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EFFECT OF NONSTRUCTURAL COMPONENTS ON AMPLITUDE-DEPENDENT DYNAMIC PARAMETERS. I: AMBIENT VIBRATION TESTS

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Abstract

A full-scale one-story steel frame with a precast cladding system was designed, and a series of tests were conducted. The precast cladding system was composed of Autoclaved Lightweight Concrete (ALC) external wall cladding panels, gypsum plasterboard interior linings, and three types of window openings. Ten test cases, including a bare steel frame case and nine other cases in which different parts of the precast cladding system were fixed to the steel frame, were tested under ambient vibration, free vibration, and shaking table tests. The objectives are to evaluate the influence of precast cladding systems on dynamic characteristics of the steel frame, to examine the effect of nonstructural components on the amplitude-dependent property of dynamic characteristics, and to evaluate the performance of the steel frame resulting from the precast cladding system. In this part, the steel frame, the precast cladding system, and the experimental works are introduced, and the ambient vibration test results are reported. The ambient vibration test results demonstrate that the precast cladding system has a significant effect in stiffening the structure and in improving energy dissipation capacity of the frame. As the response vibration amplitude is small, amplitude dependency of dynamic characteristics is not obvious in the ambient vibration tests.

Keywords: Nonstructural component; Dynamic parameter; Amplitude dependence; Ambient vibration; steel frame

1. Introduction

Nonstructural components are commonly used in building structures for architectural reasons. It is proved that they have complex interactions with the frame structure and may cause undesirable effects on the building performance[1-2]. For instance, nonstructural components contribute to the strength and stiffness of building structures, the additional mass leads to a decrease in natural frequencies, the existence of nonstructural components enhances the soft story mechanism and short column effect, etc. In spite of the significant interactions, the contribution of nonstructural components is usually ignored in the stage due to the lack of information in quantifying the complex interactions between the nonstructural components and the frame. This results in an inaccurate determination of dynamic characteristics, lateral stiffness, energy dissipation capacity, ductility, and failure mode of the frame, and leads to an unsafe design.

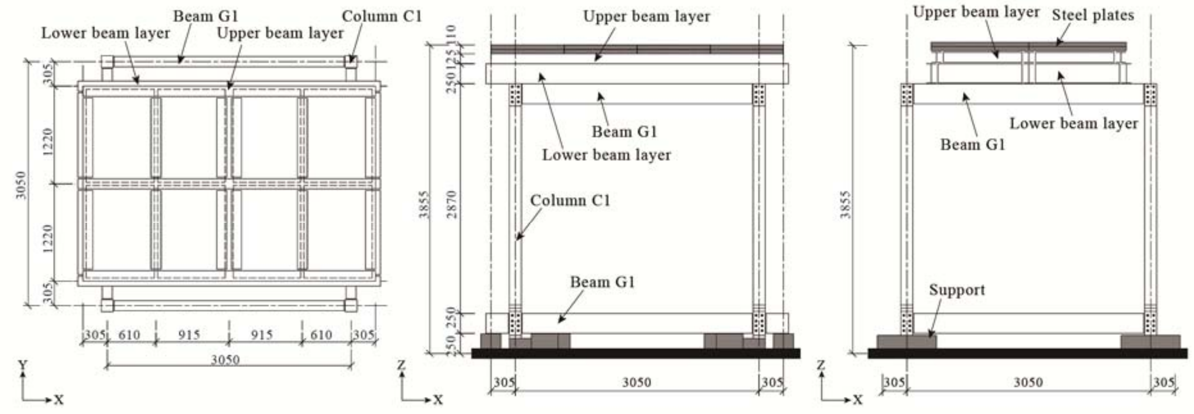
Steel frames with precast cladding systems are very common in many parts of the world. Although a number of researchers have studied the complex interaction between infill walls and reinforced or steel frame [3-5], there is still limited study about the interaction between the precast cladding system and steel frame. In an effort to better understand the complex interactions between the precast cladding system and steel frame, a series of tests were performed. Ten test cases were designed, and ambient vibration, free vibration, shaking table tests were conducted on each case. The objectives are to evaluate the influence of precast cladding systems on dynamic characteristics of the steel frame, to examine the effect of nonstructural components on the amplitude-dependent property of dynamic characteristics, and to evaluate the performance of the steel frame resulting from the precast cladding system.

In this paper, the steel frame, the precast cladding system, and the experimental works were introduced, and ambient vibration test results were reported. The free vibration and shaking table test results are reported in the following parts.

2. Experimental work

2.1 Steel frame

A full-scale one-story steel frame was designed and fabricated in a shaking table. The steel frame was designed as one section of an actual residual house, as shown in Figure 1. The steel frame was 3050 × 3050mm in plan and 3120mm high. Four corner columns marked as C1 were box section of 150mm × 150mm with 9mm thickness. The beams on the first and second floors were H section 250 × 125 × 4.5 × 9mm thick. The yield strength of the above members was 235Mpa. Sixteen steel plates were placed on the second floor to simulate real surface loads, and each weighs 4.64 kN. Two steel beam layers were set on the second floor to support the steel plates. The lower beam layer was assembled of H-section beams 250 × 125 × 4.5 × 9mm thick, and the upper beam layer was assembled of H-section beams 125 × 125 × 6.5 × 9mm thick.



(a) Plan (2nd Floor) (b) X Elevation (c) Y Elevation

Fig. 1 – The test steel frame (unit: mm)

2.2 Nonstructural components

A precast cladding system was installed on the steel frame, including Autoclaved lightweight concrete (ALC) cladding panels, gypsum plasterboard interior linings, and three types of window openings, as shown in Figure 2. A detail description of the nonstructural components is listed in Table 1. The ALC external cladding panels were fixed onto the steel frame using a typical “Rocking installation method”, as shown in Figure 3. Each ALC external wall was composed of three vertically installed general ALC panels and two corner panels, and the gaps between panels were infilled with silicone sealing compound. A standard general ALC panel has a thickness of 75mm, width of 600mm and length of 2870mm. Blots are used to connect the ALC panels to the steel frame. One end of the bolt is inserted and connected with an anchor rod in the panel, and the other end is connected with a connecting plate. The connecting plate is connected with a steel angle that is bolted to the steel frame. The “Rocking installation method” isolates wall panels from the steel frame and permits the wall panels to rotate slightly to follow deformation of the frame, thus the earthquake input is reduced, and major damage on both the frame and nonstructural components can be avoided in the event of an earthquake. Plasterboard with a thickness of 12.5mm was used as the lining material, and was attached to the internal face of the ALC external wall claddings through a wood stud frame. Three types of window openings were adopted, and the effect of window glazing system was examined.

Table 1 – Details of the precast cladding system

Components		**Dimensions**	**Weight**
ALC cladding panels		2130 × 2870 × 75mm thick	0.49 kN/m^2
Plasterboard interior linings		1830 × 2620 × 12.5mm thick	0.20 kN/m^2
Window openings	Small size	610 × 460 mm	--
	Middle size	610 × 1420 mm	--
	Large size	1830 × 1420 mm	--

Fig. 2 – The precast cladding system

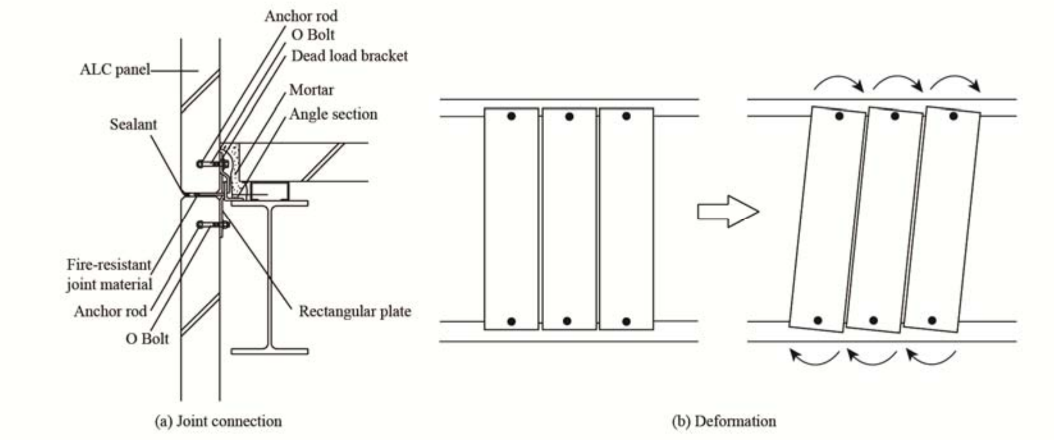


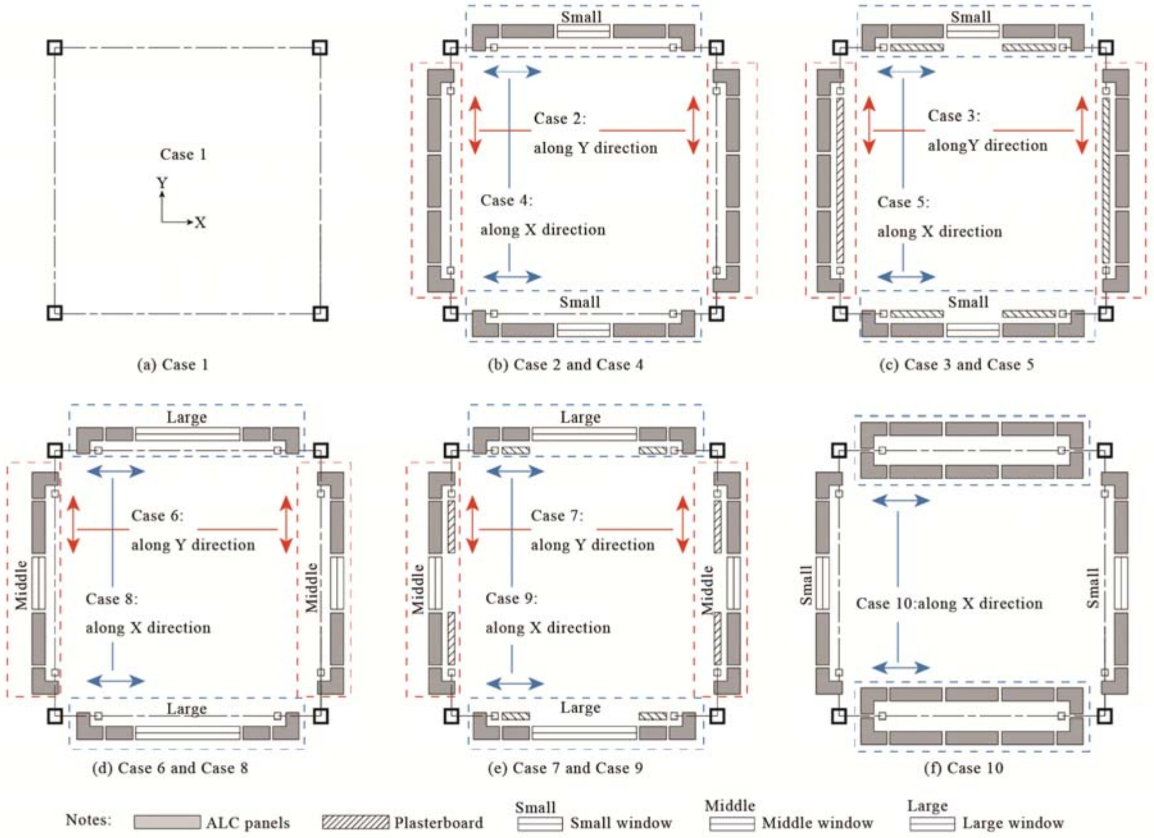
Fig. 3 – A typical "Rocking installation method"

2.3 Experimental method

Ten test cases were designed, including a bare steel frame case and nine other cases with different parts of the precast cladding system. The test cases are listed in Table 2, and a detail description is plotted in Figure 4. Nine combinations of nonstructural components were designed, and the effect of ALC cladding panels, plasterboard interior linings, and the window glazing system was examined independently. Two test cases were assembled in the steel frame simultaneously in order to speed up the experimental process, in which one test case was set along the X direction and the other test case was along the Y direction. The two test cases were regarded to be independent.

Table 2 – Summary of test cases

Test cases	**Structural members**	**Nonstructural components**			**Direction**
		ALC claddings	Plasterboard	Window openings	
1	Steel frame	--	--	--	X
2	Steel frame	ALC claddings	--	--	Y
3	Steel frame	ALC claddings	Plasterboard	--	Y
4	Steel frame	ALC claddings	--	Small window	X
5	Steel frame	ALC claddings	Plasterboard	Small window	X
6	Steel frame	ALC claddings	--	Middle window	Y
7	Steel frame	ALC claddings	Plasterboard	Middle window	Y
8	Steel frame	ALC claddings	--	Large window	X
9	Steel frame	ALC claddings	Plasterboard	Large window	X
10	Steel frame	ALC claddings of two layers	--	--	X



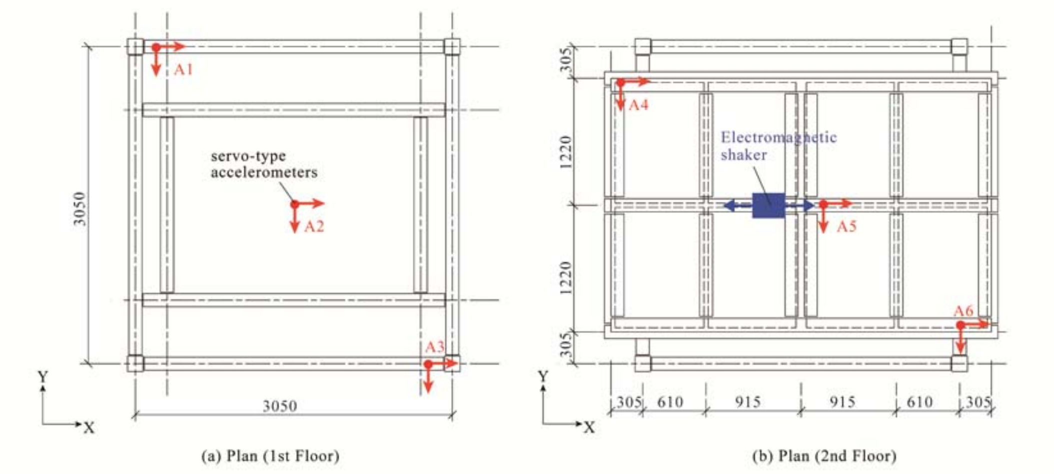
(a) Case 1 (b) Case 2 and Case 4 (c) Case 3 and Case 5

(d) Case 6 and Case 8 (e) Case 7 and Case 9 (f) Case 10

Fig. 4 – Layout of test cases

Six servo-type accelerometers were set up to collect response acceleration data. Each accelerometer can record time history acceleration data along with two directions simultaneously. Layout of the accelerometers is shown in Figure 5. Three accelerometers marked as A1 to A3 were located on the first floor, and the other three marked as A4 to A6 were located on the second floor. On each floor, two accelerometers were set at two diagonally opposite corners, and the other one was located at the center. An electromagnetic shaker was placed at the center of the second floor for the free vibration tests, and its excitation orientation was kept along with the direction of each test case.

Ambient vibration, free vibration, and shaking table tests were conducted for each case. Ambient vibration test was first conducted, then free vibration test was conducted, finally the shaking table test was conducted on the steel frame.



(a) Plan (1st Floor)

(b) Plan (2nd Floor)

Fig. 5 – Layout of accelerometers

3. Ambient vibration test results

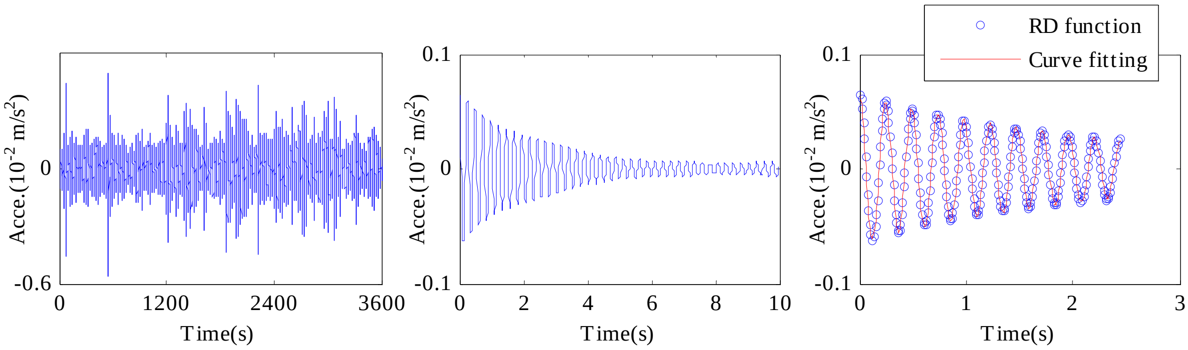
Ambient vibration test was first conducted on each test case to examine the dynamic characteristics, and the duration of the ambient vibration test was 60 minutes. As the steel frame was fabricated in the shaking table, microtremors were adopted as the main excitation, so that the measured response amplitude was relatively small.

From field measurements made over last several decades, it is recognized that structural dynamic characteristics are nonlinear parameters varying with vibration amplitude[6-7]. In order to evaluate the amplitude-dependent dynamic parameters, the Random decrement (RD) technique was applied to the ambient vibration data. RD technique assumes that the random response of a structure is a white noise signal composed of a deterministic part and a random part. With a given trigger value, the random response is divided into a series of short time segments. By taking average of a large number of time segments, the random part tends to zero and the deterministic part is obtained. The deterministic part is a free vibration signal and is called RD function. Dynamic characteristics corresponding to the given trigger value can be extracted from the RD function. The principle of the RD technique can be written in the following form,

$$z(\tau,c)=\frac{1}{2N}\sum_{i=1}^{2N}\mathrm{sgn}[y(t_i+\tau,c)]\cdot y(t_i+\tau,c)) \qquad (1)$$

where $y(t,c)$ is the random response at time t with the trigger value of c, sgn[$y(t,c)$] is the signum function of $y(t,c)$, t_i is the *i-th* time instant, $2N$ is the number of time segments.

The procedure of estimating amplitude-dependent dynamic characteristics from ambient vibration data by RD technique is described in Figure 6. The contribution of the target mode is first isolated from the ambient vibration data, then RD technique is applied to extract amplitude-dependent dynamic characteristics. A series of trigger values are given in a wide amplitude range, and corresponding RD functions and dynamic parameters are extracted. The given trigger values are physically the vibration amplitude, thus dynamic characteristics with respect to vibration amplitude are obtained.



(a) Time history (b) RD function (c) Curving fitting result

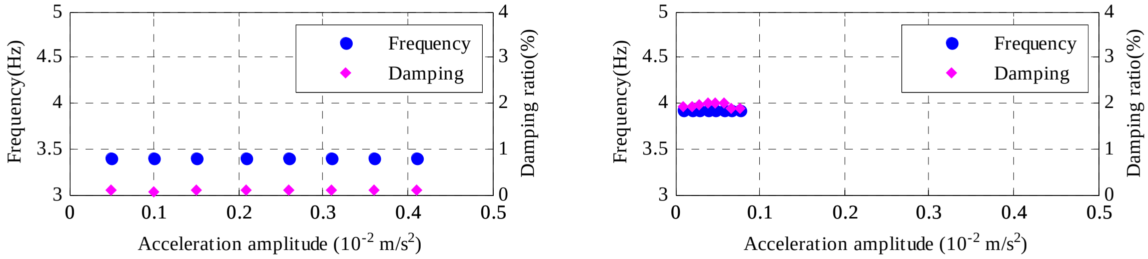
Fig. 6 – Procedure of applying RD technique to ambient vibration data

The amplitude-dependent natural frequencies and damping ratios estimated from ambient vibration data are illustrated in Figure 7. The response acceleration data at the center of the top floor is adopted. As shown in the figure, the response vibration amplitude is quite small in the ambient vibration test, which is on the order of ten to the minus three. Thus the amplitude dependency of dynamic parameters is not obvious. The natural frequencies are observed to be constant in all test cases, and a little scatter of damping ratios are observed in some test cases, i.e., a decrease of damping ratio with respect to the response amplitude can be observed in test case 5. Generally, amplitude dependency of dynamic characteristics is not obvious in the ambient vibration tests.

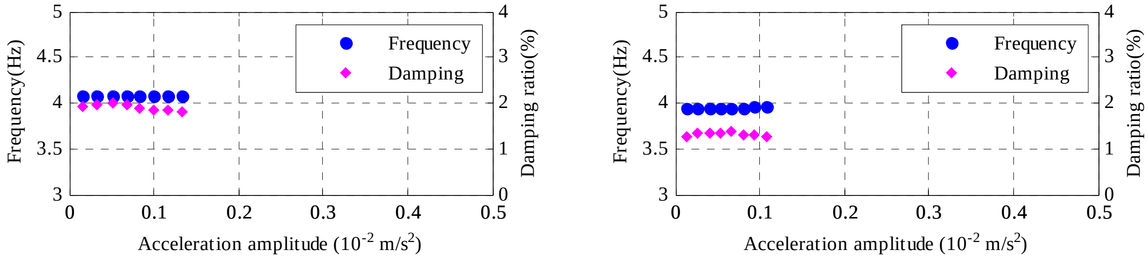
The mean values, standard deviations, and coefficients of variation of the amplitude-dependent natural frequencies and damping ratios are listed in Table 3. As shown in the table, nonstructural components make a great contribution to the structural stiffness and energy dissipation capacity. The natural frequency of the bare steel frame is 3.40Hz, and the natural frequencies of the steel frame with nonstructural components range from 3.59Hz to 4.65Hz. The nonstructural components provide an increase of natural frequency by 5% to 40%. The damping ratio of the base steel frame is merely 0.1%. However, with the addition of the precast cladding system, the damping ratios of the steel frame range from 0.9% to 2%. The precast cladding system contributes an 8-fold to 18-fold increase to the damping ratio. The increase in natural frequency indicates that the precast cladding system makes a significant contribution to the structural stiffness, and the increase in damping ratio indicates that nonstructural components play a significant role in improving energy dissipation capacity of the frame.

Table 3 – Dynamic parameters estimated from ambient vibration data

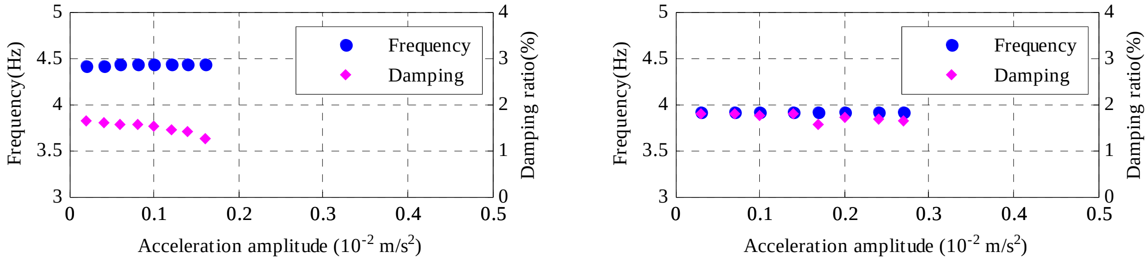
Test cases	**Natural frequency**			**Damping ratio**		
	f (Hz)	**σ_f (Hz)**	**COV (%)**	**ζ (%)**	**σ_ζ (%)**	**COV (%)**
1	3.40	0.001	0.029	0.1	0.01	10.0
2	3.92	0.001	0.026	2.0	0.05	2.6
3	4.07	0.002	0.049	1.9	0.07	3.7
4	3.95	0.001	0.025	1.3	0.04	3.0
5	4.42	0.001	0.023	1.5	0.01	0.7
6	3.90	0.001	0.026	1.7	0.09	5.3
7	4.27	0.007	0.163	0.9	0.06	6.5
8	3.59	0.005	0.139	1.2	0.12	9.9
9	3.76	0.003	0.080	1.3	0.05	3.9
10	4.65	0.006	0.129	1.9	0.02	1.1



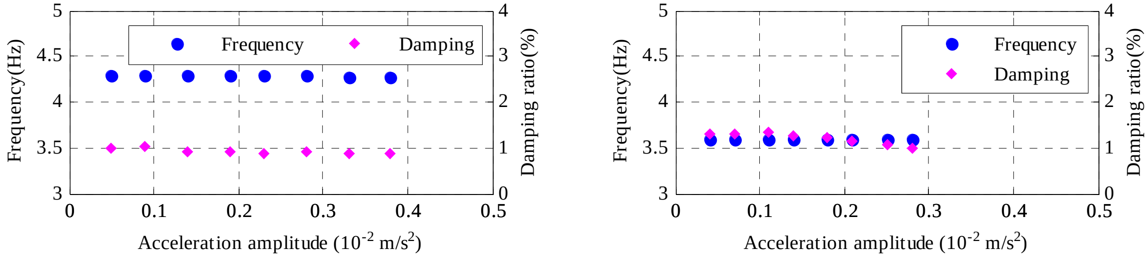
(a) Case1 (b) Case2



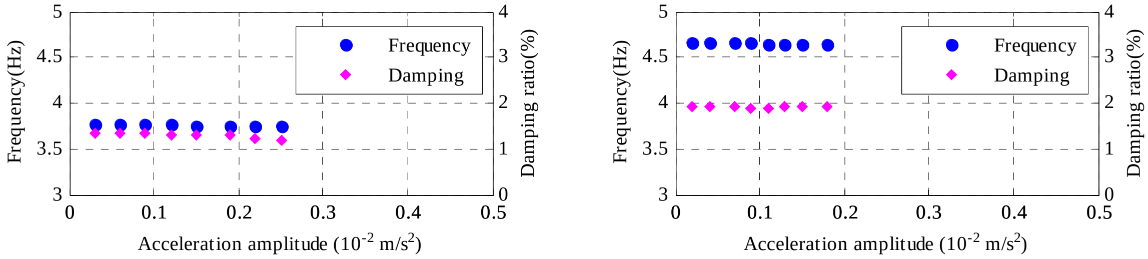
(c) Case3 (d) Case4



(e) Case5 (f) Case6



(g) Case7 (h) Case8



(i) Case9 (j) Case10

Fig. 7 – Amplitude-dependent dynamic parameters estimated from ambient vibration data

4. Conclusions

In order to study the effect of nonstructural components on the dynamic characteristic and dynamic behavior of steel frame, a full-scale one-story steel frame with different parts of a precast cladding system was tested under ambient vibration, free vibration, and shaking table tests. In this paper, the steel frame, the precast cladding system, and the experimental works were introduced, and the ambient vibration test results were reported. The free vibration test results, shaking table test results, and the discussions are presented in the following parts. The ambient vibration test results are summarized as follows.

a. Nonstructural components have a significant effect in stiffening the structure. The precast cladding system provides an increase of natural frequency by 5% to 40%.

b. Nonstructural components make a significant contribution to structural damping. The precast cladding system contributes an 8-fold to 18-fold increase to the damping ratio and significantly improves energy dissipation capacity of the steel frame.

c. As the response amplitude is quite small in ambient vibration tests, amplitude dependency of dynamic characteristics is not obvious. A slight decrease of damping ratio can be noticed in a few cases.

5. Acknowledgements

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6. References

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