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MODAL IDENTIFICATION AND COMPARISON OF A NEW PRECAST SUPERIMPOSED SLAB SHEAR WALL BUILDING AND A CAST-IN-SITU BUILDING

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Precast structures are popular in recent years due to the merits of effectiveness, safety, high quality and environmental friendliness, etc. However, their behavior is different from that of cast-in-situ. This article investigates and compares two buildings with one precast and one constructed in-situ. The precast building built with a type of new precast superimposed slab shear wall system imported from Germany and it has been applied to different structures. However, this kind of structure may have the weakness of low integrate performance, lack of design and technical experience, more complex connections between components, and large transport costs. To know more about the dynamic characteristics and integrity of the precast system, two ambient vibration tests were conducted on two buildings. Modal identification was performed using vibration data to obtain their dynamic parameters. According to the identified results, the characteristics of different buildings are discussed and compared. Due to the different floor numbers of the two buildings, the final dynamic characteristics should not be totally the same, however, the identified mode shapes are consistent with each other.

Keywords: precast structures, modal identification, Bayesian approach, field vibration test.

1 Introduction

Precast structures are prefabricated structures with the main components precast in factory and assembly in field. It converts most on-site construction to precast industrial production. This kind of structure is the future trend of building development due to many advantages, such as light weight, effectiveness. However, the biggest challenge faced is their poorer integrity performance than cast-in-situ structures, especially for the joints among different components. Thus, it is of great significance to study the seismic performance of the structure and the influence of the connections between different components. To improve the application of precast residential buildings, more study of the dynamic performance is needed to carry out.

The precast shear wall consists of two superimposed plates, while the hollow core between slabs are constructed on the site with the joint between different parts. This helps improve the integrity of the entire structure to meet both convenience and integrity requirements. It should be noted that the quality and performance of industrialized parts are higher than those built on site. Therefore, the final structure is the balance between these two features. (Stanton & Nakaki 2002, Holden et al. 2003, Wilsona et al. 2008). As a popular method, field non-destructive vibration tests are used to study the performance of structures and to monitor health status, and it is an important part of structural health monitoring and damage detection. It helps to reduce the risk of poor structural performance, especially for some important buildings (Brownjohn et al., 2005, Ko & Ni 2005, Ni et al., 2016).

In this paper, two similar residential buildings are investigated with field tests and further operational modal analysis with one precast building and one cast-in-situ building. Such investigation assists in understanding more about the actual performance of the new system in practice and promoting the use of this new type of shear wall system under different circumstances. The operational modal analysis performed is through a fast Bayesian FFT method for ambient vibration data, which is recently developed and allows practical implementation. In this method, load and response are modelled as a stationary stochastic process. It not only provides the most probable values (MPV) of the modal parameters, but also can obtain the associated posterior uncertainty analytically. This makes it possible to evaluate the accuracy of the MPVs. This issue is particularly relevant in field vibration tests arising due to measurement noise, sensor alignment error, modeling error, etc (Au 2011, Au 2012a, Au 2012b, Zhang and Au 2013). For details, please refer to Au 2011, Au 2012a and b.

2 Field vibration test

The on-site vibration test used is an ambient vibration test, which is the most economical test for common vibration tests because it is performed under normal service. For comparison, the floor plans of both buildings are almost the same. The normal building is 14-story frame-shear wall structure on the ground. The plan is divided into four similar units. The total height of the structure is 40.60 meters with the standard floor of 2.90 meters. The precast building is 13-story concrete shear wall building with a total height of 37.70 meters and a standard story of 2.90 meters. The exterior view of the precast building is shown in Figure 1.

Figure 1 Exterior view of the building

The measurement locations are all the same for the two buildings accordingly. These structures are bi-axially measured in the horizontal directions as shown in Figure 2. On each floor, two uniaxial sensors were used. For the precast building, in order to obtain a mode shape consisting of all the four elements of a high-spatial-resolution building, a total of 56 locations were designed for measurement, giving a total of 112 degrees of freedom (dofs). In each setup, there are 16 uni-axial sensors available, giving 16 synchronous measured channels. In order to cover all the dofs of interest, a total of nine setups have been designed. The digital data was recorded for 15 minutes at a sampling rate of 256 Hz in each setup.

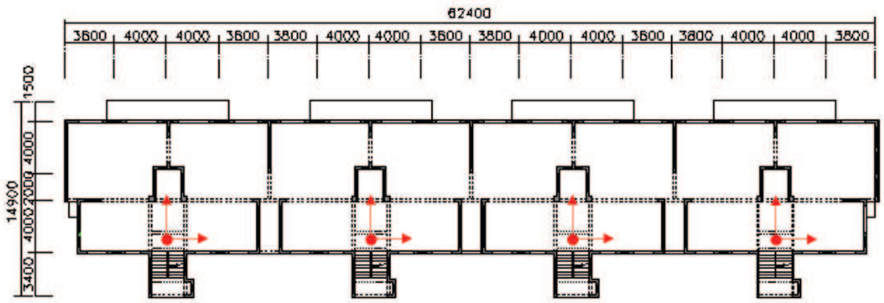
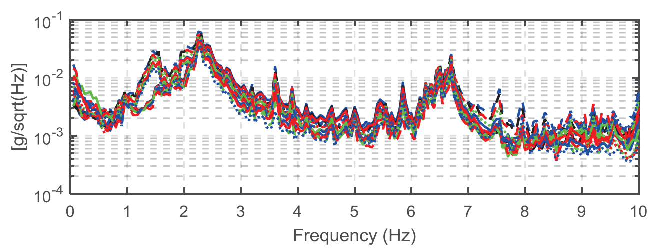


Figure 2 Measurement locations on each floor

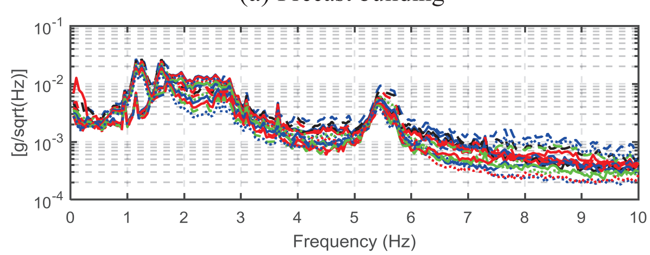
Based on the collected vibration data, operational modal analysis was carried out to obtain modal parameter values, mainly including the natural frequencies, damping ratios and mode shapes (Au et al. 2013; Yuen and Kuok 2010). The locations measured are on the roof and the stairs in the four units. The reference sensors were set on the roof, 7 / F, 8 / F connects all measuring locations to provide the global mode shape of the entire building. The sensors are oriented according to the construction wall of the stairs.

3 Modal identification results

The modal parameters of the first three modes were focused, which can be seen clearly from the power spectral density (PSD) spectra in Figure 3 for both two kinds of structures. The results were identified and discussed by the Bayesian approach.



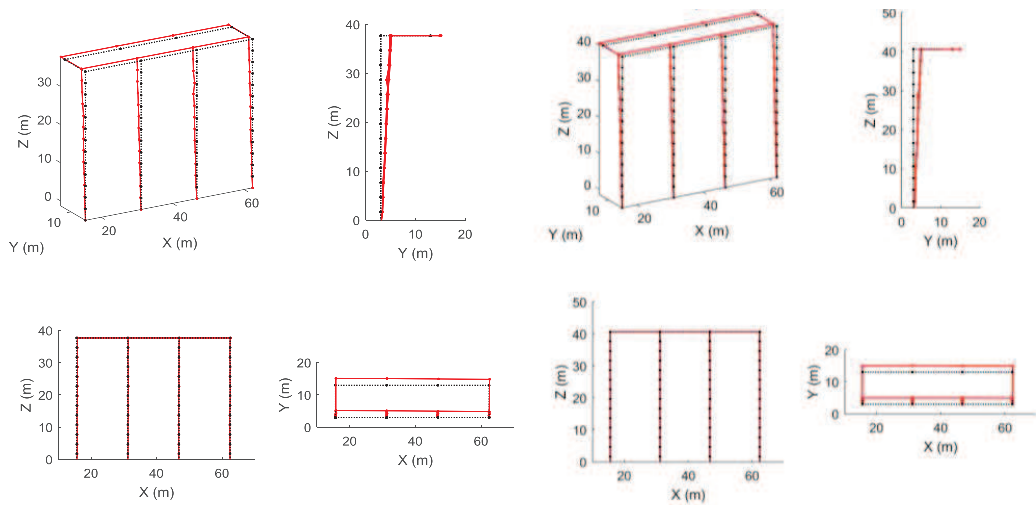
(a) Precast building



(b) Cast-in-situ building

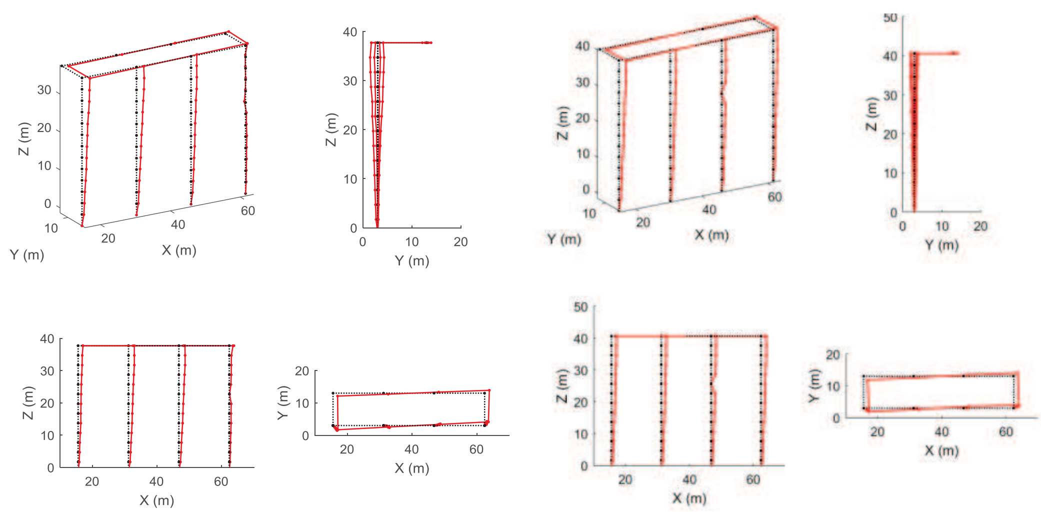
Figure 3 Identified mode shape of Mode 1

For precast building, the first mode is shown in Figure 4 with a corresponding natural frequency of 1.437 Hz and a damping ratio of 5.2%. The results shown here are the average of nine setups. For each parameter, the MPVs in the different settings are very close to each other, but have some difference. This is reasonable because the measurement location and environment for each setup are different. In the YZ view, it is clear that in this mode, the deformation is dominated by the Y-axis and is a translational mode. The strong direction of the building is the X direction and the weak direction is the Y direction, and thus the first mode is along the Y direction. In this mode, all four units are fluctuated together and the movements are consistent with each other with the largest movement at the roof. For the cast-in-situ building, although the floor numbers are different from the precast one, the mode shape has the same property with each other from Figure 4 (a) and (b).



(a) Precast building (b) Cast-in-situ building

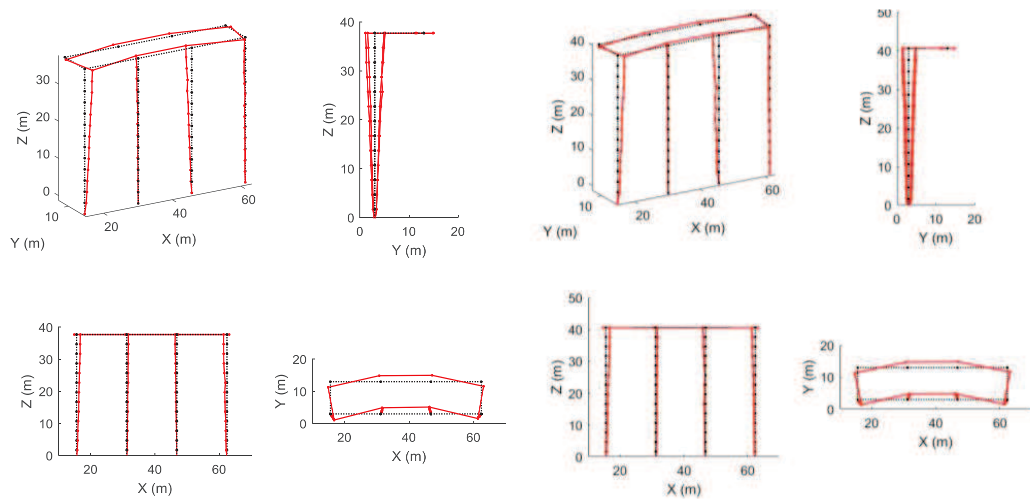
Figure 4 Identified mode shape of Mode 1



(a) Precast building (b) Cast-in-situ building

Figure 5 Identified mode shape of Mode 2

Figure 5 shows the second mode. For the precast building, it is a 2.267Hz torsion mode with a damping ratio of 10.1%. In this mode, the two units on the left move forward while the units on the right move backward. From YZ view, both sides of the building move in the opposite direction. From XY view, the center of torsion is almost at the center of the building, and the deformation of the four units is also correspondingly two by two. The eight locations of the roof measurements are consistent with the main body of the building and the movement is mainly in the Y direction. It is worth noting that the deformation of the 9th floor in the second mode is not as good as other floors, which may be attributed to the quality of data, and this phenomenon also appears in the third mode, while it cannot be seen in the first mode. Due to the complexity of the surrounding environment, on-site testing can be easily disturbed by the environment rather than in the laboratory. The noise levels in different frequency components are also different. This leads to the phenomenon that in some mode, the identification result is good while in some modes, it is not good enough. The quality of data may be improved by another measurement in the future.



(a) Precast building (b) Cast-in-situ building

Figure 6 Identified mode shape of Mode 3

Table 1. Identification results comparison of precast building and Cast-in-situ building

Mode number	Modal parameters	Precast building	Cast-in-situ building	Ratio
Mode 1	Natural frequency (Hz)	1.437	1.219	1.18
	Damping ratio (%)	5.2	4.1	1.27
Mode 2	Natural frequency (Hz)	2.267	1.782	1.27
	Damping ratio (%)	10.1	8.3	1.22
Mode 3	Natural frequency (Hz)	6.604	5.387	1.23
	Damping ratio (%)	2.6	2.5	1.04

The third mode of both buildings are the wrapping modes in Figure 6. In this mode, the entire structure, especially the roof, is forming an arch with the center outside the structure. However, they are symmetric, i.e., unit 1 corresponding to unit 4, and unit 2 corresponding to unit 3. This is the global mode of roof and stairs. From the YZ view, the deformation of the symmetrical stairs is the most overlap of all the floors. In the XZ view, the roof deforms clearly with the center moving up and the edges moving down. Unlike mode 2, the deformation in the XZ view is symmetric.

The identified natural frequencies and damping ratios are listed in Table 1. Remind that the precast building is 13-story while the cast-in-situ building of 14-story. Thus, the identified values should not be the same. The ratios of the identified results are also shown in the table. It is noted that the ratios of natural frequencies and damping ratios are all around 1.2 for almost all the three modes. This should attribute to the difference between rigid of the two buildings.

4 Conclusion

This paper presents the work on a full-scale field vibration test for a 13-story precast building, consisting of new precast superimposed slab shear wall components to investigate its performance. For comparison, a 14-story cast-in-situ building is also investigated to show the difference of dynamic parameters of the two kinds of structures. Bayesian methods are used to perform modal identification. Three modes have been identified. One is the translational mode along the weak direction of the structure, i.e., the Y direction, and the other two are the torsional modes. The building consists of four identical units, in the first mode, the four units are the same whereas in modes 2 and 3, their mode shapes are anti-symmetric and symmetrical. In general, all modes of the three modes are with high accuracy. The smooth deformation of the four units and the roof shows that the design of the shear wall, and particularly the connections between the different components, works well. The consistency of the global mode shape of the two buildings shows that the integrate performance of the precast structure is good. In addition, the results obtained in health status can also be used as a baseline for assessing the future performance of the structure.

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