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Load mapping for seamless interface between hydrodynamics and structural analyses

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ABSTRACT

This paper addresses the problem of a seamless interface between hydrodynamics and structural analyses. A pressure distribution on a hydro model computed from seakeeping analysis needs to be transferred to a structural model for evaluating structural strength and its integrity. However, due to the differences in the computation and representation methods for both analyses, the load on the hydro model may not be correctly transferred to the structural model, leading to a different load distribution on the structural model and resulting in some unbalanced force and moment components. In this paper, a method is proposed to solve this problem. A pressure distribution on the hydro model is mapped on the structural model through projection, and force and moment imbalances on the structural model are eliminated through optimization of the nodal forces on the structural model. Moreover, a viscous force distribution along the center of each member of the hydro model is transferred to the nodal forces on the structural model based on the minimum distance measure with resolving any force and moment imbalance. Examples are presented to demonstrate the validity of the proposed method.

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1. Introduction

As a demand for novel types of ships and offshore structures for operating in severe sea conditions is growing, traditional design methods may not sufficiently reflect various design requirements for such vessels. Thus, a different design strategy should be introduced during the design. To design ships or offshore structures of such types for a safe and efficient operation, ship owners and ship registers have started to consider seakeeping performance in the design phase. Theoretical and practical approaches on this problem have attracted many researchers' interest around the world [1].

Seakeeping indicates motions of a floating body when there exist waves, wind and a current. The motions in such conditions are estimated using fluid forces acting on the body, which can be computed using potential theory. Once the forces are computed, an equation of motion for the body is solved with the loads as input, and the body motions are computed with respect to time. This information is a useful reference in the hull shape design. In addition, the computed loads on the body are important in the structural design of the body because the body should be designed to avoid any structural failure under such external loads.

The loads acting on the body computed in seakeeping analysis are pressure and viscous forces. In order to compute the distribution of pressure on the body, the hull is discretized into panels, and pressure values for the panels are computed. On the other hand, the viscous forces are computed at the center points of each member of the model using an empirical formula, called the Morison's equation, which computes approximate resultant viscous forces for a structure. These two external forces need to be provided as input to structural analysis. However, when the input is prepared, the two forces should be handled differently because of the different properties of each force.

Pressure is computed on the panel model during seakeeping analysis. The panel model consists of panels approximating the shape of a ship hull or an offshore structure. The panels for seakeeping analysis are usually coarser than finite element

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meshes for structural analysis. Because of the difference of the models, pressure on the panel model cannot be directly used as an external load for structural analysis.

The pressure load on the panel model can be transferred to the structural mesh model through integration. Transferring the pressure, however, poses a few problems due to the difference of the model representation. The hydro panels and the structural meshes would not be the same although they are generated using the same underlying geometry. Therefore, the pressure load on the hydro panels may not be so transferred to the structural meshes that some unbalanced force and moments on the structural meshes are obtained, resulting in a load distribution on the structural model, which is different from that on the hydro panel model. Namely, inappropriate transfer of dynamic pressure on the body surface can result in the unbalance of the total force, which may lead to non-zero moment in the ends of the floating body. This is a physically incorrect situation, which must be avoided before the structural analysis is performed.

Transferring viscous forces to the structural mesh model can be considered as an extreme case of the pressure transfer. Viscous forces are computed on the skeletal structure of the body, and forces need to be transferred on the surface of each member. This implies that the acting positions of the forces are distinctly different, causing unbalanced force and moment components on the structural model. Therefore, the computational results for the structural analysis using these loads on the structural model cannot be trusted. Thus, achieving the same load condition on the structural mesh model is important for an accurate structural analysis.

Despite its current interest in the related fields, little literature on this problem has been reported so far. There exists a guideline called the *inertia relief*, which uses acceleration terms to introduce fictitious inertia forces to adjust the forces in the structural mesh model to eliminate unbalanced components [2]. Due to its conceptual simplicity, the inertia relief method has been widely used in practice in order to counterbalance any imbalances of the input loads on the structural mesh. However, this approach has a few shortcomings as was presented in [3]. The paper indicates that additional inertial loads are needed to rebalance the structural model, which may cause a change of structural response such as bending moment, and the additional fictitious loads are required to be relatively small to prevent any significant change of original structural loads. To overcome these problems, the load distributions are frequently inspected and adjusted manually in practice, which is not an efficient process.

A direct transfer of loads from a hydro panel model to a structural mesh model based on the sectional forces and moments of the hydrodynamic analysis is discussed in [3]. They used corrective nodal forces on the structural mesh model to counter any unbalanced component. The corrective force terms are computed using an optimization method based on quadratic programming. At each node, a corrective force component is obtained, which forms a revised force distribution satisfying the force and moment balance condition. Moreover, the unrealistic sway and surge force caused by hydrostatic restoring pressure integration is further studied, and a method to solve the problem is presented [4]. Quadratic programming is employed to compute the amount of corrective nodal forces for the structural mesh model to provide a correct load condition for the structural analysis. Malenica et al. [5] proposed a method to eliminate such a force imbalance by reformulating the equations of motion of a body for seakeeping on the structural mesh model and solving them. This approach can discard any force imbalance on the structural mesh model because no transfer of force components is performed from the hydro panel model to the structural mesh model. However, this approach requires a complicated computation on the structural model, and the computational conditions on the hydro and structural models may be different because the two methods would yield different hydrodynamic coefficients for the seakeeping analysis.

In these methods, however, the similarity of the load distribution patterns on the hydro and structural models is not taken into account. This similarity would be important to assess the local structural strength. The use of corrective nodal forces was also mentioned in [6], which presents a guide to compute such force terms on the structural mesh model manually.

In this paper, a method for transferring loads on the hydro model to the structural model is proposed. Two methods are presented: one is for mapping a pressure distribution on the hydro panels to the structural meshes, and the other is for mapping viscous forces due to the fluid to the structural meshes. For the former mapping, hydro panels influencing a structural mesh are selected, and pressure values on the panels are projected onto the mesh. The projected pressure on the mesh is then converted to the equivalent nodal forces. Once this mapping is completed, the force and moment imbalances are eliminated using an optimization method. The viscous force mapping is different from the pressure mapping. Viscous forces are provided as concentrated forces along the centers of each member of a floating body. Therefore, for the viscous force mapping, a method of distributing the forces on the structural meshes is required. In this work, a procedure is proposed that structural meshes that would be influenced by a viscous force at a point using the minimum distance measure are selected, and the force is then distributed on the meshes. This process is applied to all the viscous forces, which are then adjusted to satisfy the force and moment balance conditions.

The contributions of this paper are as follows: a novel method is proposed for a consistent transfer of a pressure distribution on the hydro panel model to the structural mesh model. The hydro panel and structural mesh models represent the same geometric shape in different domains. There exists no link between the models except for the same underlying geometry. In order to associate the hydro panel model with the structural mesh model, projection of the hydro panels onto the corresponding structural meshes is used in a local coordinate system, which is created for each structural mesh. Through this projection, the pressure distribution on the hydro panels can be mapped onto the structural meshes, and the distribution pattern of pressure on the hydro panels can be maintained on the structural mesh model. Therefore, more accurate local structural assessment can be performed. This approach is not limited only to potential flow theory. Instead, any physical properties can be transferred from one model to another when they are represented in panels or meshes. Therefore, the proposed method provides an interface connecting two different models each of which is intended for different disciplines.

Second, a novel method is proposed for transferring viscous forces on the hydro panel model to the structural mesh model. The viscous forces are computed along the centers of each member of the model, which are given as vectors at points. Therefore, mapping of a point onto surface meshes is necessary. In this paper, a new strategy for this mapping is presented and the forces are mapped on the structural meshes with maintaining the similar distribution patterns of the viscous forces.

The paper is structured as follows: in Section 2, a theoretical background necessary for the presentation of the proposed method is briefly explained. Section 3 formulates the problem of mapping between hydro and structural representation, and presents a method to solve the problem. Examples are provided in Section 4 to demonstrate the performance of the proposed method. Section 5 concludes this paper with future work.

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