# Effect of Arrangement and Area of Floor Well to Vibration Characteristics of Two Storied Wooden Houses

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**SUMMARY:**
This paper describes the effect of arrangement and area of floor well to vibration characteristics of two storied wooden houses by means of vibration table tests. This effect of arrangement and area of floor well includes the effect of mass eccentricity. Therefore, we examine separately the effect of these factors by using different series of full scale specimens. First, we examine the effect of arrangement and area of floor well by using specimen series (a). Second, we examine the effect of mass eccentricity by using specimen series(b) with eccentric masses instead of floor well. And finally, we examine the combined effects by using specimen series(c). The main results obtained by these experiments are as follows. Specimens with floor well that situated at weak wall side are apt to vibrate with small torsion caused by mass eccentricity. The relative displacements between first and second floor are apt to influenced by mass eccentricity, and those of second and third floor are apt to influenced by floor well.

*Keywords: Floor well, Mass eccentricity, Torsional vibration characteristics, Shaking table test*

## 1. INTRODUCTION

A house with horizontal floor of high rigidity can resist earthquake because of the smooth transfer of stress going up and down. On the other hand, a house with horizontal floor of low rigidity vibrates with large torsion. Some examples of studies about dynamic characteristics of low rigidity floor are shown below. As an example of experimental study, Agawa et al. (2002) carried out shaking table test about single storied wooden house with eccentricity, and made clear that relative deformation becomes predominant rather than torsional motion as a rigid body. Noguchi et al. (2006,2007) carried out shaking table test about a scaling down wooden model with floor well and reported they could control the deformation of house by regulating the rigidity of horizontal floor. As an example of analytical study, Odani et al. (2010) proposed corrected coefficients of torsion with considering a flexible horizontal diaphragm. However, shaking table test focused on the arrangement and area of floor well of full scale wooden house has never tried before.
Therefore, we carried out shaking table test about full scale two storied wooden houses with floor well to clarify the influence of arrangement and area of floor well on torsional vibration characteristics.

## 2. OUTLINE OF EXPERIMENTS

### 2.1. Specifications of specimen

The specimen is a box type of two-storied wooden house with each story height 2,730mm and each floor plan of 1,820mm×2730mm shown as **Figure 1**. The location of displacement transducers and seismometers are also shown in **Figure 1**. The relative displacements between lower and upper floor are measured by these transducers. Pillars and foundation beams are made of cedar, other beams are made of pine imported from USA and walls and floors are made of structural panel.

Specifications of specimen parts are shown as **Table 1**. The arrangement of walls and shaking direction are shown as **Figure 2**. In order to investigate the torsional characteristics easily, rigidity of walls set in shaking direction is regulated different by means of stitching structural panel and pillar by different nail space. A wall set in Y1 frame stitched by nail (length of which is 50mm) space of 300 mm is named weak wall, a wall set in Y4 frame stitched by nail space of 150mm is named strong wall, and walls set in X1 and X4 frames stitched by nail space of 200mm are named middle strong wall. Mass of 1$^{st}$ floor is 372.3 kg and that of 2$^{nd}$ floor is 274.9 kg. A payload of 180 kg is put at equal intervals on roof floor, and put 60kg per one floor board (910mm×1820mm) on 2$^{nd}$ floor.

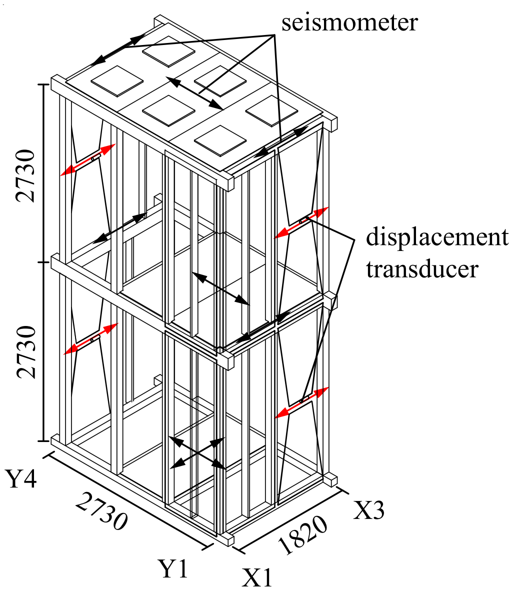



**Figure 1** Specimen

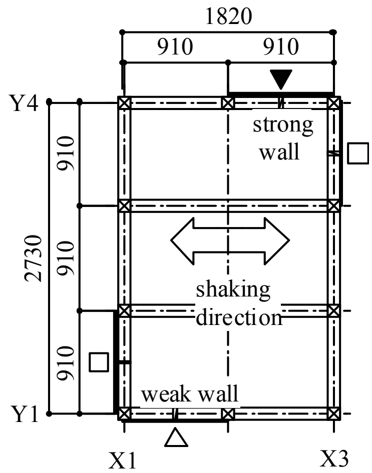


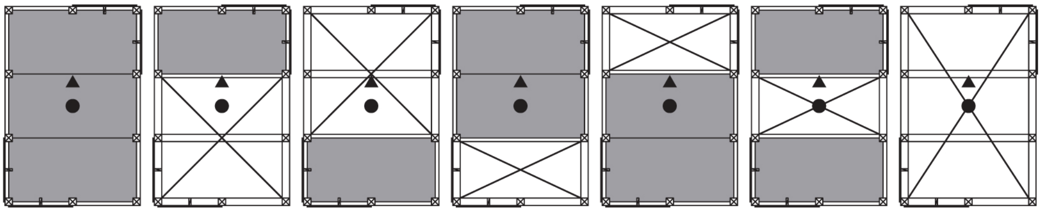

**Figure 2** Arrangement of walls

**Table 1** Specifications of specimen parts

| part | | kind of tree | size(section or thickness) | nail interval |
|---|---|---|---|---|
| beam | R.F. | pine from USA | H180×B105 | |
| | 2F. | | | |
| pillar | 2F,1F | ceder | H105×B105 | |
| floor | 3F. | plywood | 9mm | screw nail@150 |
| | 2F. | | 12mm | |
| | 1F. | | 9mm | |
| wall | Y1 frame (weak wall) | | 9mm | N50@300 |
| | Y4 frame (strong wall) | | 9mm | N50@150 |
| | X1,X3 frame | | 9mm | N50@200 |

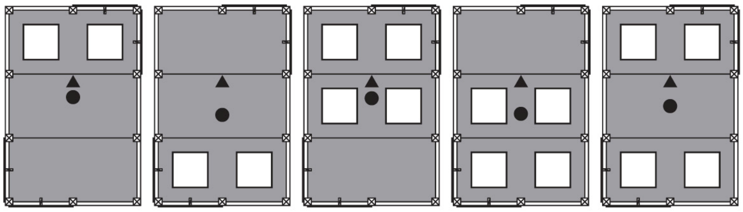
## 2.2. Types of specimen

The types of specimen are classified into three large groups in accordance with floor well type and payload type as shown in **Fig. 3**. A specimen series (a) is set to investigate the influence of floor well type on torsional vibration of these specimens, a specimen series (b) is set to investigate the influence of mass eccentricity and a specimen series (c) is set to investigate the influence of combination of floor well type and mass eccentricity. A second floor of the type A has no floor well, that of type B and D have floor wells in the weak wall side, that of type C and E have floor wells in the strong wall side, that of type F has central floor well and that of type G has no floor. A sign of circular dots(●) show a centre-of-gravity position and a sign of triangular dots(▲) show a centre-of-rigidity position.



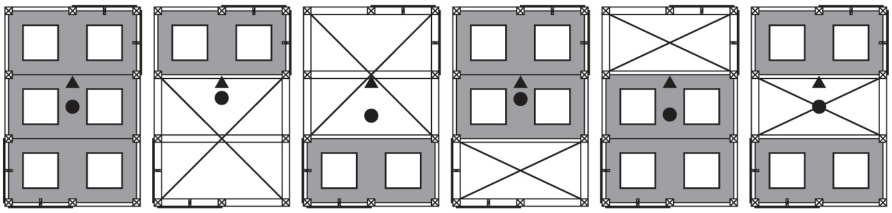
A B C D E F G

series (a): in order to investigate the influence of floor well type



AWB AWC AWD AWE AWF

series (b): in order to investigate the influence of mass eccentricity



AW BW CW DW EW FW

series (c): in order to investigate the influence of combination of floor well type and mass eccentricity

**Figure 3** Three series of specimen

### 2.3. Input motion

The specifications of a shaking table are shown as **Table 2**. The input motions generated by this shaking table for these experiments are BCJ-level 2, JMA-Kobe 1996, El-Centro 1940NS. The maximum acceleration of input motion is limited to 150 cm/s$^2$ to avoid specimens being damaged.

**Table 2** Specification of shaking table

| item | specification |
|---|---|
| maximum displacement | 150 mm |
| maximum velocity | 80 cm/s |
| frequency range | 0.1-100 Hz |
| size of shaking table | 2m×2m |
| maximum payload | 35 kN |
| maximum acceleration | 1.2 G(earthquake), 0.6 G(sine wave) |

## 3. RESULTS

### 3.1. Natural frequency

The principal interval records obtained by shaking table tests are employed to analyse the dynamic characteristics of these specimens. Fourier spectra, Fourier spectral ratios and phase lags of specimen type C induced by JMA-Kobe, maximum acceleration of which is 100 cm/s$^2$ are shown as

**Figure 4**. The normalization of Fourier spectra is carried out by means of Parzen's spectral window, the band width of which is 0.3 Hz. These figures show the natural frequency of this specimen is 3.34 Hz, torsional frequency is 6.32 Hz and the transverse natural frequency appears at 4.42 Hz.

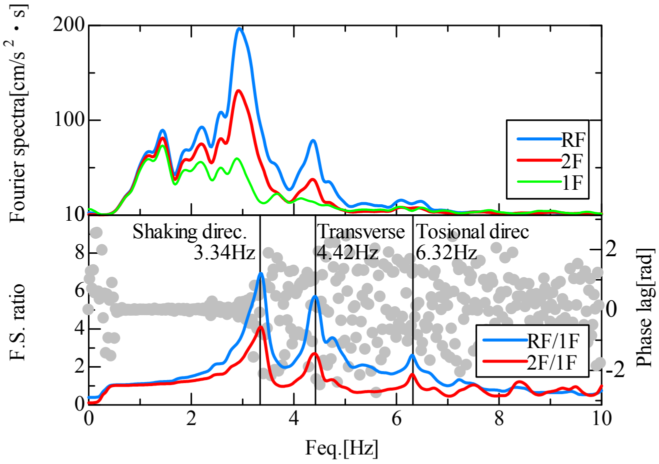



**Figure 4** Fourier spectra, Fourier spectral ratios and phase lags of specimen type C induced by JMA-Kobe, maximum acceleration of which is 100 $cm/s^2$

### 3.2. Influence of floor well type to natural frequency

The influence of floor well types to natural frequencies of specimen series (a) is shown as **Figure 5**. The input motions adopted in these experiments are six cases shown in right side of Figure 5. The horizontal axis is specimen type previously shown as Figure 3, the vertical axis is the natural frequency of specimen. From this figure, the natural frequencies induced by BCJ 50$cm/s^2$ marks of which shown as + scatter around 3.45 Hz and the deviation of them is at most 0.05 Hz(1.5%). The frequencies of type B and D, the floor wells of which set in the weak wall side, are little bit small to the average frequency, and that of type C and E, the floor wells of which set in the strong wall side, are little bit large to the average frequency.

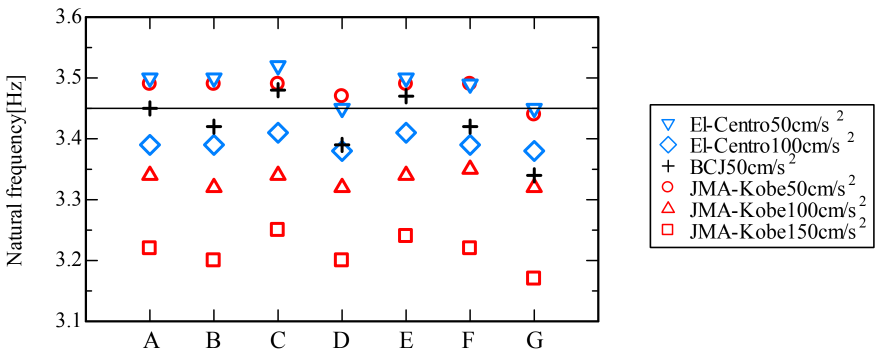



**Figure 5** Natural frequencies of specimens belong to specimen series (a)

### 3.3. Influence of floor well type to the torsional response

*3.3.1. Relative displacement ratio between upper and lower floor*

We can see a torsional vibration as a difference of relative displacement waves between upper and lower floor of Y1 frame (weak wall side) and that of Y4 frame (strong wall side) as shown **Figure 6**. From this Figure, we can see that the relative displacement of Y1 frame (weak wall side) is larger than that of Y4 frame. Therefore, we distinguish a relative displacement ratio as an indicator of torsional vibration shown as **Eqn.3.1**.

$$\text{Relative displacement ratio}=\frac{\text{Relative disp. between upper and lower floor of Y1 frame}}{\text{Relative disp. between upper and lower floor of Y4 frame}} \quad (3.1)$$

The relative displacement ratios of all specimen types are shown as **Figures 7 to 9**, respectively. In order to compare the results of these specimen series, we pick up only the results induced by Kobe 100cm/s$^2$ and compare the relative displacement of type B to F with that of type A or AW, we show **Figure 10.** The vertical axis of Figure 10 shows ratios between the relative displacement ratio of type A or AW and those of the other type. **Figure 7** are obtained by specimen series (a) to investigate the influence of floor well type, **Figure 8** are obtained by specimen series (b) to investigate the influence of mass eccentricity and **Figure 9** are obtained by specimen series (c) to investigate the combined influence of floor well type and mass eccentricity.

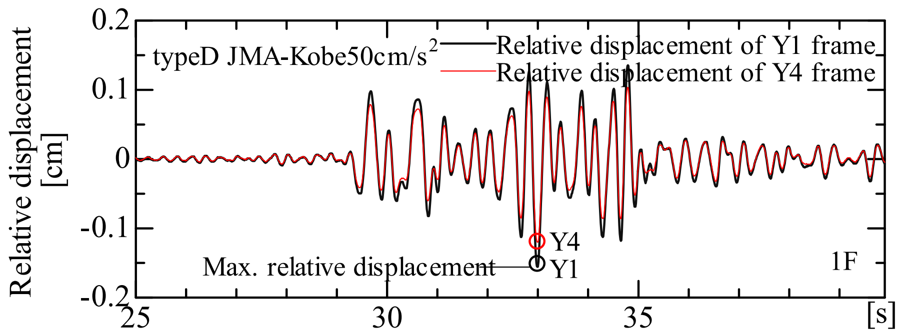



**Figure 6** Waves of relative displacement between upper and lower floor of 1$^{st}$ floor

*3.3.2. Relation of floor well type and relative displacement ratio*

From **Figure 7**, the relative displacement of 1$^{st}$ floor (left side of Figure 7) distribute from about 1.2 to 1.5, those of 2$^{nd}$ floor (right side of Figure 7) distribute from about 1.1 to 1.7 and those of 2$^{nd}$ floor are not necessarily larger than those of 1$^{st}$ floor. And also, the relative displacement ratio of type B having larger floor well on the weak wall side is larger than that of type D having half size floor well compared to that of type B. This is caused by stress concentration by setting a large floor well on weak wall side. The relative displacement ratio of type E having small floor well on the strong wall side is smaller than that of type C having double size floor well compared to that of type E. This is caused by stress mitigation by setting a small floor well on strong wall side. From these phenomena the influence of floor well size reveals remarkably when floor well set on weak wall side. From **Figure 10**, the relative displacement ratios of type B and D having floor well on the weak wall side of 1$^{st}$ floor(○) are approximately 5 % larger than that of type A without floor well, and those of 2$^{nd}$ floor(●) are approximately 10 % larger than that of type A. On the contrary, the relative displacement ratios of type C and E having floor well on the strong wall side of 1st floor are approximately 5 % smaller than that of type A without floor well. That is to say, the difference of floor well type has a great influence on response of 2$^{nd}$ floor than that of 1$^{st}$ floor.

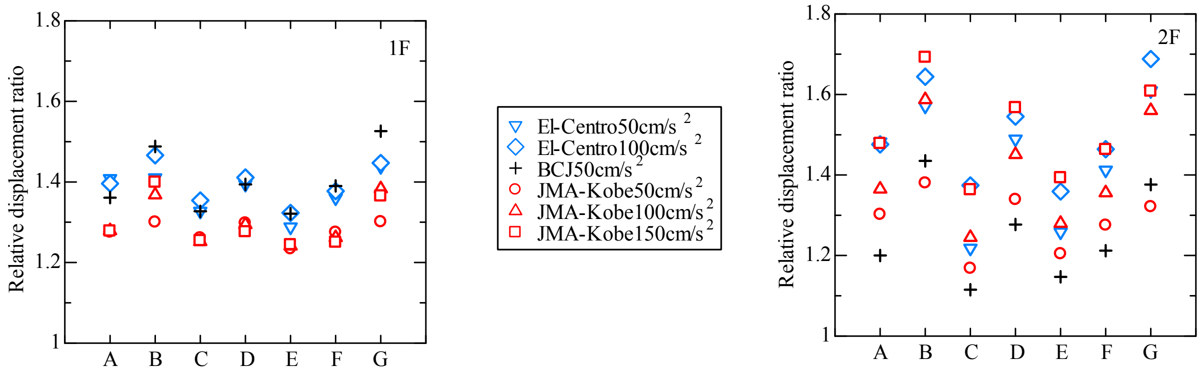



**Figure 7** Relation of floor well type and relative displacement ratio got by specimen series (a)

*3.3.3. Relation of mass eccentricity and relative displacement ratio*

From **Figure 8**, the relative displacement ratios of type AWB and AWD, the eccentricity of which is 0.14, are small and type AWC and AWE, the eccentricity of which is 0.29, are large. The above results on 1st floor as the relation of eccentricity are shown as **Figure 11**. From this figure the relative displacement ratio becomes large as the eccentricity becomes large. Next, we pay attention to the relative displacement of 2nd floor. The mass eccentricity is not exit at roof floor, therefore the relative displacement of 2nd floor becomes the same on all specimens in accordance with theory. However, the tendency of them is very similar to that of 1st floor as shown in **Figure 8**. It considered that this phenomena is caused by three dimensional effect as reported by Hikita(2009). From **Figure 10**, paying attention to the influence of mass eccentricity to the relative displacement ratio of 1st floor, those of type AWB and AWD(△) having floor well on weak wall side are smaller by 5% and those of type AWC and AWE having floor well on strong wall side are larger by 3% compared with that of type AW. From the above results caused by mass eccentricity, it becomes clear that the specimens having floor well on weak wall side are apt to vibrate with small torsion and the specimens having floor well on strong wall side are apt to vibrate with large torsion.

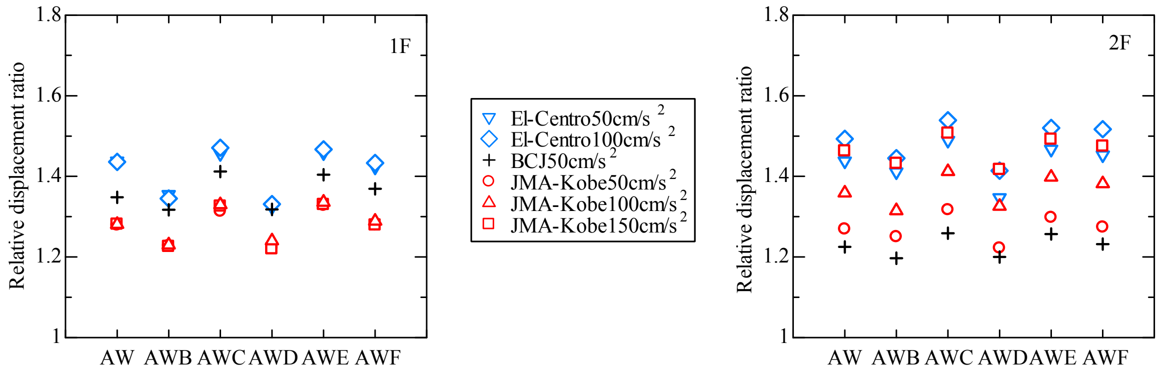



**Figure 8** Relation of floor well type and relative displacement ratio got by specimen series (b)

*3.3.4. Relation of floor well type combined mass eccentricity and relative displacement ratio*

We can grasp the torsional vibration of house having floor well by considering the results of specimen series (c). Concentrating on 1st floor, from the left of **Figure 9**, the relative displacement ratio of type BW and DW having floor well on weak wall side are small, those of type CW, EW having floor well on strong wall side and FW having floor well on centre are large compared with type AW without floor well. This is the same tendency as specimen series (b) as shown in the left of Figure 8. Concentrating on 2nd floor, from the right of Figure 9, on the contrary, the relative displacement ratios of type BW and DW having floor well on weak wall side are large, those of type CW and EW having floor well on strong wall side are small compared with type AW without floor well. This is the same tendency as specimen series (a) as shown in the left of Figure 7. From **Figure 10**, marks of empty triangle(△) exhibiting the influence of mass eccentricity and empty square(□) exhibiting the influence of floor well combined mass eccentricity have the same tendency at 1st floor and marks of black circle(●) exhibiting the influence of floor well and black square(■) exhibiting the influence of floor well combined mass eccentricity have the same tendency at 2nd floor.

From the above results, it is considered that the influence of mass eccentricity reveals remarkably on relative displacement at 1st floor and the influence of floor well reveals remarkably on it at 2nd floor.

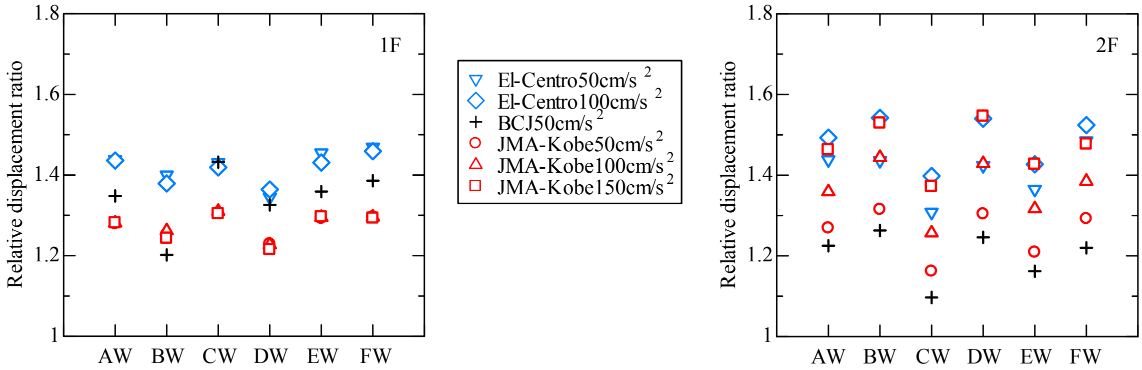



**Figure 9** Relation of floor well type and relative displacement ratio got by specimen series (c)

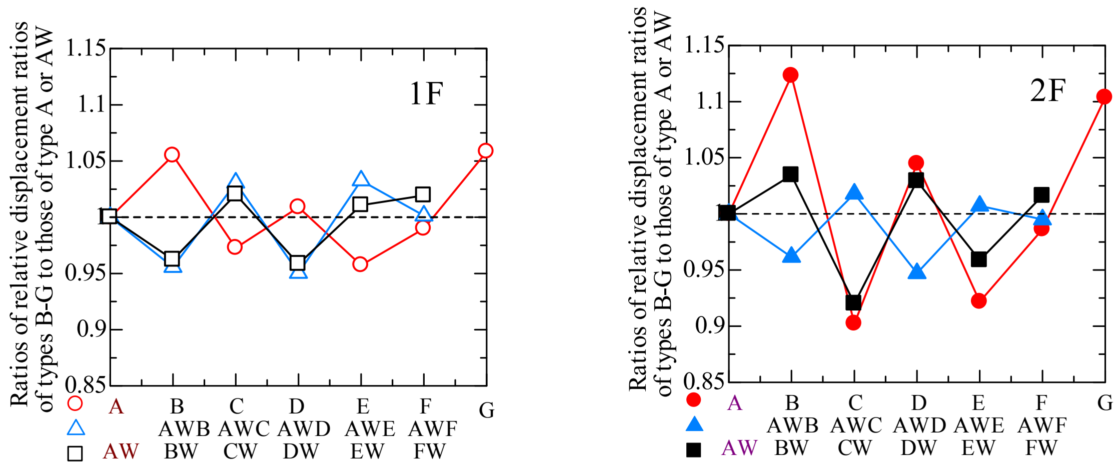



**Figure 10** Ratios of relative displacement ratios of type B-G to those of type A or AW

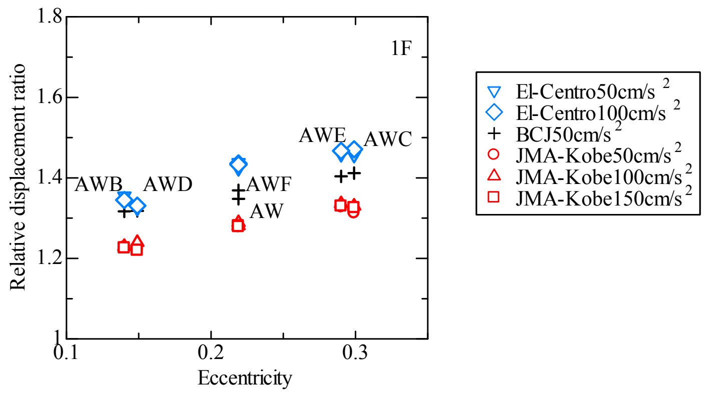



**Figure 11** Influence of eccentricity to relative displacement ratio

## 4. CONCLUSION

In order to clarify the effect of arrangement and area of floor well to vibration characteristics of two storied wooden houses we carried out a vibration table tests. This effect of arrangement and area of floor well includes the effect of mass eccentricity. Therefore, we examine separately the effect of these factors by using different series of full scale specimens.

The main results obtained by these experiments are as follows.

・The frequencies of type B and D, the floor wells of which set in the weak wall side, are little bit small to the average frequency.

・The relative displacement ratios of specimens having floor well on the weak wall side are larger than that of type A without floor well and the difference of floor well type has a great influence on response of 2nd floor than that of 1st floor.

・Specimens with floor well that situated at weak wall side are apt to vibrate with small torsion caused by mass eccentricity.

・The influence of mass eccentricity reveals remarkably on relative displacement ratio at 1st floor and the influence of floor well reveals remarkably on it at 2nd floor.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