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Calculation of structural loads of a reverse osmosis skid during operation

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ABSTRACT

The New Mansoura seawater desalination plant is a new project in the framework of bridging the water deficit in Egypt. One of the major challenges of this project is the limited available area which poses a question of how to manage the general arrangement to satisfy the technical requirements. This work aims to assess the possibility of building the structure of the reverse osmosis (RO) membrane skid structure on the basis of multi-story building. The dead weight of the skid structure can be calculated and considered in the building design. However, the main concern is the dynamic loads under high pressurized flow. In order to study this problem, the work started by CFD analysis of the flow in piping system of the membrane skid to evaluate the static and dynamic loads of the fluid flow. Then, FEA is carried out to assess the loads transmitted to the building. The forces and moments on supports and fixations are evaluated. These loads are then passed to the building design to assist the decision of considering concrete or steel structure building. Finally, the two solutions are reviewed technically and financially to choose the suitable solution under the limited area constraints. Results show that the dynamic loads of fluid flow are negligible relative to the static pressurization loads. The dynamic loads are remarkable during the build-up of fluid flow in the commissioning phase, while can be neglected during operation. The pressurization remarkably increased the load on the skid structure which bears about 85% of this load and transmits the reminder to the building structure. Results, also, depicted that the increase of static load due to of pressurization does not have a linear relation to the pressure value. Hence, the loads should be computed in each pressure range.

Keywords: Membrane-skid structure; Structure analysis; Multi-story RO plant

1. Problem description

The water scarcity is one of the basic threat of the human communities. Despite the existence of a renewable water source in Egypt, it is considered as a threated country because of its increasing population. Over the years, advances in desalination technologies have made it an economically viable alternative source of fresh water. Subsequently, in response to shortages of naturally renewable water supplies, many MENA countries developed desalination facilities [1]. By 2007, over 50% of the world's desalination potential was installed in MENA, primarily in the Gulf region (Fig. 1) [2].

The hydrological analysis confirms that per capita renewable water resources in MENA are among the lowest in the world and projects that the situation will worsen in the future (Fig. 2) [3,4].

The New Mansoura City stretches 14 km along the coastal road in the heart of Dakahlia, extending from Gamasa city all the way to the borders of Kafr El-Sheikh Governorate. This puts it 54 km away from the old Mansoura city. The city will cover an area of 4,000 acres with an investment valued at over 60 billion EGP. Capacity of the city is estimated at over a million and a half residents. The first phase of the city will be 40% of the total are (25,000 residential

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unit) [5]. The city will have different housing types: tourism residences, villas, middle-income housing, and social housing.

It is intended to construct a reverse osmosis desalination plant at New Mansoura (NMRODP), with a capacity of 40,000 m^3/d extendable to 80,000 m^3/d in future. NMRODP shall be composed of 3 streams each stream 13,500 m^3/d. The total capacity of the three streams is 40,500 and 40,000 m^3/d of the capacity will be discharged to the city and the remaining capacity of 500 m^3/d is for the internal use in the plant operation. Due to the limitation of area, the proposed arrangement suggests the possibility of one-story building to accommodate the plant equipment (Fig. 3).

Elsaid et al. [6,7] investigated the leading desalination technologies of reverse osmosis (RO), MSF, and MED were analyzed, along with different feedwaters. This article provides a mapping of the different technologies involving feedwater and brine management techniques and a detailed description of their impact on the environment.

The work of Qasim et al. [8,9] regarding different membrane fouling types, such as colloidal, organic, inorganic, and biological fouling, are addressed in this review. Principles of RO process design and the embedded economic and energy considerations are discussed. In general, cost of water desalination has dropped to values that made it a viable option, comparable even to conventional water treatment methods. Finally, an overview of hybrid RO desalination processes and the current challenges faced by RO desalination processes are presented and discussed.

Zhao [10] investigated probabilistic models of uncertainty of the fatigue strength in the S-N curves frequently used in offshore oil and gas, and the offshore wind industry based on a comprehensive fatigue test database. It then recalibrates the DFFs from a detailed reliability analysis. The results have shown that with the same target reliability while the DFFs for in air condition in T curve and D curve can remain the same as those from current standards, the DFFs for F curves are reduced especially for the corrosive environmental conditions which has the maximum reduction up to about three times.

Moghaddam et al. [11] proposed a framework to simulate fatigue crack growth from multiple corrosion pits at critical spots of the Spar-type floating support structures to examine the status of the crack during several years of operation. The proposed advanced fracture mechanics-based approach provides a methodology to assess the integrity of the structure and subsequently plan for preventive or

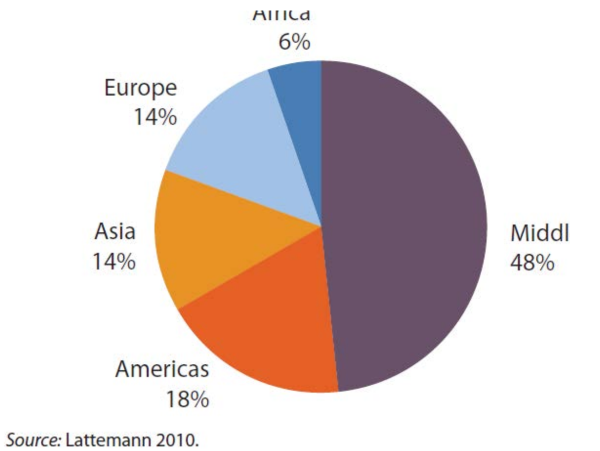

Fig. 1. Distribution of Worldwide Desalination Capacity, 2007 [2].

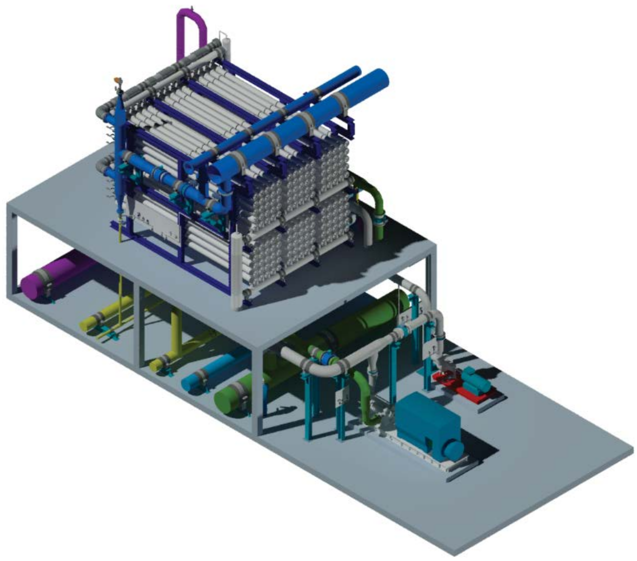

Fig. 3. Proposed arrangement of the plant.

Fig. 2. Average water stress by country, 2020–2030 [3].

curative maintenance. The crack growth rate is examined for both singular and multiple cracks at different R ratios and for different stress levels using ABAQUS XFEM. Following numerical simulations, a sensitivity analysis is carried out using Crackwise software for different values of plate thickness, R ratio and initial crack size. The numerical results are discussed in terms of the corrosion pitting effects on fatigue life assessment of floating offshore wind turbines [1].

This paper introduces the theoretical bases of work as the failure criteria of concrete structure and steel structures in the offshore conditions. This background leads the research to find the required values of the building design parameters. Then, the computational results of CFD of fluid flow and FEA of structure are investigated and the required correlations are derived. Finally, the conclusions of the research are illustrated [12].

2. Theoretical background

It is required to find the loads acting on the slab that carries the pressure vessel skid. The acting forces are classified into static and dynamic. Both dead weight of the skid, weight of pressure-vessels, weight of water under operation, and static pressure of water created by high-pressure pumps are considered as static forces. On the other hand, the dynamic forces can be regarded of two main categories; dynamic forces due to velocity of running water which causes vibrations, and transient forces during filling and discharging of pressure-vessel that can cause transient effects of pressure and vibrations [13].

The dead-weight static forces (except forces due to pressurization) are calculated from the computational package according to the given materials. These forces are multiplied by a safety factor of 1.2 to compensate for errors and differences of elaborated structure with respect to designed one. The forces due to pressurization are calculated using a CFD package [12]. In order to consider the effect of pressurization forces, the high-pressure piping system is solved and its supports to the skid structure are considered fixed and their reactions are evaluated as they are transferred to the skid structure.

In general concrete is brittle under tension and has limited deformability under compression. Typical values for strength under tension are 8-12 times smaller than under compression. A similar ratio holds for the ultimate strains. Under compression 0.25% are normal, then one enters the instable regime of strain softening up to a strain of about 0.35%. The brittle behaviour under tension does not mean, that linear-elastic behaviour rules. It can be strongly nonlinear elastic and is dominated by the growth of a dominant crack. Under compression however multiple cracks form and develop instantaneously perpendicular to the maximum principal stress [14]. The envelope for concrete is relatively independent on the loading history, hence the principal stress criterion can work. The maximum compressive strength can be reached, when a compressive stress is applied perpendicular to the main compressive stress that closes the cracks.

3. Computational results

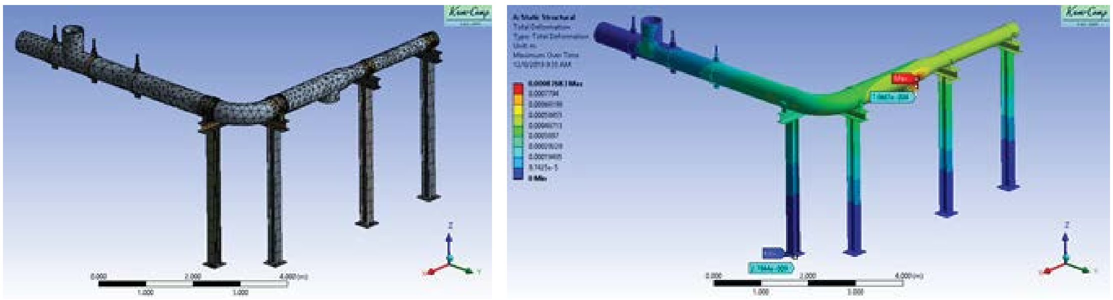

Fig. 4. Mesh and static structure analysis of hinged piping.

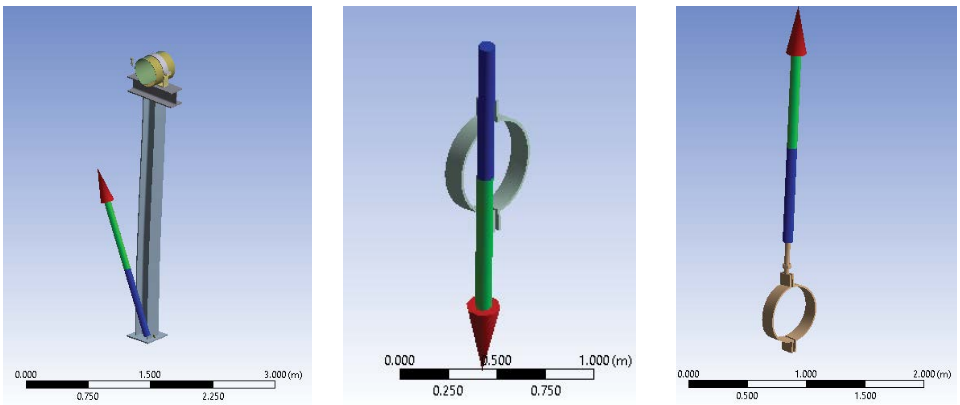

Fig. 5. Loads on supports.

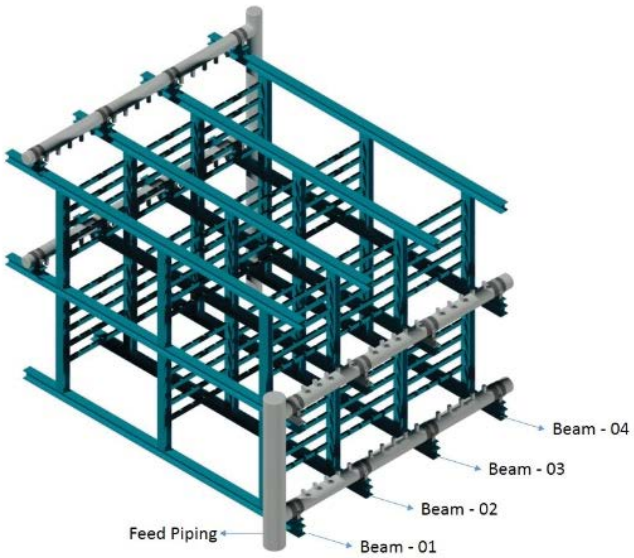

Fig. 6. Membrane-skid structure arrangement.

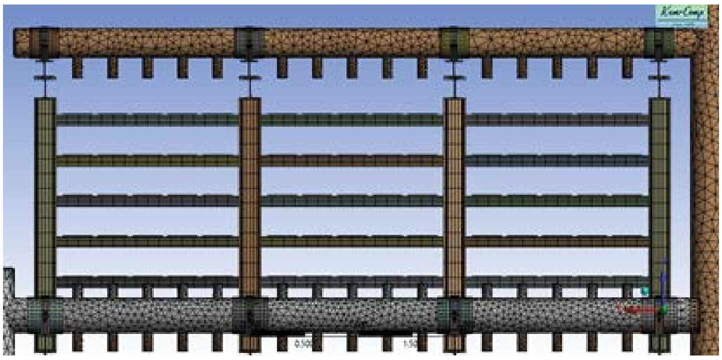

Fig. 7. Mesh of pressurized pipes.

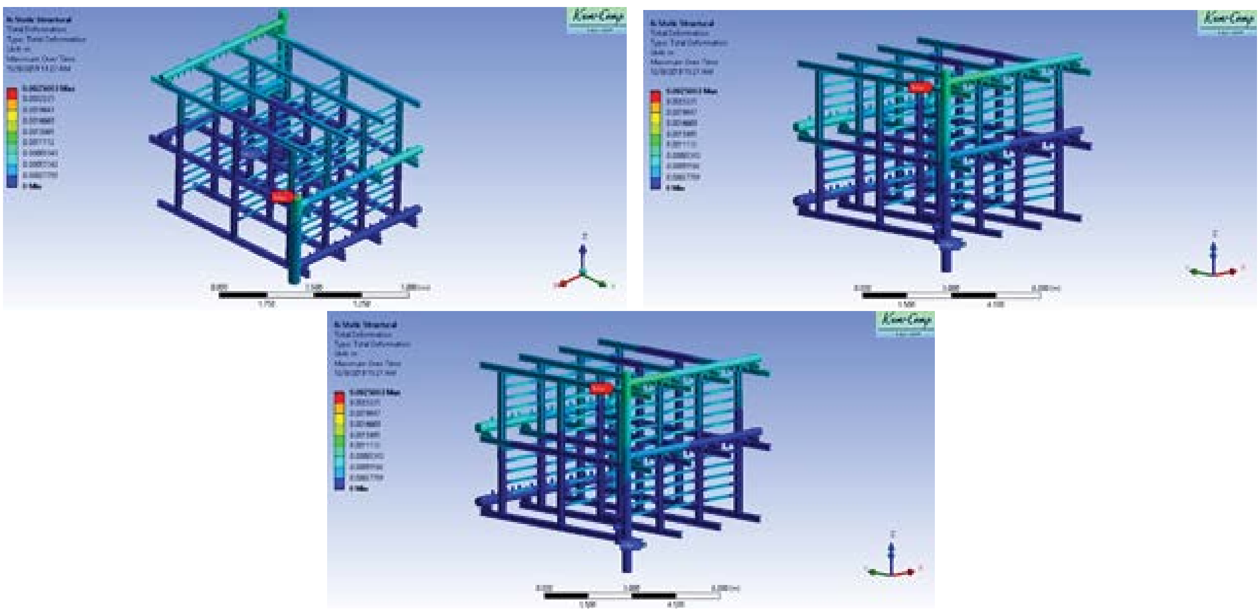

Fig. 8. Analysis of pressurized pipes.

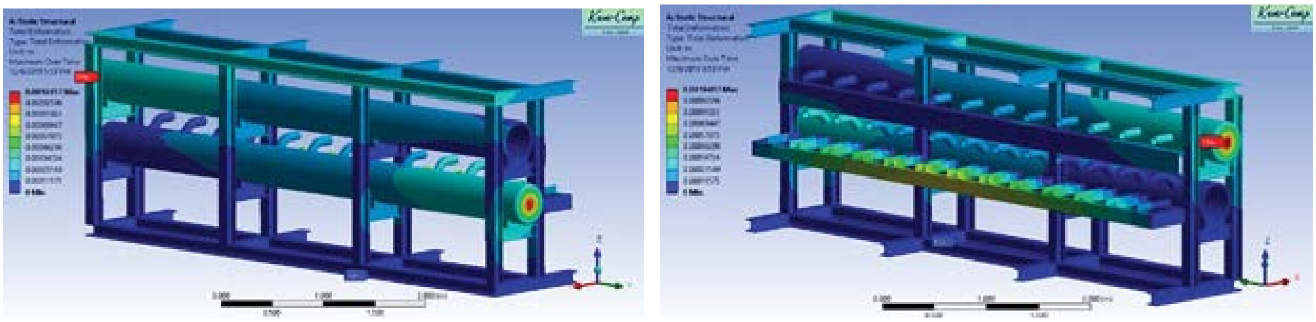

Fig. 9. Analysis of PX change.

4. Conclusions and recommendations

The analysis work was carried out using a computational package. Both static and dynamic loads were taken into consideration. All materials have linear isotropic behaviour. Firstly, a CFD analysis were carried out to evaluate the pressurization loads and flow-induced pressures on the high-pressure piping system. Secondly, these results were used as inputs of the FE structural analysis of the pipes and their influences on the skid structure. Then, the skid structural analysis was carried out to depict the loads transmitted to the ceiling slab. The design loads were considered as 125% of calculated loads.

Considering the four I-section steel beams of the skid base, results showed that:

- Reactions of first beam are x = 3.94 KN, y = 0.227 KN, z = 56.92 KN.
- Reactions of second beam are x = 0.325 KN, y = 0.432 KN, z = 227.97 KN.
- Reactions of third beam are x = 1.373 KN, y = 0.0872 KN, z = 251.9 KN.
- Reactions of fourth beam are x = 4.45 KN, y = 0.6251 KN, z = 121.1 KN.

Considering I-section steel beams of the PX skid base, results showed that:

- Reactions are x = 8.376 KN, y = 15.62 KN, z = 12.24 KN.

Considering supports that hanging the high-pressure pipes directly to the ceiling slab, the forces on supports are:

- Reactions of first support are x = 2.765 KN, y = 3.004 KN, z = 14.428 KN.
- Reactions of second support are x = 1.07 KN, y = 0.043 KN, z = 14.63 KN.
- Reactions of third support are x = 0.878 KN, y = 1.733 KN, z = 18.26 KN.
- Reactions of fourth support are x = 1.516 KN, y = 0.934 KN, z = 20.65 KN.
- Reactions of fifth support are x = 0.086 KN, y = 0.917 KN, z = 2.504 KN.
- Reactions of sixth support are x = 0.083 KN, y = 0.783 KN, z = 0.17 KN.

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