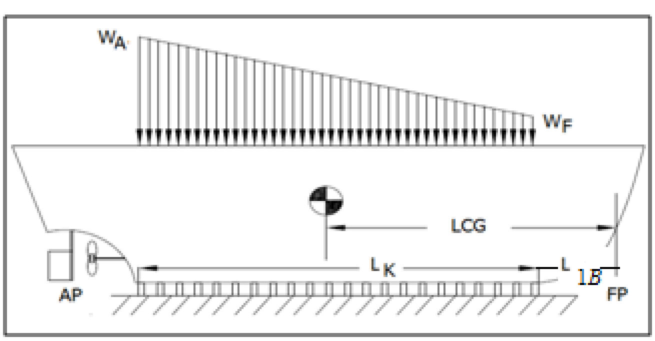

Fig. 8 Trapezoidal Weight Distribution [10]

$$w_A = \frac{W}{L_K} + \frac{6We}{L_K^2} \quad (2)$$

$$w_F = \frac{W}{L_K} - \frac{6We}{L_K^2} \quad (3)$$

$$e = L_{CG} - \frac{L_K}{2} - L_{1B} \quad (4)$$

Where e is Distance from centerline of keel bearing length to vessel LCG. Once the load distribution had been determined, docked ship weight could be incorporated in the FE model along with other loads involved in this load case as shown in Table 7.

Table 7: Weights Involved in Load Case LC3

Description	Group	Weight (Ton)
Ballast water	Volume	2086.37
Pumps and piping on bottom	Plate	65
Keel blocks and pipes on deck	Plate	200
Safety deck fittings	Plate	3
Weather deck fitting	Plate	8
Dock side crane	Nodal	70
Docked ship	Nodal	1773
Dock lightweight	N/A	1919.95
Total weight in LC.3		**6125.32**

5. RESULTS AND DISCUSSION

The draft and corresponding hydrostatic pressure distribution are obtained by balancing the weights under consideration. The resulting shearing force and dock's longitudinal bending moment are calculated as shown in Fig. 9 and Fig. 10, respectively. Fig. 11 shows the dock's transverse bending moment distribution.

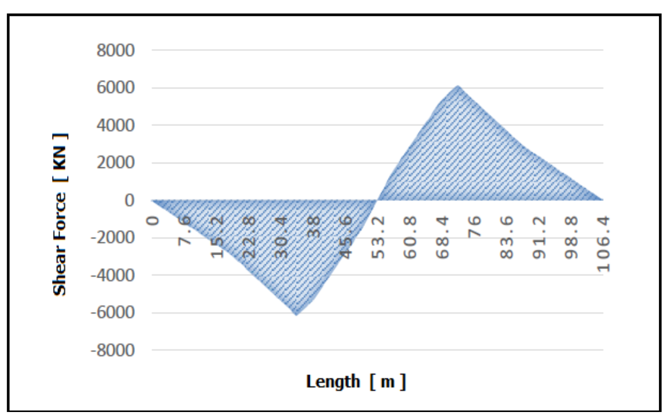

Fig. 9: Shearing Force Diagram

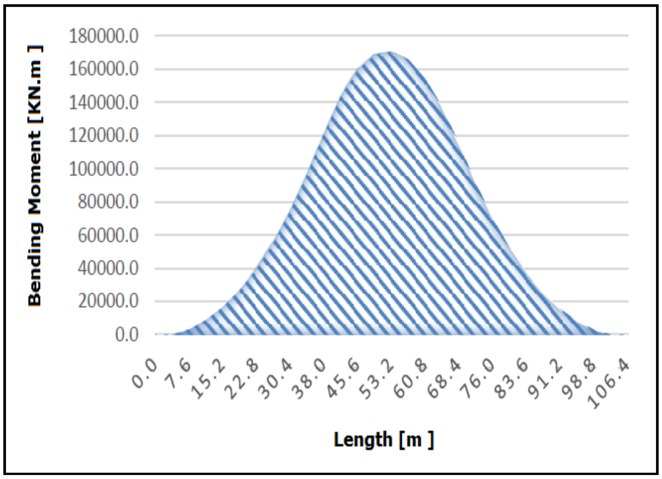

Fig. 10: Longitudinal Bending Moment Diagram

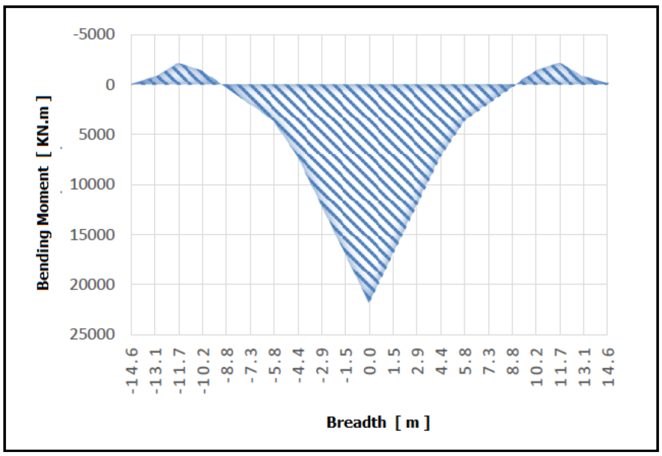

Fig. 11: Transverse Bending Moment Diagram

The dock's structural behaviour is explained throughout the output of normal and Von Mises stresses shown in Fig. 12 and Fig. 13, respectively. Also, Fig. 14 shows the deflection plot of the dock with the maximum deflection within the dock's centerline amidships area.

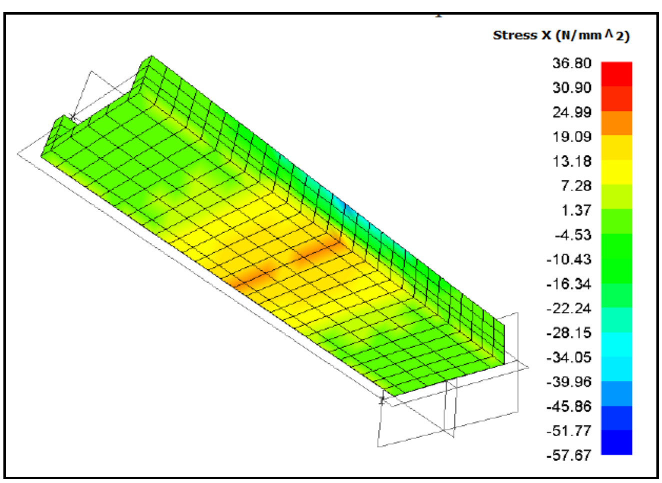

Fig. 12: Normal Stresses Plot in X Direction

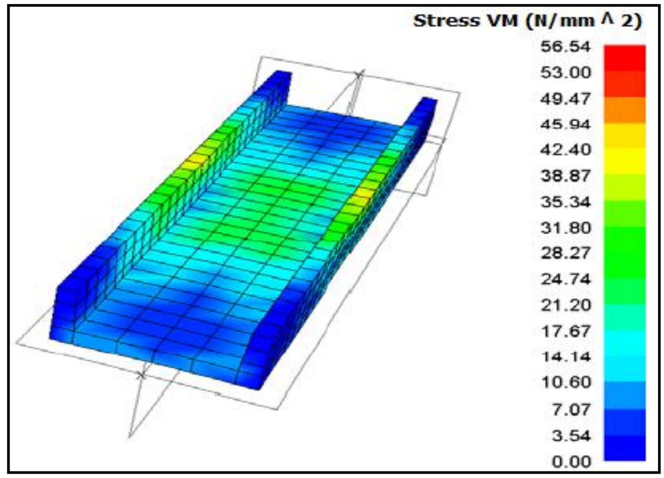

Fig. 13: Dock's Von Mises Stresses

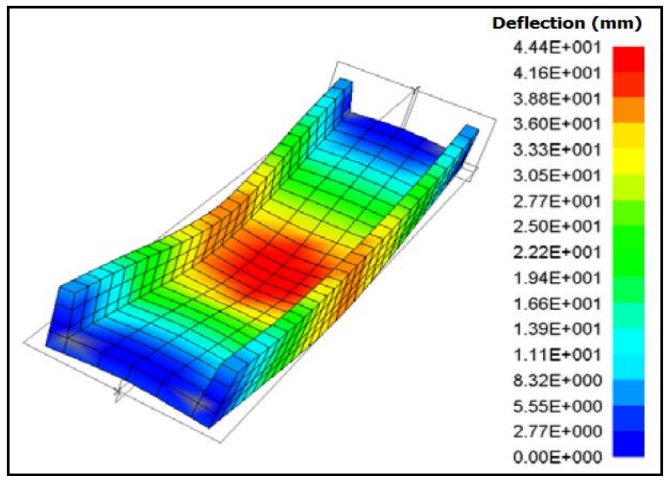

Fig. 14: Dock's Global Deflection

The main target is actually the calculation of dock's structural adequacy. Fig. 15 shows that dock's panels have satisfactory positive adequacy parameter; the most critical adequacy value detected is 0.116 with a panel collapse stiffener flexure failure mode (PCSF).

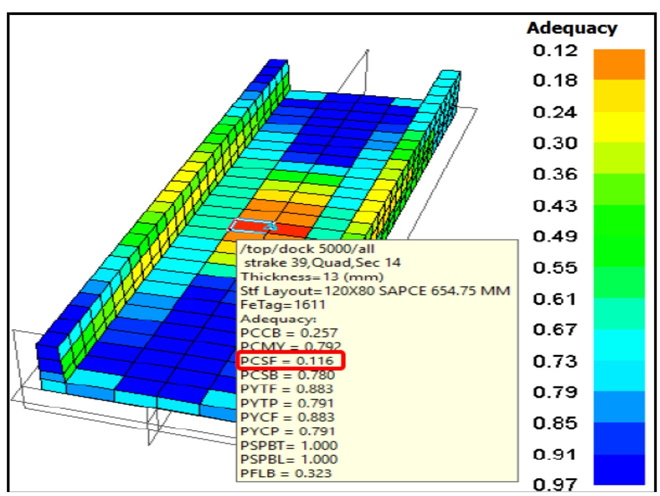

Fig. 15: Panels Adequacy Plot

It can be noticed that the most critical area is the area under dock's centerline keel blocks within tug keel bearing length. However, the structural members in this area remain safe with an acceptable safety margin. However, the model exhibits that the areas approaching collapse have a Von Mises stress of 56.54 MPa as shown in Figure 13, which is actually very small compared to the steel yield stress and reveals a design weakness. Dock's frames have also positive adequacy parameter as illustrated in Fig. 16; the most critical adequacy value is 0.865 with frame yield, tension in flange failure mode (BYTF). Other failure modes defined by the software had not been detected.

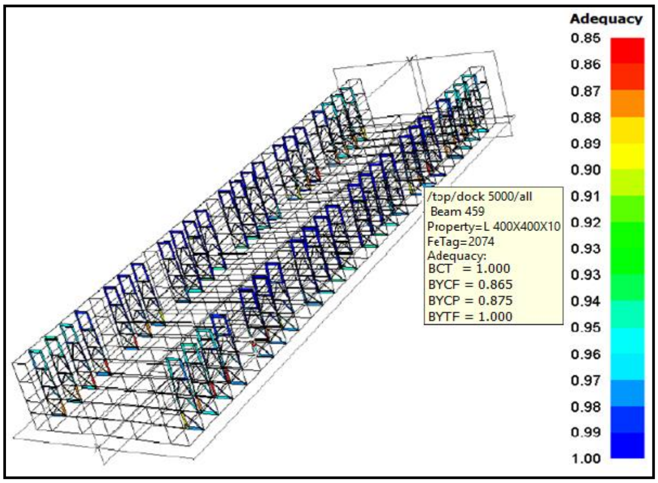

Fig. 16: Frames Adequacy Plot

According to the overall results of adequacy parameters, "AHT 100 ton" could be safely docked by "PORT SAID" floating dry dock. However, the minor failure modes depicted may be eliminated by an alternative ballast water distribution in floating dock compartments in order to avoid overstressing dock's structure. A modification of the standard ballasting system (pumping plan) used in the load case LC3 had been applied to the developed FEM model. A trial and error process had been carried out in order to attain the optimum ballasting system. These trials were investigated using MAESTRO by monitoring the values of deflection, bending moment and adequacy parameter. The required pumping plan would result in a lower deflection and bending moment values and greater adequacy parameter values [11].

The final weights after modification of the ballasting system are given in Table 8.

The analysis of the docking system using the optimized pumping plan had shown that the maximum deflection had been reduced by about 33%, and the maximum bending moment had been reduced by 30%. The critical values of the adequacy parameter had also been increased by about 30% [11].

Table 8: Weights Involved in Load Case LC3M (Modified Ballasting System)

Description	Group	Weight (Ton)
Ballast water	Volume	2354.56
Pumps and piping on bottom	Plate	65
Keel blocks and pipes on deck	Plate	200
Safety deck fittings	Plate	3
Weather deck fitting	Plate	8
Dock side crane	Nodal	70
Docked ship	Nodal	1773
Dock lightweight	N/A	1919.95
Total weight in LC3M		6393.51

6. CONCLUSION

The "load per meter run" criterion is highly simplified and may underestimate the dock's structural safety. The final decision concerning the acceptance of a specific docking operation would be better based on a complete structural simulation and analysis. The developed global 3D FE model supports the dock structural design and promises to be an efficient and reliable tool for the assessment of critical docking operation. Such a model would help to attain the optimum pumping plan of the dock in order to reduce the deflection and stress levels and eliminate any possible collapse mode. The introduced procedure may be easily reproduced for similar docks.

7. REFERENCES

[1] Heger, R. (2005), "Dockmaster's Training Manual", Heger Dry Dock Inc., Holliston, U. S.

[2] DRS Defense Solutions, LLC, Advanced Marine Technology Center (2011),"NVR Strength Criteria Implementation into MAESTRO Finite Element Analysis Application", NSRP Ship Design & Material Technologies Panel Project

[3] Ross, J.M., (2001), "Analysis of the Maximum Allowable Deflection of the "Adept" (AFDL-23) ", Proteus Engineering Division (prepared for Gulf Copper Ship Repair. Inc. by Anteon Corporation)

[4] Ramli, R. and Sobri, A.F(2018)," Design and Analyses of a Ship Floating Dry-Dock", chapter in book: Engineering Applications for New Materials and Technologies

[5] Heger, R (2003), "Floating Dry Dock Accidents Involving Transverse Bending Failure of the Pontoon", RINA International Conference, London

[6] Crandall, P.S.(1966), "Problems of Dry Docking Unusual Ships", Journal of Marine Technology, Vol. 3, 493-501

[7] Suez Canal Authority (SCA)–Port Said Shipyard (2017) "In Your Way from West to East Hemisphere. TARIFF - Docking & Undocking Repairs and

Services”, http: //www.suezcanal. gov.eg/ FlipPDFFiles/ Shipyards/ index.html#p=1

[8] Aveva Marine 12.1 (2017), Initial Design module, http:// www. aveva. com/ en/ Solutions/ Product_Finder/ AVEVA_Initial_Design/

[9] Amirikian, A.(1975), “Analysis and design of floating dry docks”, The Society of Naval Architects and Marine Engineers, SNAME, Vol. 65, 307-361.

[10] Taravella, B.M.(2005) “Accuracy Assessment of Methods for Predicting Dry Dock Block Reactions”, Journal of Marine Technology, Vol. 42, 103-112

[11] El-Maadawy, M.(2018), "Structural Safety Assessment of Floating Dry Docks", M.Sc. thesis, Faculty of Engineering, Port Said University.

تقييم المتانة الإنشائية لحوض عائم أثناء عملية رفع

الملخص

يناقش هذا البحث دقة معيار الحمل للمتر الطولي والذى يستخدم كطريقة تقييم مبسطة لتحديد إمكانية قبول تنفيذ عمليات رفع الوحدات البحرية على الحوض العائم من حيث السلامة الإنشائية وذلك للأحواض العائمة الغير معلوم الحمل الطولى المسموح به لها. تم اختيار أحد الأحواض العائمة المملوكة لترسانة بورسعيد البحرية والمسمى "بورسعيد" لتطبيق الدراسة عليه، حيث تمت نمذجته وتحليله باستخدام نظرية العناصر المحدودة بفضل توافر جميع البيانات الفنية للحوض. وقد تمت الدراسة مع أخذ جميع مراحل عملية الرفع فى الإعتبار لاتخاذ القرار السليم الذ يضمن السلامة الإنشائية للحوض. وقد اعتمدت الدراسة على معامل الملاءمة الذي يتم حسابه بالبرنامج المستخدم في التحليل باعتباره مقياس جيد لإكتشاف المواضع المشتبه حدوث خلل انشائى بها وكذلك تحديد أنماط الانهيار الإنشائي لمختلف أجزاء الحوض. يعد النموذج الثلاثى الأبعاد الذى تم إنشائه لهذا الحوض العائم أداة مهمة ومفيدة يمكن إستخدامها أيضا للوصول الى خطة مناسبة لملء تنكات الحوض وذلك لتقليل الإجهادات الناتجة عن عملية الرفع بدلا من رفضها. بينت الحالة التى تمت دراستها أن معيار الحمل للمتر الطولي هو معيار مبسط الى حد كبيرقد يكون غير دقيق وكافى لتقييم عمليات الرفع وبالأخص العمليات الحرجة منها.