AN INVESTIGATION OF INFLUENCE OF HORIZONTAL CRACK AND LOADING STATES ON THE MODAL PARAMETERS OF REINFORCED CONCRETE SLAB

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1. INTRODUCTION

Rebar corrosion in reinforced concrete (RC) bridge deck slabs leads to horizontal cracks and deterioration within the slabs (Ikehata et al. 2020). To investigate such damage and deterioration of RC slabs through vibration-based structural health monitoring, two RC slabs under different damage conditions, with and without artificial horizontal crack, were tested in the laboratory (Gohar et al. 2020). Variation in natural frequency of lower modes for specimen without horizontal crack was observed to be random with increasing load, whereas a decreasing trend was observed for the other specimen. For analytical insights into the experimental results, finite element modal (FEM) analysis was conducted in this study. Also, the coordinate modal assurance criteria (COMAC) was evaluated for damage identification using mode shapes. Around the corners of the artificial horizontal crack, COMAC was observed to be lower than the center which means the change in mode shapes due to modeled damage was more around the corners than at the center.

2. EXPERIMENTAL AND ANALYTICAL METHODS

Two RC slab specimens with the same structural details were tested (Gohar et al. 2020). To model a horizontal crack, a hard vinyl chloride plate was installed in Specimen 2 as shown in Fig. 1. On each specimen, free vibration tests were performed at five different loading states from 0 kN to the last load after failure as indicated in Fig. 2, and vibration measurements were taken using fifteen accelerometers attached at the bottom of each specimen. Details can be found in (Gohar et al. 2020). From the vibration data, the modal properties were identified using the Eigenvalue Realization Algorithm (ERA). For FEM analysis, all parts of the specimen, including rebars, were modeled using solid elements in ANSYS workbench 2020R2. Material properties were kept the same as experimental ones. Elastic supports with varying stiffness were used under the specimen to observe the effect of the boundary conditions on natural frequency.

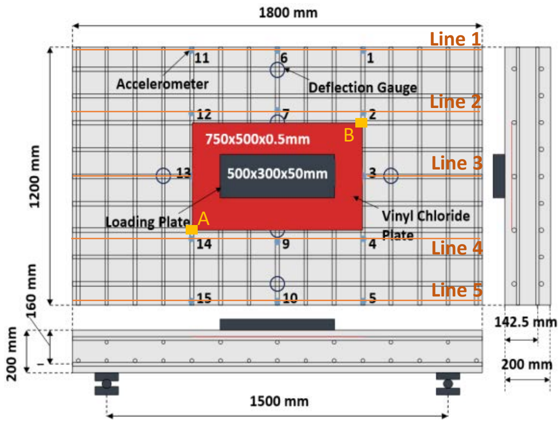

Fig. 1 Model Dimensions

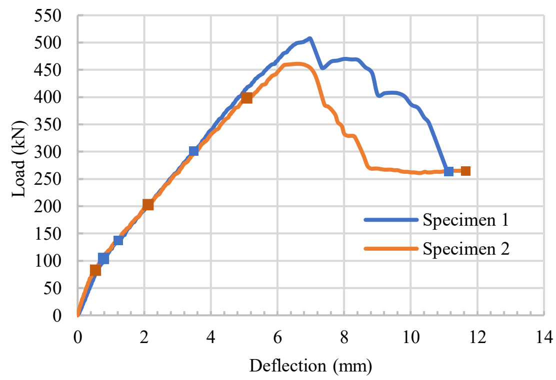

Fig. 2 Load-Deflection curves for both specimens (Note: Marked points indicate the loads after which free-vibration tests were performed)

3. RESULTS AND DISCUSSIONS

3.1 Variation in Natural Frequency with Increasing Load

Modal natural frequencies of Specimen 1 for the first and third bending vibration modes at five loading states are shown in Fig. 3. Random variation was observed in the natural frequencies of lower mode of Specimen 1 between different loading states as shown in Fig. 3. Whereas, for higher mode, a decreasing trend in natural frequency was observed with increasing load. Change in boundary conditions could be the reason for random variation in the lower modes' natural frequencies of Specimen 1. Mortar was used to connect the slab with supports. There was a possibility of breakage of mortar during experimentation, which could influence the boundary conditions. Effect of boundary conditions on natural frequencies of different modes was assessed from FEM analysis. The stiffness of the supports was varied and the change in natural frequencies was observed. The results are shown in Fig. 4. An increase in natural frequencies of all modes was observed by increasing the stiffness of the supports. From Mode 1 to 6, the percentage difference between the natural frequencies obtained using different support conditions tended to reduce and reached 0.5% and 4.8% from 17% and 37.5%, respectively, as presented in Fig. 4. These results show that the frequency of higher modes does not get affected by the change in the support condition

Keyword: Reinforced concrete slab, boundary condition, horizontal crack, dynamic response, coordinate modal assurance criteria
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significantly. The boundary conditions have a less or negligible influence on higher modes because of the formation of more number of nodes (Carne et al. 2007). Thus, the experimental results implied that a decrease in frequency of higher modes was observed due to reduction in stiffness with the damage aggravation in different loading states.

3.2 Change in Mode Shapes by Modeled Damage

For damage identification and localization, COMAC was evaluated at each sensor location using similar mode shapes of both specimens. COMAC for each of five lines along the longitudinal axis of slabs, as shown in Fig. 1, were obtained by taking average of the COMAC evaluated individually at three sensor locations along each line. As a result of modeled damage inside Specimen 2, the average COMAC calculated for Lines 2 and 4 were found to be less than those for other lines as presented in Table 1. However, the COMAC at central line, i.e., Line 3, came out to be more than Lines 2 and 4, which means the change in mode shapes due to modeled damage was more around Lines 2 and 4 than at the center. Edge of the vinyl chloride plate could behave as weaker points so it could be a reason for lower COMAC for Lines 2 and 4 than Line 3.

Table 1: Average Coordinate Modal Assurance Criteria (COMAC) for Specimen 2 with respect to Specimen 1 at 0kN; ERA

Line	1	2	3	4	5
Sensor	1,6,11	2,7,12	3,8,13	4,9,14	5,10,15
COMAC	0.949	0.891	0.946	0.890	0.913

For comparison purpose, COMAC was estimated at the center (around accelerometer 8) and edge points of vinyl chloride plate (Fig. 1) using analytical mode shapes. The results are presented in Table 2. COMAC estimated for both edge locations around Lines 2 and 4 was observed to be less than the central location.

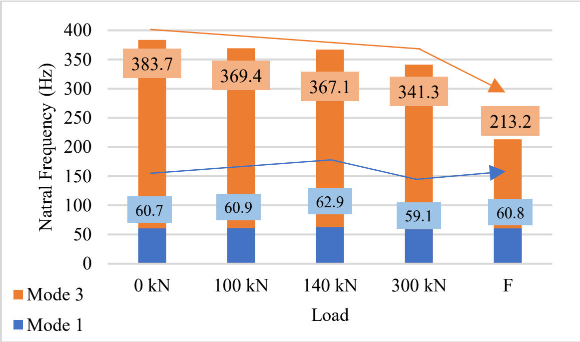

Fig. 3 Natural frequencies of 1st and 3rd bending mode for all loading states of Specimen 1; ERA

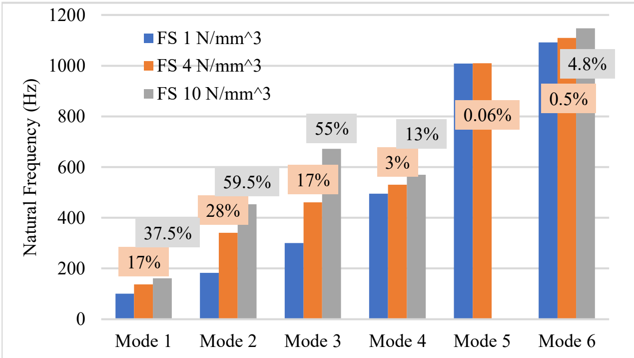

Fig. 4 Natural frequency of different modes of Specimen 1 for different boundary conditions; FEM

(Note: FS is the foundation stiffness per unit area, and the numerical values are the percentage changes in the natural frequency of specimen with FS 4N/mm^3 and FS 10N/mm^3 with respect to FS 1N/mm^3)

Table 2: Coordinate Modal Assurance Criteria (COMAC) for Specimen 2 with respect to Specimen 1 at 0kN; FEM

Location	A	Center	B
COMAC	0.981	0.998	0.981

4. CONCLUSIONS

This study led to conclude that the frequency of lower modes gets affected by the change in boundary conditions, however, the influence of boundary conditions is insignificant on higher modes. Thus, when correlating experimental and analytical results for damage identification, higher modes can be used to avoid the influence of the difference between real and assumed analytical boundary conditions. The edges of structural damage could behave as weak points, so it could be a reason for the change in experimental mode shapes due to modeled horizontal crack being more along the edges of the crack than at the center. Similar changes were observed in the mode shapes identified from the FEM analysis as well that affirms the experimental results.

ACKNOWLEDGMENT

The support from Mr. Kyosuke Yamaura, a former graduate student of Saitama University, in conducting the experiment described in this paper is highly appreciated.

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