Investigation of Dynamic Characteristics of a Submerged Tube : A Comparative Study of the Developed Code and the Commercial Software

Won Man Park[a], Sungman Son[a], Tae Hyun Chun[b], Heung Seok Kang[b], and Choengryul Choi[a]*
[a]*ELSOLTEC, Giheung-gu, Yongin, Gyeonggi-do, 16950, Korea*
[b]*Korea Atomic Energy Research Institute, Yuseong-gu, Daejeon, 34057, Korea*
[*]*Corresponding author: crchoi@elsoltec.com*

1. Introduction

Nuclear power generation consists of two major systems to convert the heat generated from the fuel into electrical power [1]. The primary system transfers the heat from the fuel to the steam generator. A steam generator is the last part of the primary system as well as the beginning of the secondary system. It generates steam using the transferred heat of the primary system. The secondary system actuates large turbines using the generated steam and product electric power from the kinematic energy of the turbines. Thus, the steam generator is one of the key compositions of the nuclear power plant.

Despite its importance, damage to the steam generator is reportedly one of the major reasons for the decrease in the utilization rate of nuclear power plants [2]. Not only in Korea but also in America, heat pipe leakage in the steam generator is one of the key issues of shutdown operation. Therefore, it is essential to secure the structural safety of the steam generator and its heat pipes for the safe operation of nuclear power plants. In this study, we developed a simple finite element (FE) analysis code for estimating wear caused by fluid-elastic instability. As the first step of the verification of the code, we investigate the dynamic characteristics of a beam structure using the developed code, the results were compared to the results of the commercial FE analysis code.

2. Materials and Methods

A two-dimensional FE code for calculating the mechanical behaviors of the beam structure was developed using MATLAB 2017b (MathWorks, Natick, MA), a commercial numerical computing program. Euler-Bernoulli beam, in which pure bending deformation of the beam in the midplane is considered, was used in this study. The Euler-Bernoulli equation describes the relationship between the beam's deflection and the applied load. When the distributed load q is applied on a beam, the curve ω(x) describing the deflection of the beam in the loading direction at a specific position x can be calculated as the following equation.

$$\frac{d^2}{dx^2}\left(EI\ \frac{d^2\omega}{dx^2}\right) = q \qquad \text{(Eq. 1)}$$

Where E is the elastic modulus, and I is the second moment of area of the beam's cross-section.

The Newmark method, a commonly used numerical integration technique to calculate the dynamic motion of a structure, was used in this study. The governing equation of the Newmark method consists of the mass, damping, and stiffness of a system as follows:

$$M \cdot a + C \cdot v + K \cdot u = F(t) \qquad \text{(Eq. 2)}$$

where M, a, C, v, K, u, and F(t) are the mass matrix, the acceleration vector, the damping matrix, the velocity vector, the stiffness matrix, the displacement vector, and the applied force vector at time t, respectively.

Dynamic characteristics of a submerged object are affected not only by its own mass but also by internal and external fluid. Tubes considered in this work are submerged; however, the internal space of tubes is empty. Therefore, only external fluid effects were considered. The added mass per unit length was calculated from the formular introduced in the previously published report [3, 4]. Then, the mass effect was applied using the modified density, which includes the tubes' own mass and added mass, was applied to the tube.

$$M_{total} = M_{tube} + M_{added} \qquad \text{(Eq. 3)}$$

In this study, as the first step of the development of the code for predicting tube wear based on its dynamic motion, we calculated the dynamic characteristics of a tube consisting of two sections, rectangular slender and tube, then the predicted natural frequency using the developed code was compared to the natural frequency predicted by the commercial FE software Abaqus/Standard (Dassault Systèmes, Waltham, MA, USA).

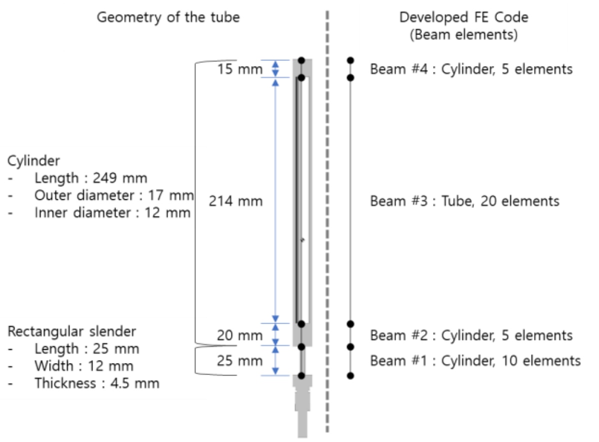

Fig. 1. Geometry of the tube consisting of two sections tube and rectangular slender, and FE model of the tube using beam elements

The geometry of the tube was shown in Fig. 1. The structure consists of two sections, tube and rectangular slender. The bottom of the rectangular slender was fixed like a cantilever beam. FE models of the structure were developed using beam elements for the developed code and continuum elements for the commercial software. With consideration for the cross-sectional geometry of the tube section, the FE model was developed using four different beams in the developed code, including cylinder, tube, cylinder, and rectangular beams (Fig. 1). For the commercial software, the FE model of the structure was developed using the quadratic tetrahedral elements, while the linear tetrahedral elements were used for the surrounding water (Fig. 2).

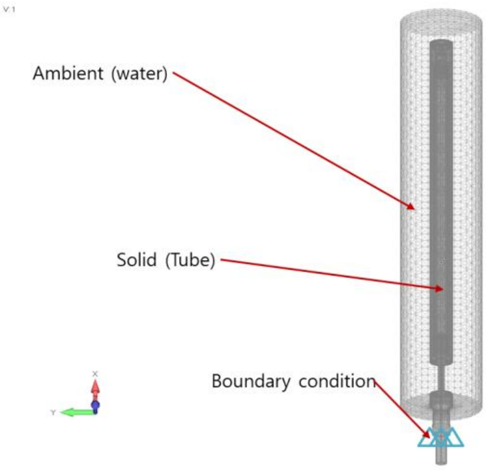

Fig. 2. FE model of the submerged tube for commercial software using tetrahedral solid elements

3. Results

The deformed shape of the first and second eigenmodes of the tube used in this study is bending to the thin and thick planes, respectively. Because the developed code is for a two-dimensional beam structure, to calculate the natural frequency of the second eigenmode was calculated using a rotated tube by 90° along the longitudinal direction. The predicted natural frequencies of the first two eigenmodes were 50.9 Hz and 116.8 Hz by the commercial FE code, and 52.5 Hz and 121.1 Hz by the developed code (Table 1). The predicted natural frequencies by the developed code showed differences of 3% compared to the predicted results by the commercial code in the first two eigenmodes.

Table 1. Predicted natural frequencies of the first two eigenmodes of tubes in the air using commercial and developed FE codes

Eigen mode	Commercial FE code	Developed code
1	50.9 Hz	52.5 Hz
2	116.8 Hz	121.1 Hz

When the tube is submerged, the predicted natural frequency of the first eigenmode by the commercial code was 46.1 Hz. The developed code predicted 47.7 Hz, and it is different from the results of the commercial code by 3%. Both predicted values in the water ambient condition by the commercial and developed code were lower than the natural frequencies in the air by 9%.

4. Discussions

A FE code was developed to calculate the dynamic response of the two-dimensional beam and eventually to estimate the wear of the steam generator tubes based on work rate. Even though the developed code is for two-dimensional problems, only 3% differences were shown in the prediction of the natural frequency for the first eigenmode in air and water ambient conditions. However, for better verification of the developed code, more comparison to the beam FE models or analytical results should be necessary.

The authors plan to do more research for the accurate validation of the code, further research including element convergence study, static and dynamic response test, and prediction of the work rate. Based on the results of the future study, the authors expect that the developed code could be a nice tool for predicting tubes in the steam generated.

Acknowledgement

None.

REFERENCES

[1] Pressurized water reactor systems, USNRC Technical Training Center, 2020
[2] S. D. Cho, B, K, Kim, Maintenance and Plant Shutdown for Steam Generator, Proceedings of the Korean Nuclear Society Spring Conference, 2000.
[3] R. G. Dong, Effective mass and damping of submerged structures. United States, 1978.
[4] M. Hassan, Flow-induced vibrations in nuclear steam generators. In: Steam generators for nuclear power plants, Elsevier, 2017.