Master thesis : Development and Technical Feasibility of a Dry Dock System for a Floating Wind Turbine Installation Platform

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Faculté : Faculté des Sciences appliquées
Diplôme : Master : ingénieur civil mécanicien, à finalité spécialisée en "Advanced Ship Design"
Année académique : 2021-2022
URI/URL : http://hdl.handle.net/2268.2/16559

Development and Technical Feasibility of a Dry Dock System for a Floating Wind Turbine Installation Platform

submitted on August, 2022

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Master Thesis

ABSTRACT

To achieve the goal of the sustainable development of environment, floating offshore wind turbine(FOWT)will play a major role in enabling the green shift and achieving the renewable energy goals. FOWTs have many advantages, therefore many large scale floating offshore wind farms are being planned. At the same time the capacity and size of the actual wind turbines grow rapidly. There have been many concept studies and pilot projects exploring different designs of FOWTs and their functionality. However, in the current stage the turbine integration and heavy maintenance have so far been assumed to be done at a port. Considering the size of the FOWTs, this presupposes that there are ports nearby with sufficient water depth in the channel and at the quayside, with no air draft restrictions due to bridges or power lines, and sufficient bearing capacity for onshore cranes. Integrating the turbine on a floating foundation by making use of state of the art heavy lift vessels as an alternative to being dependent on suitable base ports is extremely challenging due to the relative motions between the two floating objects. To overcome this limitation, KONGSTEIN contributed to developing a new concept for the turbine integration and heavy maintenance of FOWTs offshore. A FOWT installation platform consisting of dry dock system can be beneficial for executing this goal with the ability of assembling and installing the FOWTs offshore without mobilizing a base harbor ashore. The idea is to lock the floating foundation inside the dry dock, thus there will be no relative motion between the vessel and the floating foundation and the lifting operation will be significantly safer and easier to control.

This feasibility study aims to evaluate the technical feasibility of the dry dock gate design for the dry dock system of a floating wind turbine installation platform. The concept design of the dry dock for wind turbine generators have a capacity of 18+ MW is based on an exemplary wind energy area with high water depth, harsh wave and swell conditions. The market research is done afterward for choosing and ranking the most suitable gate design for the objective. The second phase of this study is the technical feasibility study. After the properest gate type is chosen, the modeling and load analysis for the structure is preformed. The hydrodynamic load case for the target area is used as the input for the gate deformation simulation. The global and local model structure with the chosen gate type is analyzed in next steps. Finally, the suitability of chosen gate design for this specific application will be evaluated based on the market research and the technical analysis. According to the evaluated result it can be said that the gate design for this study is relatively conservative, the improved suggestion for the present design gate would be following provided.

Key Words: FOWTs installation platform, Structure strength, Dry dock gate design

ACKNOWLEDGEMENTS

Words cannot express my gratitude to my supervisors/reviews Professor Florian Sprenge, and Tim Müller from KONGSTEIN for their continuous support of my master's study. I also would like to express my appreciation to my defense committee, who generously provided knowledge and expertise, without them I could not have undertaken this journey. Additionally, this endeavor would not have been possible without the generous support from the EMSHIP+ education program(former Erasmus Mundus) in Advanced Design of Ships and Offshore Structures, who financed my master's study.

I am also sincerely grateful for the encouraging and guiding eyes of Rune Tvedt and Junheng Zhang. Through they have incredibly busy days, they are always willing to take the time to answer questions of my research. With their professional knowledge and experience, I am able to perform my thesis. Their professionalism and patience are to be admired.

I would like to express my thank to Royal HaskoningDHV and Heger Dry Dock, your kindly participation added a precious practical perspective to my research.

I appreciate the support from members of the University of Rostock and DNV for providing me with the analysis software and guidance that assist me in completing this study. It was a learning experience that I really enjoyed it when I start learning how to use the software and eventually be able to perform the analysis.

Moreover, I am grateful to my cohort members, office mates, and all members of this meaningful and advanced EMSHIP program for your late-night feedback sessions, and moral support. Without your precious support, it would not be possible to conduct this research.

Lastly, I would be remiss in not mentioning my family, especially my parents. Their belief in me has kept my spirits and motivation high during this process. Thank you for your patience and understanding as I completed my studies.

1 INTRODUCTION

The expansion of floating offshore wind farms is considered one of the new major markets in the offshore wind industry. To achieve the goal of 2000 GW capacity with net zero emissions in required 1.5°C pathway scenario by 2050, Aegir (2022) estimated that the annual installation rate of wind turbine in 2030 needs to be the seven times of 2020, Fig.1 shows the expectation of the installed offshore wind capacity. Floating offshore wind turbines can be installed at very high water depths, which allows offshore wind farms developed in more areas worldwide. FOWTs are installed further away from the coast with higher and more stable wind speeds, therefore having a higher capacity factor. With more advantage, such as more efficient installation, maintenance and less environmental impact, the demand of floating offshore wind turbines are gradually increased. One of the feature of floating wind turbines is that they can be completely pre-assembled in the base port and then towed upright into the installation field. However, this presupposes that there are ports which, among other things, have sufficient water depth at the quayside for the required draft of the fully assembled floater, and whose access is not limited by bridges or power lines. Moreover, there are often no suitable ports available at near by the planned floating wind energy areas. Besides the increase in the number of offshore wind turbines needed, the capacity and size of wind turbines are also growing. The state of art crane vessel to install the turbines can be upgraded to a certain extent, however, the challenge with a floating assembly offshore is the heavy-lift operations that are performed in unsheltered areas where either between two floating objects or between a crane vessel and a floating foundation. In another word, the relative motion between the crane vessel and floating foundation is a major task that definitely needed to be considered. To overcome this limitation, the new technology for the installation of floating offshore wind turbines becomes an essential topic for the green energy industry.

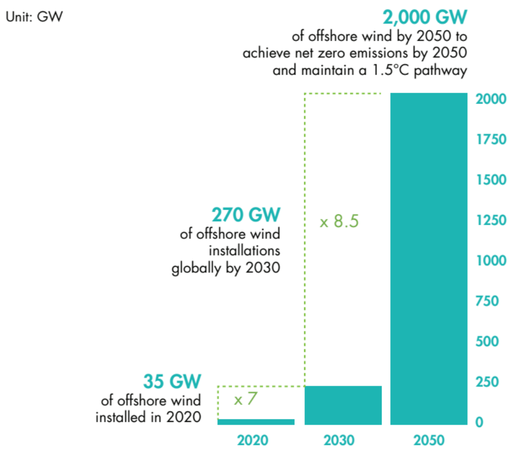

Figure 1: Expected Installed Offshore Wind Capacity
(Source:Aegir (2022))

1.1 Problem Statement

This feasibility study aims to evaluate the technical feasibility of the dry dock gate design for the dry dock system of a floating wind turbine installation platform. The installation platform consists of dry dock system which is designed for the maintenance and installation of floating offshore wind turbines. The wind turbines (maximum two turbines per ship) should ideally completely assembled (foundation, tower, nacelle, blades) on the platform. The idea is to lock the floating foundation inside the dock, thus the lifting operation will be much more controlled compared with the unsheltered area. In present study focus on the evaluation of the technical feasibility of the gate design for the dry dock where the turbine integration will be performed.

1.2 Methodology

The analysis methodology presents in this study by following steps. First, making the concept design of the dry dock based on the exemplary wind farm area project and the expected utilizing floating offshore wind turbine (FOWT) with 18+MW capacity. The market research is done afterward for choosing and ranking the most suitable gate design for the objective.

The second phase of this study is the technical feasibility study. After the properest gate type is chosen, the modeling and load analysis for the structure is required. The exemplary offshore wind farm sea state information, and the extreme sea state/ wave condition of this area will be considered for hydrodynamic load analysis. Hydrodynamic load acting on the object is an important factor that should definitely be considered when estimating the structure strength for a new design. The hydrodynamic load case will be an input for the gate deformation simulation.

The dry dock gate deformation and integrity are analyzed by the steps shown in Fig.2. The global model will be first analyzed by finite element method with the design load. Once check the global structure behavior has the consistency with the reality and fulfills the regulation, the local model for the interesting region can be created and simulated with the basis of the global model simulation results.

The last stage of this study is the feasibility discussion. With the market research and technical analysis result, the chosen gate design for the floating platform dry dock system are evaluated if the product fit the required mission. Based on the analysis, the improved suggestion for the proposed design would be provided.

To complete the analysis, the software POSEIDON, ShipLoad and ANSYS are utilized. The procedure are illustrated in Fig.2.

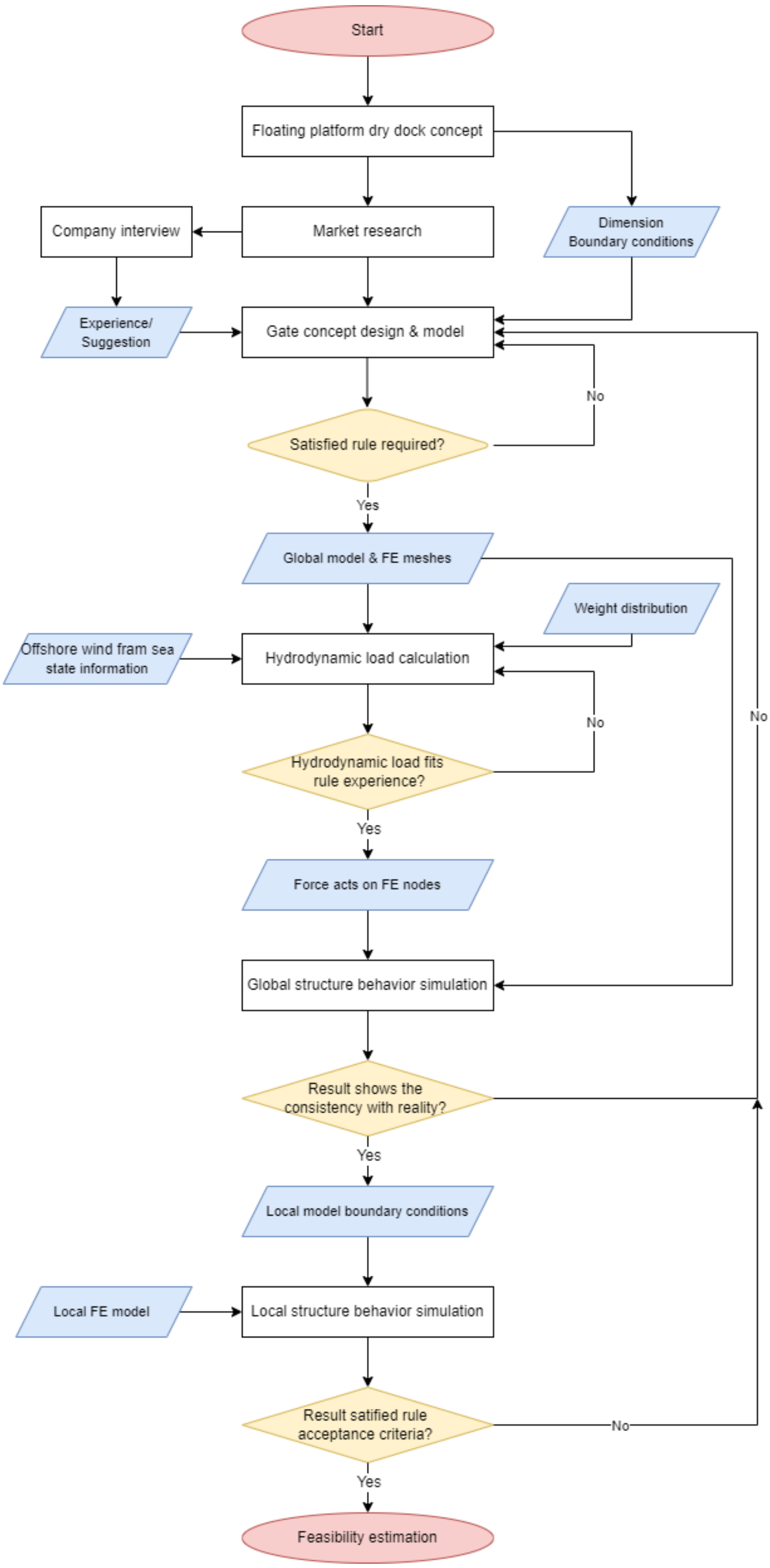

Figure 2: Analysis Flow Chart

2 THE FLOATING DRY DOCK CONCEPT

The concept design of the dry dock system is designed for the floating offshore wind turbine foundation with 18+MW capacity.

In current stage, there are lots of project planning for capacity of 18+MW. The floating foundation proposed to be considered as reference in this study is a typical semi-submersible foundation. The sketch of the foundation for turbine can be seen in Fig.3. The foundation size for 18+MW turbine are scaled based on the reference of 14+MW turbine.

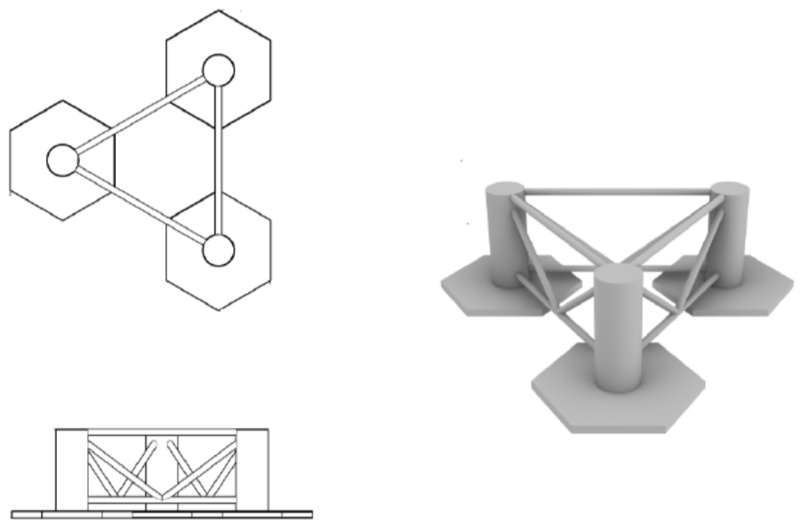

Figure 3: Sketch of Semi-Submersible Foundation

To be able to perform the installation and maintenance for FOWTs the dry dock system needs to be designed according to the demand. Based on the dimension of the reference semi-submersible foundation, the dry dock system for floating platform can be designed.

3 MARKET STUDY FOR GATE DESIGN

To achieve the aim to design the gate for the dry dock system, the market research of the existed gate design for the large opening dock is done, which can be the reference for the gate design of the subject. In this section the common used gate types and the comparison of them are discussed. The evaluation for gate type that is appropriate for the design floating platform are carried out based on the market research result, as well as the suggestion provided by experience dock gate design companies. The typical gate types are only described in general terms.

All kind of gate types have their own cons and pros. The most common gate types are mitre gate, sector gate, floating caisson gate, sliding caisson gate, and flap gate. Based on the requirement of the subject, the miter gate and sector gate are not possible for the large opening entrance(wider than 50 meters), thus the gate type ranking is performed among the other three types. For choosing the best designed gate type, the weight function (Eq.1) is used. The result expressed with weighted average are shown in Table 1.

3.1 Gate Type Ranking

Most common requirements in the choice of dry dock gate are reasonable costs, control limitation,and ability of maintenance. According to the operation scenario, the requirement of the objective are listed below:

- Dock gate needs to be able to operate offshore (in wave condition).
- Dock gate should be suitable for wide entrance, considering the 18+MW FOWT foundation size.
- Gate need to be able to operating in semi-immersed position.
- Gate can stand the difference water level between inside and outside of dock, during turbine install operation.
- Gate design should be able to stand the initial hydrodynamic pressure for the depth required by the dock.
- Possibility of maintenance in site/ ease of maintenance to lower down the maintenance fee.
- Do not require too much power for operation the gate.
- Ease of operating and storage the gate.

$$\frac{\sum f(a)\boldsymbol{w}(a)}{\sum \boldsymbol{w}(a)} \tag{1}$$

Table 1: Gate Type Ranking Result.

	Weight factor	Sliding /Rolling	Floating /Caisson	Flap
Width of entrance	24	1	3	2
Depth of entrance	24	1	3	2
Cost of construction	20	2	1	3
Ability to stand different water pressure between dock and sea level	14	1	3	2
Ease of maintenance	8	1	3	2
Parking space availability	5	1	3	2
Provision of power	5	2	1	3
Weighted average		1.25	2.50	2.25

4 SCANTLING FOR THE GATE AND DESIGNED PLATFORM

The gate type selected based on the requirement of design platform needs to be modeled for the further analysis. The dry dock gate and designed platform modeling are required for further analysis. The scantling and modeling of global structure are satisfied with the DNV rules, and preformed by software POSEIDON. The finite element (FE) model is used as the input for the hydrodynamic load analysis and structure deformation simulation.

5 HYDRODYNAMIC LOAD ANALYSIS

Based on the target area information, the hydrodynamic load analysis can be carried on by the software ShipLoad, which was provided by DNV, with the global finite element model of the designed platform. According to the rule provided by DNV (2018), in ShipLoad hydrodynamic calculations can be used to derive rule loads such as hull girder loads.

According to the main particulars of the platform, the design moment can be calculated by DNV (2021b) Rules Part 3 Chapter 4. The still water bending moment for both hogging and sagging conditions are computed by the Eq. 2 and Eq. 3, respectively.

$$M_{sw-h-min} = f_{sw}\left(171C_wL^2B\left(C_B+0.7\right)10^{-3} - M_{wv-h-mid}\right) \tag{2}$$

$$M_{sw-s-min} = -0.85f_{sw}\left(171C_wL^2B\left(C_B+0.7\right)10^{-3} + M_{wv-s-mid}\right) \tag{3}$$

ShipLoad provides the reference design waves required to achieve the prescribed bending moment values, which is based on equivalent design waves (EDWs). The Fig.4 shows the comparison of the vertical bending moment distribution along structure length between the value required by DNV rule and the load case defined in ShipLoad.

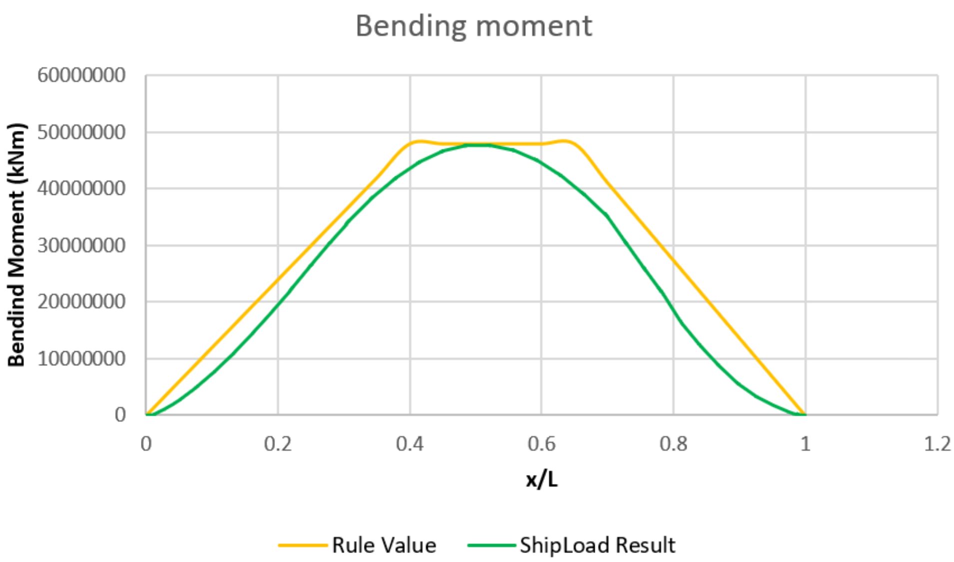

Figure 4: Comparison of the Vertical Bending Moment Distribution

6 DRY DOCK GATE DEFORMATION AND STRUCTURAL INTEGRITY EVALUATION

The structure deformation and integrity analysis is analyzed by the results provided from ANSYS. Inputting the global FE model gotten from POSEIDON and the load-cases results analyzed by ShipLoad, ANSYS can calculate and simulate the behavior of global structure. After checking the performance of global structure based on the applied wave is consistent with the reality, the local model analysis is carried on in ANSYS as well. The element types for structure are beam 188 and shell 181 based on the requirement for FE analysis (DNV, 2021a).

6.1 Permissible Stress

Regarding the stress acts on the structure, the permissible maximum equivalent stress required by DNV (2021a) rule can be calculated based on the the Eq.4, where the k is the material factor. The permissible maximum equivalent stress for each material which are used in present design are calculated and indicated in the Table 2, which are used to evaluated the global and local model simulation results for the designed platform and gate.

$$200 * f_1 = 200 * 1/k \tag{4}$$

Table 2: Permissible Maximum Equivalent Stress

	1	2	3	4
Yield Stress [N/mm^2]	235	315	355	390
Material Factor k	1	0.78	0.72	0.66
Permissible Stress [N/mm^2]	200	256.4	277.8	303.0

7 CONCLUSION AND RECOMMENDATIONS

The objective of this master thesis is to perform a feasibility study for a dry dock gate design. The dock gates are utilized for a floating offshore wind turbine installation platform, which consists with two dry docks for installation and maintenance the floating offshore wind turbine at aft and fore of the floating platform. It has been shown in this study that the market researching, design/modeling logic, and structure strength analysis procedures. The conclusion and recommendation of this feasibility study are provided.

7.1 Conclusion

The gate design for the dock of the floating platform is an important task due to the operating condition. The platform needs to be able to carry out the mission in the target wind farm area, the wave condition offshore is a factor must be take into account when constructing the floating platform and its equipment. The essential requirements for the dock gate helps to rank the different gate types. Among the common used dock gate types, the floating caisson gate is chosen for the floating platform considering the ability of achieving the demand function for the operation scenario.

After the proper gate type, floating gate, is chosen, modelling for the gate and scantling for the global floating platform is done for further analysis. The dimension of gate is designed corresponding to the dimension of the floating platform and its dry dock where the installation and maintenance is processed. The target is to utilize the platform for the offshore wind turbines which has the capacity more than 14+MW, thus the platform is designed based on the dimension of the 18+MW offshore wind turbines.

The structure strength analysis is performed assumed while the operating period which means the dock is closed situation. The global model is modeled considering the gate is embedded. The scantling detail is based on the DNV rule required for the floating dock and steel platform. The global finite element model with coarse meshes is generated as input for computing the hydrodynamic load acts on structure. The global load analysis is proceed with the assumption of global model as a hull girder. The wave load analysis is completed considering the target area sea state information and the most critical situation required by rule. The hydrodynamic results are calculated based on equivalent design waves (EDWs). The vertical bending moment distribution along structure length specified in DNV rule is the reference for validating the designed wave load cases.

The overall global structure behavior under the designed load cases is fulfill the expectation for the load cases condition, regarding the deformation and equilibrium stress of the structure. The local strength analysis for interesting area, where is the dock gate structure, is carried out based the global model analysis result as boundary conditions. The result obtained from local structure strength analysis shows that the floating gate design is satisfied the requirement requested by DNV rule and is able to achieve the feature demanded for the floating platform operation.

With the basis of the simulation result and market research out come, the feasibility of the dock gate design is considerable high. Due to the procedures done for this feasibility study are the simplification of the reality, the results obtained can be influenced or affected by the uncertainties. There are some aspects are recommended to be taken into account for the further work.

7.2 Recommendations for Future Work

Further works could be carried out based on this thesis, as described the analysis is a simplification of the reality. There are some recommendations are provided to improve the performance of analysis and the gate structure design:

- Because it is in concept design stage, the weight distribution for load analysis applied in this study is a draft arrangement and estimation for the floating platform. The more detail information should be provided and utilized in the further design loop.
- The design wave load is slightly smaller than the rule required value, the correction factor should be applied in the further analysis for more accurate result.
- Both the global and local model analysis result show the stress acts on the gate structure is far below than the rule required value, which means the current structure designed is too stiffed. The thickness of plating and stiffened system can be reduce to decrease the weight and lower the cost of the structure at the same time.
- Due to the global economic recession and inflation situation, the material cost and labor cost may varies dramatically. The cost estimation should be evaluated more detail.

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