Study on Computer Numerical Simulations Calculation of Structural Wind Load

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***Abstract*— Wind load is one of extremely important loads to the structure. This paper firstly introduced the calculation theory on the numerical simulations for the structural wind load and the computational fluid dynamics basic equation (CFD). But in the fact, there is a fluid-structure interaction interface between the wind as a fluid and the structure, that is wind and structure have an effect to the other side in the contact surface. Based on this, an engineering instance is used to analysis the fluid-structure interaction in a two-dimensional plane, and the results are recorded that the displacement information of the solid domain, the velocity information and the pressure information of the fluid domain. Computer simulation technique is a very important role in the engineering.**

***Keywords*— wind load, Computer simulation, CFD, fluid-structure interaction, numerical simulations**

I. INTRODUCTION

Now the span roof structures and the high-rise buildings have specific modeling, large span, high body, light weight, soft stiffness and small damping, which make the enhanced sensitivity for the structure to wind loads[1]. At home and abroad, the hurricane damage caused by lack of consideration in wind-resistant design also often occurs. In short, the wind disasters lead to the structural damage and the loss is very serious. Because of the close relation between structural wind engineering research and the national economy, the study get more attention and the rapid development, and the wind resistance design to the structure can not ignored in many major projects[2],[3].

□. BASIC EQUATIONS OF CFD

A. Continuity Equation

The continuity equation is called the mass conservation equation of the air micelle[4], is

$$\frac{\partial \rho}{\partial t}+\sum_{i=1}^{3}\frac{\partial\left(\rho u_i\right)}{\partial x_i}=0\left(i=1,2,3\right) \qquad (1)$$

where ρ is the air density, $u_i\left(i=1,2,3\right)$ are the speed in direction $x\left(x_1\right),y\left(x_2\right),z\left(x_3\right)$.

B. Motion Equation

The motion equation is the momentum equation for a solid volume element dv in the fluid, the force balance equation as Newton's second law, is

$$\frac{Du_i}{Dt}\rho dv=F_i\rho dv+\sum_{j=1}^{3}\frac{\partial\sigma_{ij}}{\partial x_j}dv\left(i=1,2,3\right) \quad (2)$$

where $$\frac{Du_i}{Dt}=\frac{\partial u_i}{\partial t}+\sum_{j=1}^{3}u_j\frac{\partial u_i}{\partial x_j} \quad (3)$$

F_i is the component of F, and the force to surround the volume element dv;

σ_{ij} is the internal stress of the volume element dv.

C. Newton Fluid Equation

In the application of the fluid mechanics, the fluid with the internal shear stress is called the viscous fluid or the Newton fluid. Provided by the tensor arithmetic rule, the total stress tensor σ_{ij} at any points can be decomposed as the compressive stress p and the partial stress d_{ij}, is

$$d_{i,j}=2\mu\left(e_{ij}-\frac{1}{3}\delta_{ij}\sum_{k=1}^{3}e_{kk}\right)\left(i,j=1,2,3\right) \quad (4)$$

$$\delta_{ij}=\begin{cases}1 & i=j\\ 0 & i\neq j\end{cases} \quad (5)$$

So we can get the following stress be expressed as

$$\sigma_{ij}=-p\delta_{ij}+2\mu\left(e_{ij}-\frac{1}{3}\delta_{ij}\sum_{k=1}^{3}e_{kk}\right)\left(i,j=1,2,3\right)$$

(6)

D. Navier-Stokes Equation

The famous Navier-Stokes equation is got by the formula 6 into the formula 3, is

$$\rho\frac{Du_i}{Dt}=\rho F_i-\frac{\partial p}{\partial x_i}+\sum_{j=1}^{3}\frac{\partial}{\partial x_j}\left\{2\mu\left(e_{ij}-\frac{1}{3}\delta_{ij}\sum_{k=1}^{3}e_{kk}\right)\right\}$$

(7)

If the viscosity coefficient throughout the fluid is a constant, the above formula can be written as

$$\rho\frac{Du_i}{Dt}=\rho F_i-\frac{\partial p}{\partial x_i}+\mu\left(\sum_{j=1}^{3}\frac{\partial^2 u_i}{\partial x_j^2}+\frac{1}{3}\frac{\partial\sum_{k=1}^{3}\left(\partial u_k/\partial x_k\right)}{\partial x_i}\right)$$

(8)

Ⅲ. ANALYSIS OF THE FLUID-STRUCTURE INTERACTION

A. Basic Concepts of Fluid-Structure Interaction

Under the fluid's action, the response of the structure such as a flexible structure produces a greater impact to around the fluid field, such as displacement, velocity and acceleration. But the change of the flow field further change the size of the flow force in the surface of the structure, thereby form the interaction between the structure and the fluid, referred to as fluid-structure interaction[6].

B. Basic Equation of Fluid-Structure Interaction

From the nature, the analysis to the fluid-structure interaction should establish the following equation:

$$\begin{bmatrix} A_f & A_{fs} \\ A_{sf} & A_s \end{bmatrix} \begin{bmatrix} \Delta X_f \\ \Delta X_s \end{bmatrix} = \begin{bmatrix} \Delta B_f \\ \Delta B_s \end{bmatrix} \qquad (9)$$

where A_f , A_s are respectively corresponding to the fluid non-coupling matrix and the solid non-coupling matrix, A_{fs} , A_{sf} are respectively corresponding to the fluid coupling matrix and the solid coupling matrix.

Ⅳ. EXAMPLE ANALYSIS

A. Geometric Modeling

The solid is a portal frame structure, shown as Fig 1, the size is 3 m × 4 m, the elastic modulus is 2.0 × 10^9N/m^2, the Poisson's ratio is 0.3.

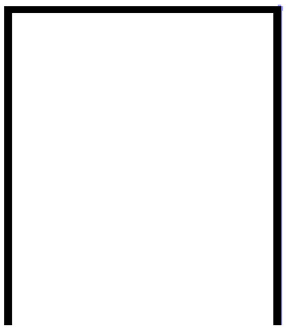


Fig 1 Computational model of solid domain

The fluid is the incompressible viscous fluid, the size is 125.59 m × 32.89m, shown as Fig 2, the density is 1.2kg/m^3, the viscosity coefficient is μ=2.0 × 10^{-5}N · s/m^2.

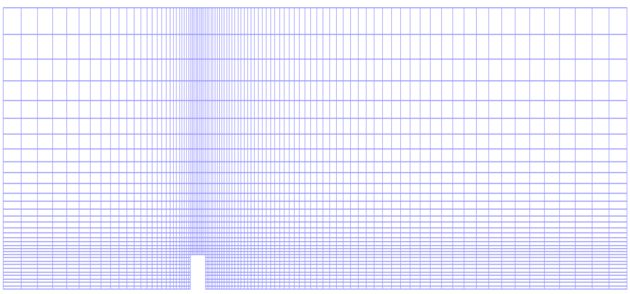


Fig 2 Computational model of fluid domain

B. Meshing and Boundary Conditions Set

1) Solid domain is divided with a beam element, and assumed to be large strain and small deformation. Solid element mesh and node numbers are shown as Fig 3.

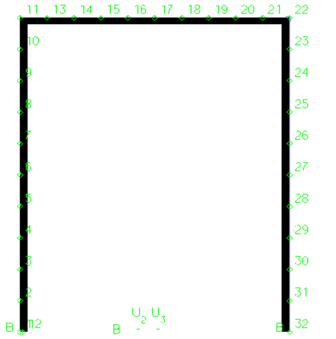


Fig 3 Meshing and nodes of solid domain

2) Fluid domain is used as a square plate unit and there are 796 mesh nodes. The flow field meshing is shown as Fig 4.

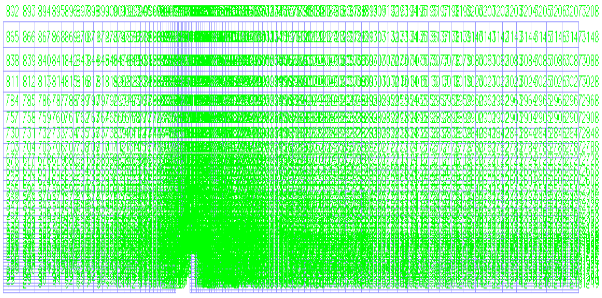


Fig 4 Meshing and nodes of fluid domain

3) Boundary Conditions Set

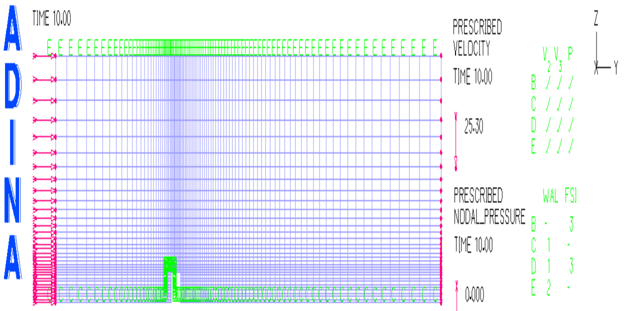


Fig5 Imposed figure of boundary conditions

C. Displacement Results of Solid Domain

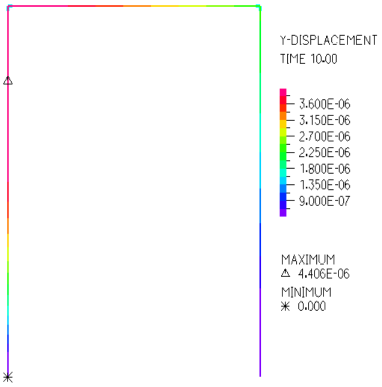


Fig 6 Displacement in y direction of solid domain

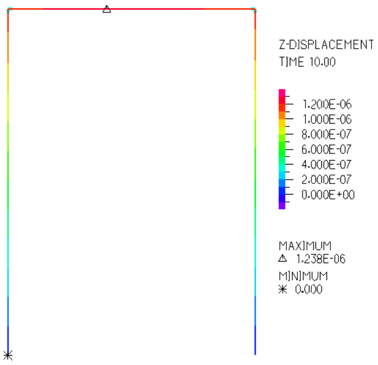


Fig 7 Displacement in z direction of solid domain

D. Velocity Calculation Results of Fluid Domain

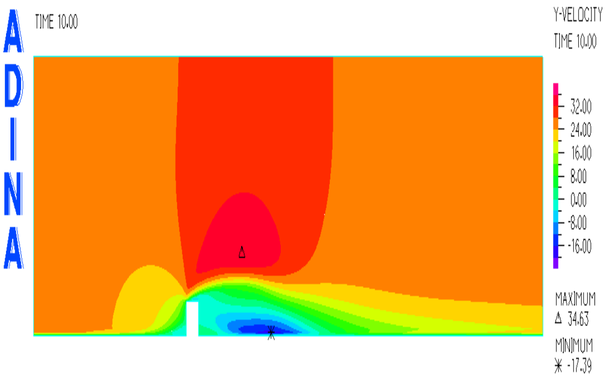


Fig 8 Speed in y direction

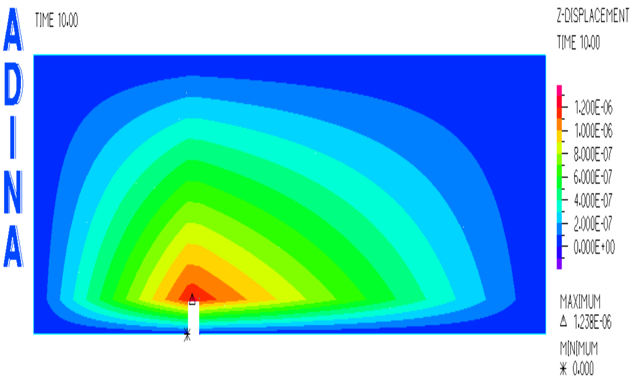


Fig 9 Speed in z direction

E. Pressure Results of Fluid Domain

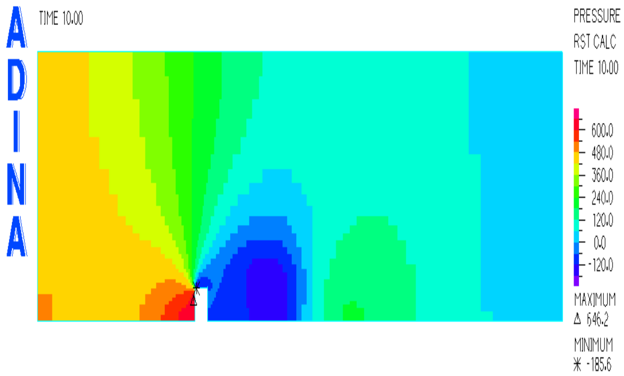
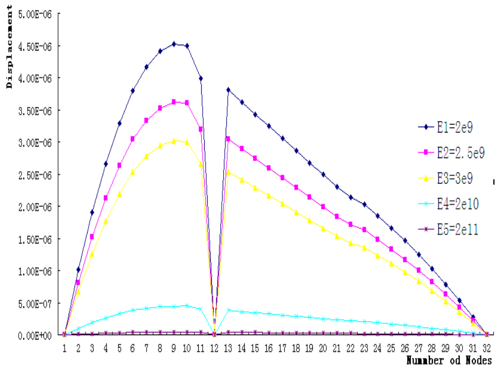


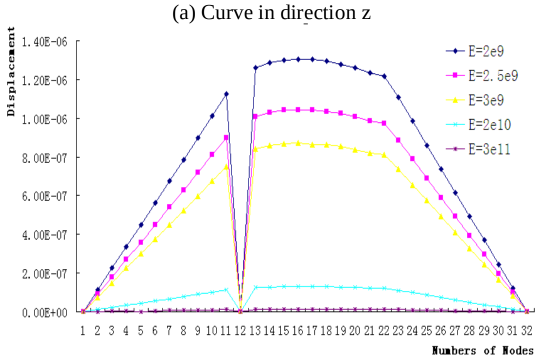
Fig 10 Pressure of fluid domain

F. Comparison and Analysis on Different Intensity Structure

This portal frame is defined as the beam element in ADINA, and it's the horizontal and vertical beam are used a same member. Due to the height and width of the beam, the connection point between two beams is regarded as the rigid end. Fig 11 is shown as the solid's displacement with different elastic modulus under the same wind load.



(a) Curve in direction z



(b) Curve in direction z

Fig11 Curve on the solid's displacement with the elasticity coefficient

Shown as from Fig 11, under the uniform wind load, nodal displacement gradually decreases with increasing structural stiffness. In the windward area, the displacement in direction y gradually increases with height to be in the quadratic relationship, and the displacement in direction z gradually increases with height to be in the linear relationship; in the crosswind area, the displacement in direction y gradually decreases to be in the linear relationship, while the displacement in direction z essentially unchanged; in the leeward area, the displacement in direction y and z gradually decreases with height reduces.

. CONCLUSION

Based on the finite element software ADINA, the data transfer interface in two-dimensional plane is analyzed, and the results recorded the speed, the displacement and the pressure of the fluid domain, and the displacement of the solid domain. According to the analysis results, the solid has a greater impact on the surrounding fluid, and computer simulation technique is a very important role in the engineering.

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