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A CAD/CAE integration technology and its application in hydraulic engineering

Wei Xie[1], Liaojun Zhang[1*]

[1]College of Water Conservancy and Hydropower Engineering, Hohai University, Nanjing, 210098, China

[*]Corresponding author's e-mail: ljzhang@hhu.edu.cn

Abstract. The CAD and CAE technologies are usually applied independently in water conservancy projects, and the connection between the design and analysis procedures is not close enough, which greatly reduces the efficiency of the application of these two technologies. Taking a typical pumping station as an example, a CAD/CAE integration technology is studied on and applied for the precise modelling and the simulation calculation of a complex finite element analysis problem in hydraulic engineering, and the parametric technology is utilized for the structural optimal design in this paper. It turns out that the technology can help significantly improve the efficiency of the iterative design-analysis-optimization process and provide a feasible and efficient analysis method for the design of water conservancy projects.

1. Introduction

With the rapid development of 3D design technology, the computer-aided design (CAD) technology has become one of the most important tools in the field of engineering design to date. And the computer-aided engineering (CAE) technology, represented by the numerical analysis software, generally has shown a weak pre-processing function, in which the modelling process is cumbersome with a relatively low efficiency. Presently, in the field of aviation, aerospace and machinery, the close combination of the CAD and CAE technologies has attracted great attention and entered the practical stage. For example, the CATIA software has been introduced into the numerical simulation calculations for parametric fine modelling and more realistic finite element analysis [1-5]. And the CAD/CAE integration has gradually become a trendy topic in the field of engineering [6-8].

Presently, the CAD and CAE technologies are usually applied independently in hydraulic engineering. In compliance with the conventional procedures, most of the designers create the design drawing or establish the geometric model in the CAD platform. After that, the pre-processing module of the CAE software is utilized by the CAE engineers to establish the specific geometric model in accordance with the design, the grid is generated to obtain the numerical model and the finite element analysis is eventually carried out, which is a very complicated process. Whereas if the calculation result does not meet the design requirements, the design model needs to be re-modified and the above workflow be repeated. In addition, when performing the above conventional procedures in hydraulic engineering, it is difficult to establish a seamless, bidirectional connection of data between the CAD and CAE platforms, carry out the accurate simulation of the characteristics of the engineering structures, and achieve a closed cycle of the whole design-analysis-optimization process. Because there is difficulty in identifying the common complex spatial surfaces in hydraulic engineering and only the one-way transmission of data is accessible between the CAD and CAE platforms. Therefore, the research, development and application of an accurate, efficient and seamless CAD/CAE integration technology in hydraulic engineering are worthy of investigating, which can effectively improve the precision, efficiency and economical performance of the hydraulic engineering design.

Based on the interactive interface CAPRI developed by MIT, with CATIA as the CAD platform and ANSYS Workbench as the CAE platform, a CAD/CAE integration technology is studied on in this paper. Taking the engineering design of a typical pumping station in hydraulic engineering as an example, through the parametric technology in the CAD platform, a visual 3D geometric solid model is accurately established. And then the grid is finely divided by the ICEM CFD software to meet the high precision requirements of fluid calculation for grid, with the computational degrees of freedom reaching millions. And the fluid-solid coupling calculation is implemented using the CFX software and the ANSYS Mechanical software in the CAE platform, which are capable of interactively accessing each other. What's more, the re-modification of the calculation model is quickly realized with the parameters modified through the interface technology, so that the design optimization can be efficiently carried out according to the structural vibration response. The technology proposed in this paper helps provide a feasible and efficient method for the CAD/CAE integrated design of water conservancy projects.

2. CAD/CAE integration technology

The concept of the CAD/CAE integrated design is shown in figure 1. In the finite element analysis of hydraulic engineering, the key to achieving CAD/CAE integration is the correct choice for CAD/CAE platforms. Taking the pumping station project as an example, the following requirements should be satisfied: as for the selection of the CAD platform, it should be able to solve the complex graphic processing problems in hydraulic engineering design, such as the flow passage design of complex special curved surfaces, the 3D distorted hydraulic components design, and the complex engineering terrain simulation; with regard to the choice of the CAE platform, it should possess the distinct advantages of compatibility, fidelity, data reusability and a powerful simulation analysis ability on the basis of identifying the data information; a seamless and bidirectional data connection interface is needed between the CAD and CAE platforms, which is an essential prerequisite of the close, efficient connection of the design and analysis procedures.

2.1. CAD parametric technology

Due to its powerful CAD function, the CATIA software has a worldwide leading position in aerospace design and some other fields. Its parametric and conceptual modelling concepts can help achieve the objective of the efficient designing and optimization. Therefore, CATIA is selected as the CAD platform in this paper. The parametric design process is shown in figure 2. Any set of parameters obtained by adjustment corresponds to a new design scheme and is utilized for model regeneration, which is efficient, accurate and easy to operate. With CATIA introduced into the water conservancy projects in this paper, the problem in the conventional hydraulic engineering design can be solved that the CAD modelling process is time-consuming and laborious but the design result is not ideal.

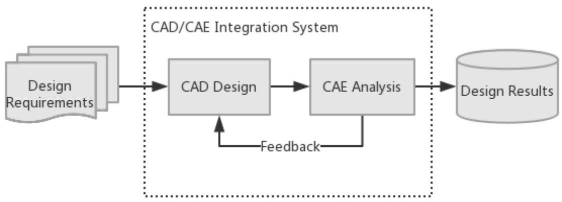

Figure 1. The concept of CAD/CAE integrated design.

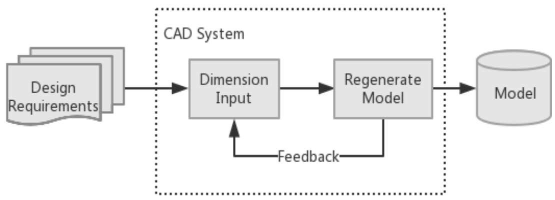

Figure 2. The parametric design process.

2.2. CAE collaborative simulation technology

While maintaining the diversification of core technologies, ANSYS establishes a workbench environment for collaborative simulation. In the environment each solver is regarded as a component, making it possible to invoke different CAE solvers at the same time. The ANSYS Workbench has a powerful simulation analysis ability and wide application ranges, such as the simulation analysis of strength, stiffness, stability, temperature, seepage, seismic design and multi-field coupling. In addition, it has an outstanding interactive function and strong interoperability with the major software. Therefore, ANSYS Workbench is selected as the CAE platform in this paper.

2.3. CAD/CAE seamless and bidirectional data transmission technology

The CAD technology of the CATIA software allows it to carry data to the current mainstream CAE software for numerical analysis through the interfaces with a high data fidelity. And the ANSYS Workbench utilizes the geometric integration solution and a unique plug-in architecture to maintain its relevance to the CAD systems. It can directly use the model of a heterogeneous CAD system without conversion to other intermediate geometry formats.

Based on their interactive features, the CAPRI interface technology developed by MIT has been able to realize the CAD/CAE integration technology, with CATIA as the CAD platform and ANSYS Workbench as the CAE platform. Not only can the advantages of the two platforms be fully utilized, but the seamless and bidirectional data transmission between them can also be realized. Thus it can help effectively solve the problem of the reading limitations of the CAD models in hydraulic engineering analysis, characterized by the loss, distortion, incompatibility and poor reusability of data. In addition, the introduction of CATIA makes it possible to parameterize the entire hydraulic engineering design process and carry out more realistic numerical simulation calculations in a relatively short time.

2.4. CAD/CAE integrated design technology

The CAD/CAE integrated design method of hydraulic engineering is proposed in this paper, based on the combination of the CAD parametric technology, CAE collaborative simulation technology and CAD/CAE seamless, bidirectional data transmission technology. In addition, the key Parameter Manager (PM) is utilized in this technology to enhance the design iteration. And the smart and selective update function in ANSYS Workbench is used in order to fully utilize the advantage of the strong assembly capability of CATIA and to effectively improve the efficiency.

As shown in figure 3, through parametric modelling (PD) and parameter(P) setting in CATIA, a precise model carrying parameters (P) is established. And then the precise geometric model as well as the parameters (P) is imported into ANSYS Workbench (WB) through the seamless connection (SC) interface CAPRI for finite element analysis (FE Analysis). If the design result is satisfactory, then END, otherwise based on the Parameter Manager in ANSYS WB, the parameters are adjusted to obtain a new set. And the smart updates (SU) of the model in accordance with the adjustment is carried out through the seamless connection (SC) interface CAPRI. This cycle keeps going on until a satisfactory result appears for structural optimization, with the precision, efficiency and economical performance of the hydraulic engineering design effectively improved upon and a closed cycle of the whole design-analysis-optimization process achieved.

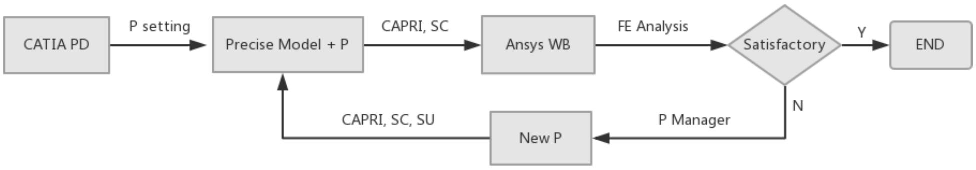

Figure 3. The CAD/CAE integrated design technology.

3. Engineering application

The pumping station studied on in this paper is a large-scale axial flow pumping station, located in Jiangsu Province, China. And the steel-made flow passage is employed in the scheme, with the elbow inlet and straight outlet passages adopted. The structure style is relatively more complicated, and the strength and vibration problem is one of the key problems of concern in the design. Thus the proposed CAD/CAE integration technology is utilized in this paper for the design. As for the flow passage of complex special curved surfaces and the 3D distorted hydraulic components, the parametric modelling is carried out. And then the numerical simulation calculation and the optimal design of the pumping station project are accomplished through the seamless data connection in this paper.

3.1. CAD integral model establishment

3.1.1Parametric design of blades. In this paper, the blade design software Bladegen in the field of mechanical manufacturing is added to the modelling process to make the blade design parameterized. The meridian projection of the blade is the key factor to control its shape. The shape of the inlet and outlet edges of the blade is determined by setting the coordinate parameters of the meridian plane (axial plane) projection. While the thickness variation of the blade body is automatically realized by setting the inclination angles and the spline curves of thickness variation of the normal layers such as the inner and outer edges. The spline curve of thickness variation of the outer edge and the 3D design of the blade are shown in figure 4 and 5, respectively.

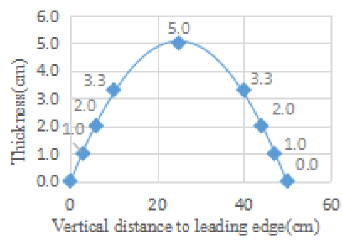

Figure 4. Spline curve of thickness variation of the outer edge.

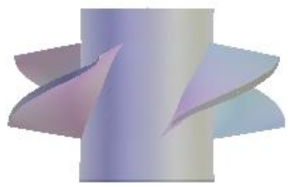

Figure 5. 3D design of the blade.

3.1.2 Geometric Modelling and Assembly. In CATIA, the water pump device is assembled first, and the components are perfectly fitted in the assembly relationship by adding constraints such as coincidence constraints, as shown in figure 6. Based on CATIA's powerful surface design and assembly capabilities, the complex three-dimensional flow passage is finely simulated to the maximum degree. For example, as for the modelling of the elbow flow channel, through importing the CAD contour lines to CATIA and setting the dimensional parameters of each variable section, a smooth and complete, parametric 3D surface is generated efficiently, which is consistent with the real object. What's more, the ideal gradient is realized between the rectangular sections (the inlet and outlet sections) and the common circular sections. The optimization of the various detailed dimensional parameters is eventually carried out in ANSYS Workbench. The visual assembly drawing obtained after rendering is shown in figure 7.

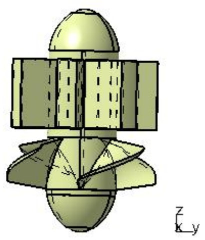

Figure 6. Water pump device design.

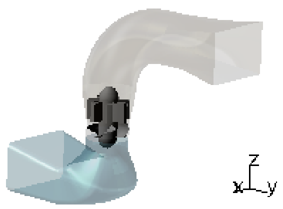

Figure 7. Visual assembly drawing.

3.2. CAE numerical model establishment

In the traditional pre-processing method, the computational grids of the water body and the structure need to be established separately. While with the professional pre-processing software ICEM CFD, the coupling modelling of the water body and the structure can be completed quickly. The total tetrahedral mesh of the water body is generated based on the octree algorithm and the topology structure, and the cross-scale meshing technique is utilized to refine the mesh of the blade rotation region, especially with the boundary layer grid refined by five layers. And a seamless match between the grids of the water body and the complex flow path is obtained through Boolean operations, achieving a perfect coupling between the water body and the structure. In addition, through its grid editing technology, it is possible to generate complex grids with millions of nodes in a short time. With the above technology applied, there are 270606 nodes and 1559101 elements generated of the computational model grid of the pumping station, with degrees of freedom reaching millions, which satisfies the high precision requirements of fluid calculation for grid, and makes the simulation more refined. The grid generation speed is about 1500 elements per second, which is highly efficient. The model topology diagram and the grid diagram are shown in figure 8 and 9.

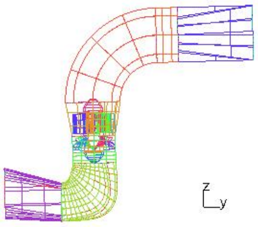

Figure 8. Model Topology.

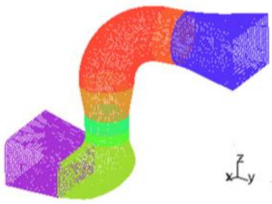

Figure 9. Model Grid.

3.3. Design optimization analysis

The CAD/CAE integrated design analysis is carried out based on the interface technology CAPRI between CATIA and ANSYS Workbench. For example, for the optimal design of the wall thickness of the flow channel, with the wall thickness set as the optimization parameter, the finite element calculation model is established and then utilized for finite element calculation in ANSYS Workbench. The influence of the wall thickness variation on the structural displacement and stress is studied on, and the strength and stiffness of the structure analyzed and evaluated. And the final optimum design scheme is determined through the design-analysis-optimization process, which is difficult to realize by the traditional method in which the CAD and CAE technologies are applied independently of each other. The total deformation and equivalent stress contours of the steel-made flow passage with a thickness of 1.5cm are shown in figure 10 and 11, respectively. While the total deformation and equivalent stress contours of the passage with a thickness of 2cm are shown in figure 12 and 13, respectively. It can be seen that the deformation and stress are significantly reduced when the wall thickness is increased to 2cm.

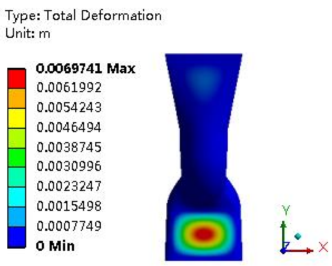

Figure 10. Total deformation contour(1.5cm).

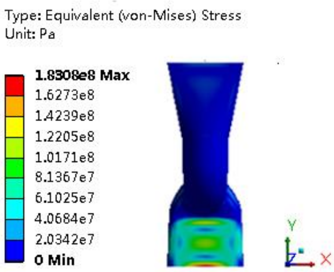

Figure 11. Equivalent stress contour(1.5cm).

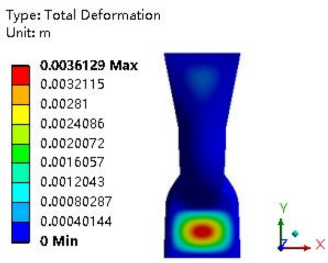

Figure 12. Total deformation contour(2cm).

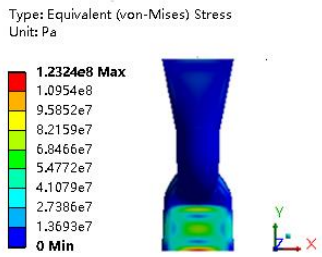

Figure 13. Equivalent stress contour(2cm).

4. Conclusion

(1) An integrated design technology that integrates the CAD parametric modelling technology, CAD/CAE seamless bidirectional data transmission technology and CAE collaborative simulation technology is proposed in this paper, which helps provide an efficient and feasible method for the modern design of water conservancy projects.

(2) It can be drawn from the engineering application example that the CAD/CAE integrated design technology proposed in this paper can effectively optimize the design scheme of water conservancy projects and helps provide a new design idea and analysis method for hydraulic engineering construction.

Acknowledgments

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