Modal Analysis of Small Masonry Columns

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Abstract: The paper presents modal analysis of four small brick columns. This non-destructive method was used for detection of damage and quality of two different mortars. The small brick columns were made from four bricks and mortar. Two of them were made using one type of mortar and the second two using another type. The multi reference modal analysis was used for investigation of the differences in dynamic behavior. Conclusion summarizes the comparison of dynamic behavior of columns and damage detection in some of them.

Keywords: brick; masonry structure; mortar; modal analysis; vibration; experiment.

1 Introduction

The modal analysis is well known method for modal parameters identification not only for large structures [1] but also for small ones. It can be also used for monitoring of dynamic behavior changes in time [2,3] or for damage identification of a specimen [4]. The paper presents multi reference modal analysis used for stiffness comparison of two types of mortar and for damage identification of the small masonry columns.

2 Tested Specimens

The four masonry columns were prepared for the purpose of this test. Each column was made from four bricks. For the connection of bricks two different types of mortars were used. The first one was composed from 70% of limestone binder (L) and 30% of metakaolin/cement binder (MK), the next part was crushed brick (CB) from the brickyard Bratronice and the last one was sand (S) from Zálezlice. This is why the first two specimens were named as LMK_SCB_1 and LMK_SCB_2. The second two specimens were made from the mortar without crushed bricks. Thus they were named as LMK_S_1 and LMK_S_2.

3 Measurement System of the Modal Analysis

We did a visual inspection of the columns before starting the modal analysis and we found some cracks in mortar on specimens LMK_S. Therefore the measurement system with two different positions of the reference response transducers was used for the better damage detection – one was placed in the left upper corner of the column and the other in the left lower corner of the column. The measurement system Brüel & Kjær consisted of two acceleration transducers 4519-003, the impact hammer 8206 and the measurement station Front-end 3560-B-120. The measurement was carried out on two perpendicular vertical sides of the column in a chosen net of points. The response transducers were placed to two reference positions and then the specimen was stroked by an impact hammer in all chosen points. The Frequency Response Functions (FRF) were evaluated for all measurement points from the impact force and response records using Fast Fourier Transform (FFT). Two sets of modal parameters (one from each response transducer) were evaluated based on the resonance peaks in FRFs.

4 Modal Parameter Identification for LMK_SCB specimens

The eight natural frequencies and mode shapes were evaluated for both specimens LMK_SCB and for both reference accelerometers. The examples of the first four natural modes of the specimen No. 2 are shown in Fig. 1 and Fig. 2. These modes look like the modes of the rigid body. Modes evaluated from both reference transducers look very similar thus modes only from the upper one are presented. From the side view of the Fig. 1 and Fig.2 there is evident that mortar of the specimens is softer than bricks because displacements in mortar are bigger than on bricks.

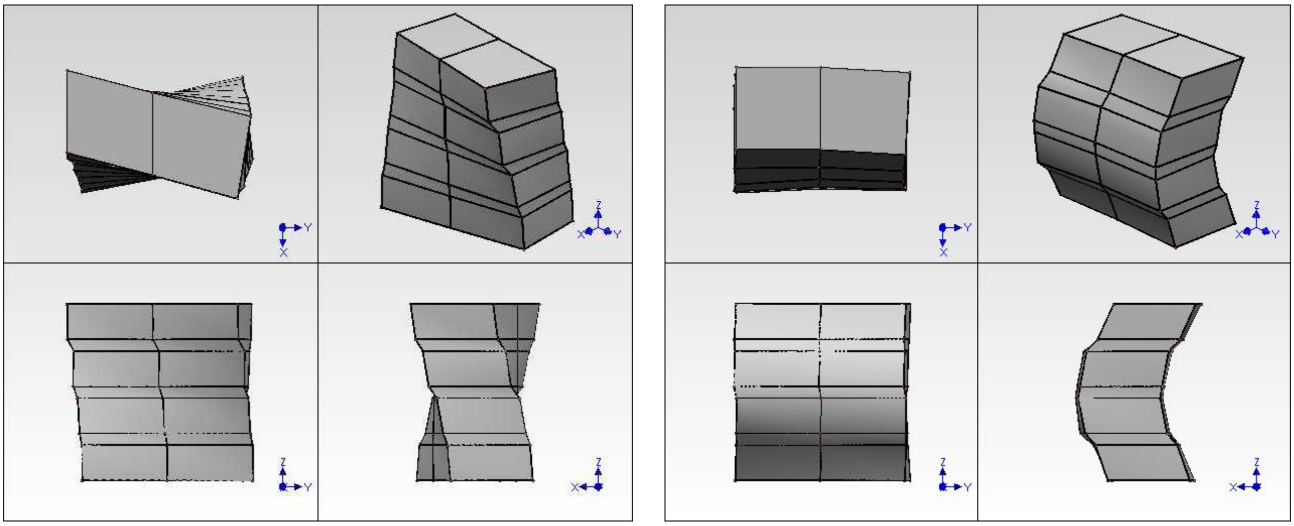

Fig. 1: The 1st and 2nd natural modes of the specimen LMK_SCB_2,f_1 = 1715 Hz and f_2 = 2298 Hz

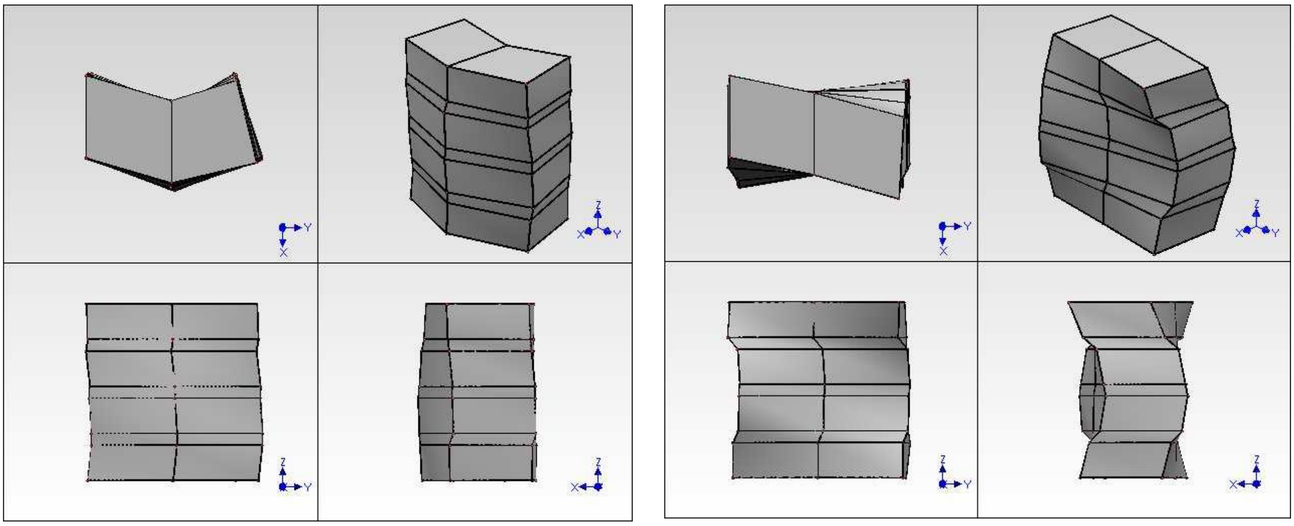

Fig. 2: The 3rd and 4th natural modes of the specimen LMK_SCB_2,f_3 = 3027 Hz and f_4 = 3247 Hz

5 Modal Parameter Identification for LMK_S specimens

The eight natural frequencies and mode shapes were evaluated for both specimens LMK_S and for both reference accelerometers. The examples of some natural modes of the specimen No. 2 are shown in Fig. 3, Fig. 4 and Fig.5. In contrary to the specimens LMK_SCB, these ones do not vibrate like the rigid body. The modes evaluated from two reference positions for the same natural frequency differs very much (see Fig.3-5). In each figure there are presented two modes for the same frequency – left one evaluated from the transducer placed in the upper left corner of the specimen and right one evaluated from the transducer placed in the lower left corner.

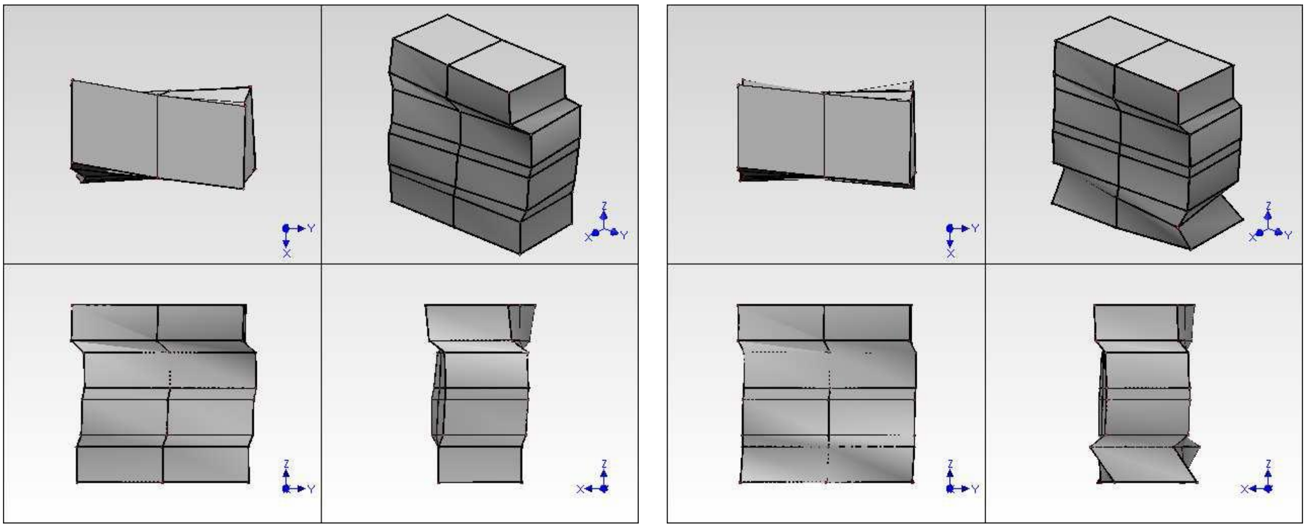

Fig. 3: The 1st natural mode of vibration of the specimen LMK_S_2, f_1 = 1153 Hz
(left – upper transducer, right – lower transducer)

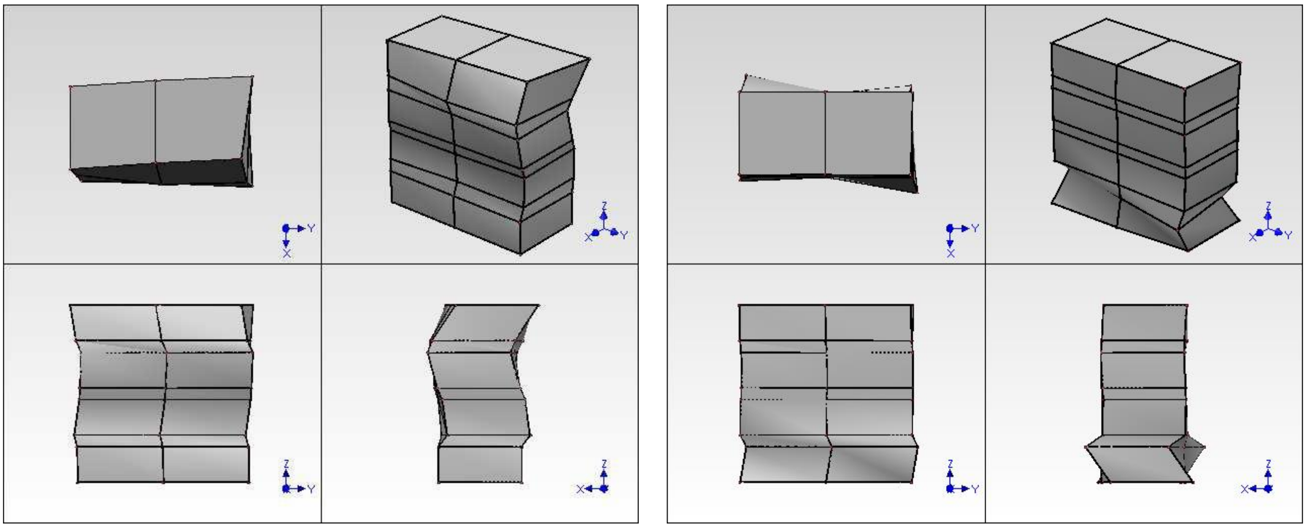

Fig. 4: The 2nd natural mode of vibration of the specimen LMK_S_2, f_2 = 1497 Hz
(left – upper transducer, right – lower transducer)

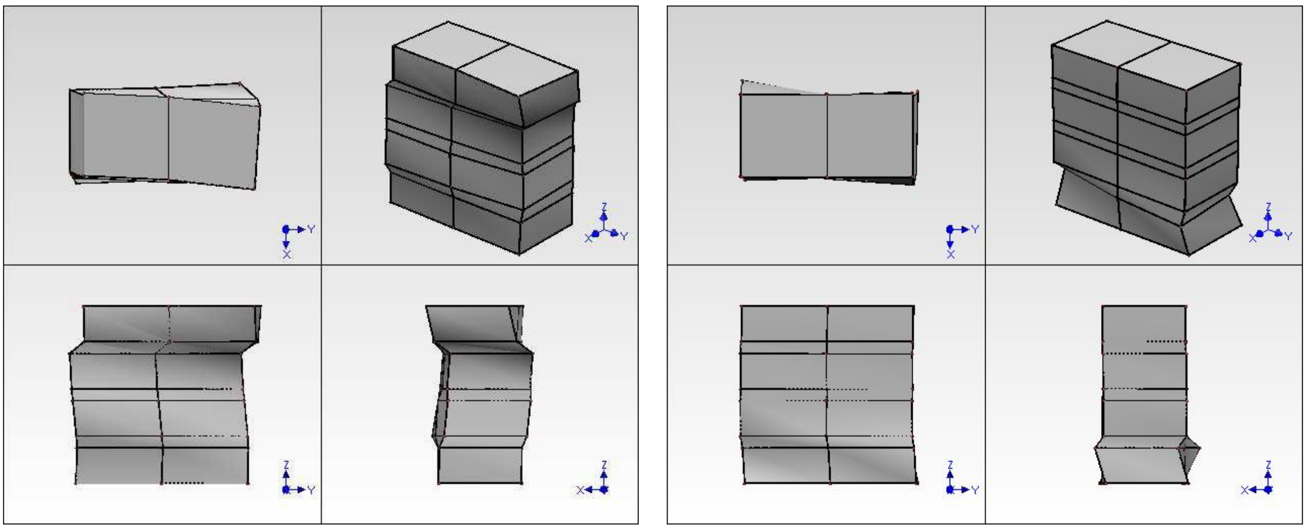

Fig. 5: The 3rd natural mode of vibration of the specimen LMK_S_2, f_3 = 1735 Hz
(left – upper transducer, right – lower transducer)

6 Damage Detection

The natural modes of the specimens LMK_SCB look like the rigid body motion without any big dissimilarity which can signalize the crack presence. There is only visible that mortar has lower stiffness than bricks.

Both specimens LMK_S have totally different dynamic behavior. The natural modes of the specimen LMK_S_2 evaluated from the two reference acceleration transducers differ very much. The upper brick vibrates especially in the modes evaluated from the upper transducer (Figs. 3-5 – left) and lower brick in the modes evaluated from the lower transducer (Figs. 3-5 – right). The excitation signals from the middle part of the column were not transferred to the upper reference transducer and were partly transferred to the lower one. Based on these results the cracks were identified in the lower and upper mortar joints.

The very similar state was observed also for the specimen LMK_S_1, for which the results evaluated from two reference transducers also differ. But in this case only upper brick vibrates independently. Thus the crack was identified in the upper mortar joint.

7 Conclusion

The modal analysis used for comparison of dynamic behavior of small masonry columns made from two types of mortar is presented. Based on the results, it is obvious that the mortar LMK_SCB is much better than LMK_S. Also the damages in the mortar joints were identified using the multi reference modal analysis. This method proved to be very useful for identifying damage and stiffness of mortar joints in these types of specimens.

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