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TENSION ESTIMATION OF ELASTIC CABLES USING VIBRATIONAL METHOD

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ABSTRACT

This paper presents a simplified method for the evaluation of the tension in elastic cables and tendons based on vibrational method. The accuarcy and simplicity of this method is compared with other methods. Force transmitting members in different structures including, cable-stayed bridges, post-tensioned segmental bridges and so on as axially one-dimensional tensioned structures reflect the health of entire system, therefore a rapid tension estimation is needed for condition monitoring. Estimated tension with numerical pre-determined formulas of string theory, beams theory with different boundary conditions are compared with estimated tension conducting mode shape ratios and modal frequencies for multiple measurment. Furthermore, sensor location and mode selection of mode shape functions method is simplified by dominating the first mode to simplify the error function with changing reference sensor location to mid-length as Equation 1.

$$Error = \left(\emptyset_{ik} - \widehat{\emptyset}_{jk}\right)^2 = \left[cosin\left(\frac{\pi x_j}{l}\right) - \widehat{\emptyset}_{jk}\right]^2 \tag{1}$$

Application examples for four different models show that the accuracy of tension estimation using pre-determined formulas is less accurate in comparison with the mode shape functions method, and requires better estimate of mass and length. In this research three methods are applied on four different FE models using software package ABAQUS and using MATLAB toolbox developed by the authors. The proposed approach was tested on four models studied before as shown in Table 1. In the models 1 and 2, two linear springs are used to simulate the elastic constraints from rubber-to-rubber distance. The spring coefficients are assessed to find the best fit coefficient for the identified modal frequencies during actual measurements for the first two models (1.0 e+7 N/m for the first model and 5 e+6 N/m for the second model).

Five locations at 0.1th, 0.15th, 0.2th, 0.25th, 0.3th and 0.5th of the cable length are chosen to obtain the acceleration responses. Then, the FFT is used to determine the nodal displacement of each node to determine mode shape ratios and effective vibration length as shown in Figure 1.

Table 1. Input parameters for FE models.

Model No.	Length (m)	Mass/Length (kg/m)	EI (kN-m^2)	Cable force (kN)	Discription	Ref.
1 spring	29.3	61.30	731	2560	Stay cable	Chen et al., 2013
2 spring	126.42	18.00	577	2050	Stay cable	Chen et al., 2013
3 tendon	8.436	0.774	147.5	12	Seven wire strand	Chen et al., 2018
4	18.54	6.125	1.77	100.08	Tendon	Wenzel et al., 2005

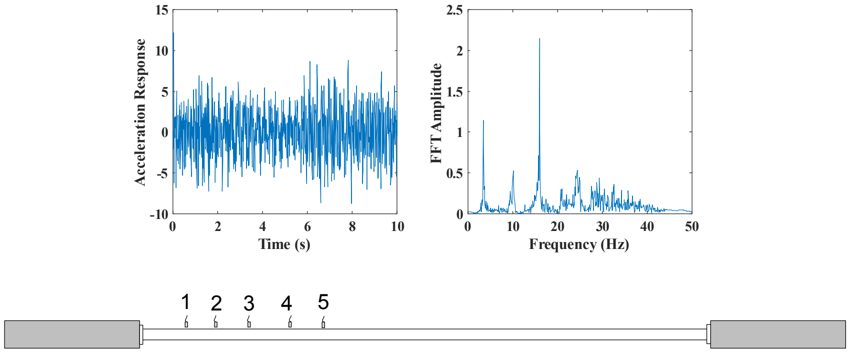

Figure 1. The acceleration responses of ambient vibration and the FFT spectrum (for 0.3 L location).

CONCLUSION

Long cables as model 2 can be examined precisely with string theory where tension is dominant for tension estimation. While, beam theory includes models with more complicated conditions. For model 2 and 1 as stay cables, hinged-hinged beam theory shows more accuracy by considering rubber to rubber distance as vibrational length of cable for tension estimation. However, effective vibrational length can be determined through optimization, but rubber to rubber distance shows fairly acceptable accuracy. The mode shape function method requires more sensors and optimization as disadvantages compared to previous approach, however the most advantage of this methods is that it works for all cases without considering the geometrical and boundary condition.

Despite all the research in the field of the tension estimation for elastic cables and tendons, a comparison is needed in engineering practice to evaluate the simplicity and effectiveness of all the approaches. In this study, different approaches are compared for simplicity, accuracy, sensor arrangement and number of sensors.

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