SENSITIVITY ANALYSIS AND IDENTIFICATION OF CROSS-SECTIONAL MODES OF A BELT-CONVEYOR STRUCTURE USING OPERATIONAL VIBRATION

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Abstract: The cross-sectional modes (CSMs) are sensitive indicators of structural local damages. In this paper, at first, the sensitivities of the CSM frequencies to various corrosion cases are studied numerically for the main member of a belt conveyor structure. The results show that the frequency-reduction sensitive regions correspond to the regions with large shear strains of the member. Furthermore, experimental modal analyses are conducted to the real belt conveyor structure using operational vibrations. The first three CSMs are identified successfully.

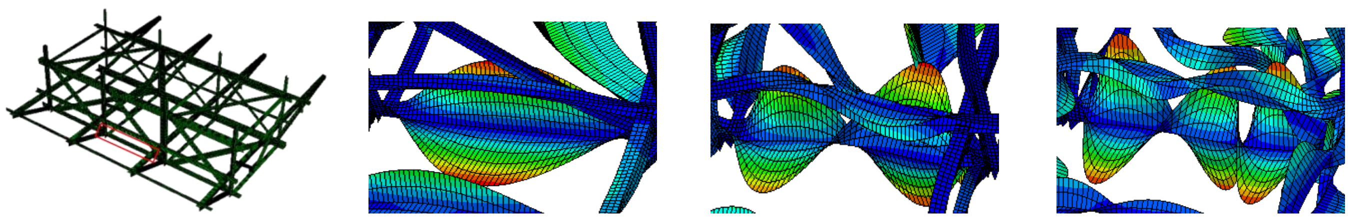
1. INTRODUCTION

Belt conveyor is usually supported by steel truss structure, where some members are severely corroded. The CSM-based damage identification method was firstly proposed by Rana et al. (2019) for a belt-conveyor structure. In the eigenvalue analysis, the CSMs were found as modes with significant torsional vibrations in the cross-sectional direction. Three types of CSMs existed in the high-frequency range, i.e. 100Hz~500 Hz, and they were named as the 1st, the 2nd, and the 3rd CSM based on their half-wavenumber. When local damages were included in the main member, the reductions of the CSM frequencies were significant. The application of the technique was further validated using hammer tests on a real belt conveyor structure. Following the study, Kato et al. (2018) employed acoustic excitations to detect the CSMs in experiments. Comparing the CSMs of a healthy and a damaged member, the frequency reductions were evident.

This paper aims to fill the gaps of the previous studies, including 1) the CSM frequency sensitivities to different corrosion cases; 2) the experimental modal analyses using operational vibrations.

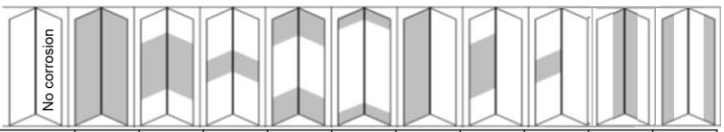
2. NUMERICAL INVESTIGATIONS OF CSM FREQUENCY SENSITIVITIES TO CORROSIONS

A FEM model is constructed using the commercial FEM software ABAQUS, which is shown in Fig. 1(a). The FEM model is part of a real belt conveyor structure. In the model, the span of each main member is 1.255 m in the longitudinal direction; the horizontal and vertical distance between main members are 1.57 m and 1.0 m respectively. The cross-section of the main member is L90 mm×10 mm. To investigate the CSMs of the structure, the four-node shell elements are applied. There are 39296 elements are 51508 nodes in the FEM model. The material of the structure is steel, and the Young's modulus, the poison's ratio, and the density are 200 GPa, 0.3, and 7800 kg/m^3. In this study, only the main member within the red box in Fig. 1(a) is focused. Without the introduction of corrosion, the first three CSMs of the member are shown in Fig. 1(b)-(d). The CSM frequencies are 173 Hz, 328 Hz, and 543 Hz respectively.



(a) (b) (c) (d)

Fig. 1 (a) The FEM model; (b) the 1st CSM (173 Hz); (c) the 2nd CSM (328 Hz); (d) the 3rd CSM (543 Hz)



	case1	case2	case3	case4	case5	case6	case7	case8	case9	case10
Pattern	Total	Center	Center	End	End	Single total	Single center	Single center	Inner flange	Outer flange
Size	L	L/2	L/5	L/4×2	L/10×2	L	L/2	L/5	D/2(L)	D/2(L)
Smallest CSA for 30% reduction (cm^2)	12.6	12.6	12.6	12.6	12.6	15.3	15.3	15.3	15.3	15.3
Smallest CSA for 60% reduction(cm^2)	7.2	7.2	7.2	7.2	7.2	12.6	12.6	12.6	12.6	12.6

Note: CSA = cross-section area

Fig. 2 The corrosion patterns

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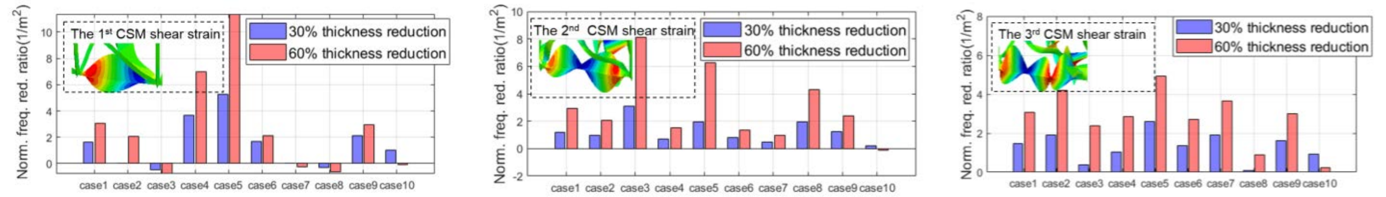


(a) (b) (c)

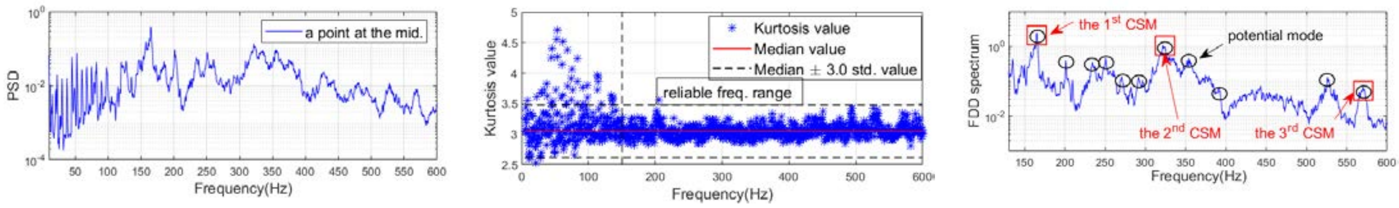
Fig. 3 The NFRRs for the single beam model; (a) the 1st CSM; (b) the 2nd CSM; (c) the 3rd CSM

Subsequently, corrosions are introduced in the FEM model. They are simulated as multiple thickness-reduction regions in the member. 10 corrosion patterns are shown in Fig. 2. For each pattern, two levels of severities are considered, i.e. 30% and 60% thickness reduction. Therefore, 20 cases are studied here. To compare the sensitivities of the corrosion case, the frequency reduction ratios are first calculated, then the frequency reduction ratios are normalized by the areas of the corrosion regions. The bar figures of the normalized frequency reduction ratios (NFRRs) for the single beam model are presented in Fig. 3. The frequency-reduction sensitive regions correspond to the regions with large shear strains. For example, for the 2nd CSM, the sensitive corrosion regions are case3, 5, and 8, they locate at the ending and middle parts of the member.

3. EXPERIMENTAL MODAL ANALYSES USING OPERATIONAL VIBRATIONS

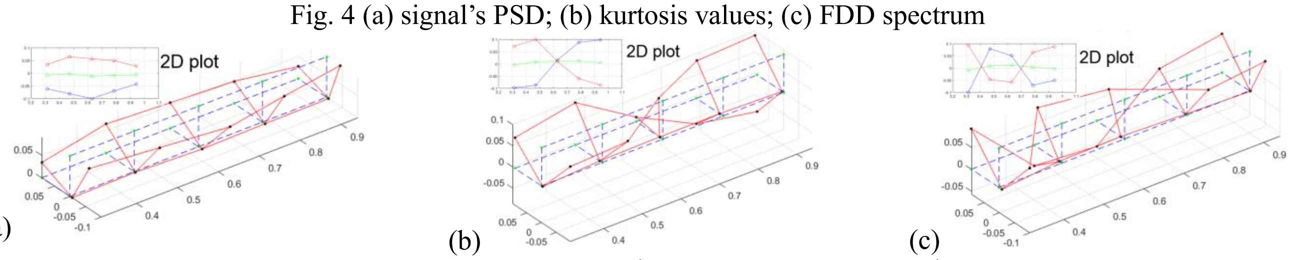
The real belt conveyor structure is tested in the operational environment. Velocities of 5 cross-sections in a main member are measured. In each cross-section, there are three measurement points, i.e. the vertical flange point, the horizontal flange point, and the corner point of the L shape.

The frequency spectrum shows many prominent vibration components. The procedures of extracting 3 CSMs are presented in the following: 1) the kurtosis checking is employed to distinguish harmonic excitations from the potential true natural frequencies, i.e. the kurtosis values largely deviated from 3.0 indicate harmonic excitations; 2) the frequency-domain decomposition (FDD) method is then applied to extract the potential modes from the reliable frequency range obtained from the last step; 3) the modes are classified into the three groups of CSMs based on their half-wavenumber; 4) the CSM indices proposed by Kato. et al. (2018) are calculated for the modes, the one with the largest CSM index in each group is regarded as the corresponding CSM. The signal's PSD, the kurtosis values, and the FDD spectrum of the experiment are shown in Fig. 4. The three CSMs obtained are shown in Fig. 5, the frequencies are 165 Hz, 322 Hz, and 570 Hz. They are close to the results of the FEM model.



(a) (b) (c)

Fig. 4 (a) signal's PSD; (b) kurtosis values; (c) FDD spectrum



(a) (b) (c)

Fig. 5 (a) the 1st CSM (165 Hz); (b) the 2nd CSM (322 Hz); (c) the 3rd CSM (570 Hz)

4. CONCLUSION

The sensitivities of CSM frequencies to various corrosion patterns are studied in the paper. It is found that for each CSM the frequency-reduction sensitive regions correspond to the corroded regions with large shear strains. By using operational vibrations, three CSMs are extracted successfully. The CSM frequencies are close to the FEM results, which shows the consistency between the numerical and the experimental method.

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