BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 43 (1965), pp. 819-827

# 52. *On the Damage to Window Glass in Reinforced Concrete Buildings during the Earthquake of April 20, 1965.*

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(Read June 22, 1965.—Received Sept. 30, 1965.)

## Abstract

The damage to window glass in reinforced concrete buildings during the earthquake of April 20, 1965 is investigated. In order to interpret the cause of damage, the natural periods of the buildings were measured and the deflections were estimated using earthquake response analysis. The results indicate that the deflections are ranged between 0.4 and 2.0 cm which are between 1/5000 and 1/1000 in angle. From these results and the observation of damage it is concluded that the cause of damage to window glass is not by large displacement but by the "steel sash", "fixed" and "hardened putty".

## 1. Introduction

In Japan comparatively little attention has been paid to the failure of window glass in modern buildings caused by earthquakes, though this kind of damage has been reported in foreign countries.

The earthquake which occurred on April 20, 1965 in Shizuoka Prefecture, was not so severe but only moderate and caused minor damage to wooden houses, roads, railways, etc. However, the most remarkable damage caused by this earthquake was the failure of window glass in some reinforced concrete buildings, and the question has arisen what the main reason for the failure was. First of all, it was considered that the large deflection of building frame induced during the earthquake caused the relative displacement of steel sash which was large enough to break the window glass inside it. The measurement of natural periods of buildings were made to estimate the deflection of building frame during the earthquake, together with the observation of damage to window glass and surrounding building elements.

In the present paper the results of the natural period measurement of the buildings and the estimated interstory displacements are described, and then, the cause of glass failure is discussed considering the above results and the observation of damage.

## 2. Outline of the Earthquake and the Resulting Damage

### *2.1 Earthquake*

According to the Japan Meteorological Agency the outline of the earthquake is as follows:

| | |
|---|---|
| Origin time | $8^h 43^m$, $20^d$, IV, 1965 (local time); |
| Epicenter | 34.9°N, 138.4°E; |
| Focal depth | about 40 km; |
| Magnitude | M=6.2 by Gutenberg-Richter scale; |
| Intensity | IV: Shizuoka, Hamamatsu, Mishima, Yokohama, Kofu, Omaezaki, Funatsu and Aziro. |

### *2.2 Damage in general*

It was reported by the authorities of Shizuoka and Aichi Prefectures and Japanese National Railways and by T. Matsuda and M. Shibano of ERI[1)] that several wooden houses suffered minor damage such as fallen roof tiles, cracks in stucco walls, concrete berm and concrete ground floor, failure of window glass, etc., and that cracks in road and settlement of railroad bed were found in several places.

### *2.3 Damage to window glass in reinforced concrete buildings*

It was also reported that window glass was broken in the following four buildings.

Shida Hospital in Fujieda
Shimizu City Hall
Ihara Middle School in Shimizu
Watch Tower attatched to Hamamatsu City Hall

The outline of these buildings and description of damage both to window glass and other parts of buildings are listed in Table 1.

It should be noted that there are many other similar modern buildings in this area without any damage to window glass.

1) T. MATSUDA and M. SHIBANO, *Bull. Earthq. Res. Inst.*, **43** (1965), 625-639.

Table 1. Damage to window glass.

| Name of building | Number of story | Number of sheets of broken glass | | Damage to other part of building |
|---|---|---|---|---|
| | | Total | "Fixed" type | |
| Shida Hospital | 5 | about 130 (11%) | more than 100 (20%) | no damage |
| Shimizu City Hall | 6 | about 60 ( 4%) | 55 ( 9%) | slight damage to structure |
| Ihara Middle School | 3 | about 30 ( 3%) | more than 20 ( 4%) | slight damage to finishings |
| Watch tower attatched to Hamamatsu City Hall | Tower | 41 (46%) | 26 (87%) | cracks in beams and columns |

Note: 1) The structures of these buildings are made of reinforced concrete except that the light gage steel is partially used in Shida Hospital and the steel reinforced concrete is used in lower stories of Shimizu City Hall.

2) The figures in brackets indicate the ratio of the number of sheets of broken glass to the total number of sheets in the building expressed in percentage.

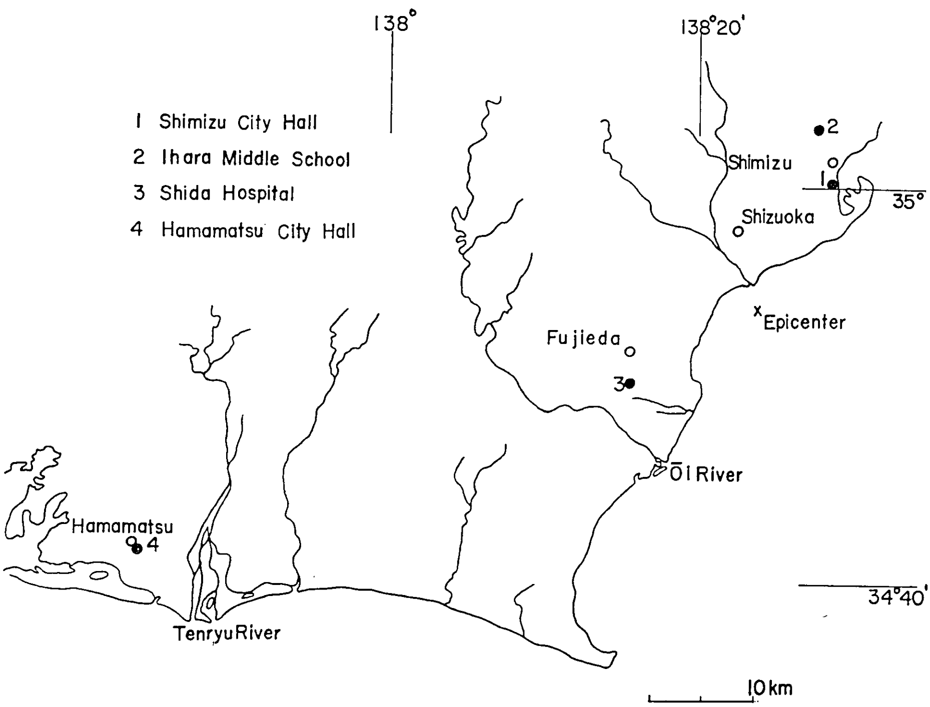


Fig. 1. Location of damaged buildings.

## 3. Measurement of natural period of buildings

If a building has a long natural period, it will be subjected to large interstory deflection which will give the forced displacement and resulting damage to the window glass in the building even in case of moderate earthquake. It was not unnatural to consider that the large deflection of this kind was the main cause of the glass failure of these four buildings. To estimate the deflection of the buildings during the earthquake, it is necessary to know the natural period of vibration of the buildings and earthquake ground motion.

Measurement was made by recording the micro tremor of the buildings with a micro tremor meter which was placed on the roof or top floor of each building. The fundamental natural period was determined from the period-frequency curve in which a two-minute record was analyzed. The results are listed in Table 2.

Table 2. Estimated interstory displacement.

| Name of building | Component | Natural period<br>sec | Maximum displacement at the top of the building relative to the base<br>cm | Interstory displacement<br>radian |
|---|---|---|---|---|
| Shida Hospital | EW<br>NS | 0.29<br>0.27 | 0.42—0.60<br>0.39—0.66 | 1/2600~1/3800<br>1/2400~1/4000 |
| Shimizu City Hall old building | EW<br>NS | 0.45<br>0.45 | 1.3 —2.0<br>1.0 —1.6 | 1/1000~1/1600<br>1/1500~1/2000 |
| Shimizu City Hall new building | EW<br>NS | 0.60<br>0.52 | 1.1 —2.3<br>1.9 | 1/ 900~1/1800<br>1/1000 |
| Ihara Middle School | EW<br>NS | 0.30<br>0.28 | 0.36—0.54<br>— | 1/2800~1/4000<br>— |

As is seen in Table 2, the natural periods of buildings are ranged between 0.27 and 0.60 sec. These are not extraordinarily long compared with those of the ordinary buildings which are ranged between 0.06 and 0.10 sec. times the number of stories.

## 4. Estimation of story displacement

The story displacement of the buildings during the earthquake was estimated from the measured natural period and the earthquake record with the aid of response analysis technique.

The earthquake record used in this analysis was the accelerogram obtained with the SMAC accelergraph installed at the surface of the ground in Shimizu City.

Estimation of the displacement in Shimizu City Hall is illustrated below.

(1) From the measured natural period of 0.45 sec, the maximum relative displacement for one-mass system is calculated as $\delta=1.1$ and 1.7 cm for the earthquake record in Shizuoka and Shimizu, respectively.

(2) Assuming that the fundamental mode of vibration was predominant during the earthquake, the maximum relative displacement of the building is estimated as

$$y=\beta u\delta=1.2\times(1.1\sim1.7)=1.3\sim2.0\text{ cm}.$$

Where $\beta$ and $u$ are the participation factor and the normal function, respectively.

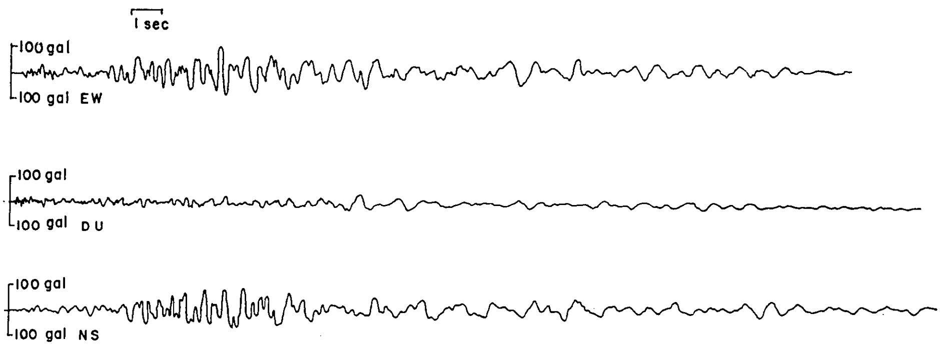


Fig. 2. Accelerogram recorded on the ground in Shimizu city.

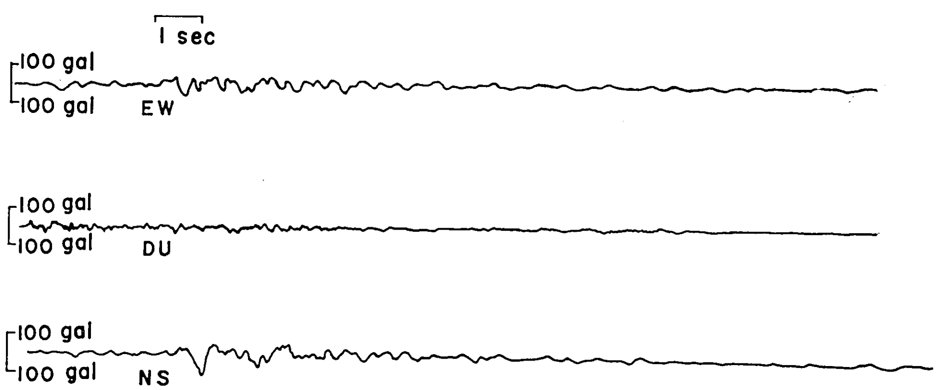


Fig. 3. Accelerogram recorded at the basement of Shizuoka Administration Building of Japanese National Railways in Shizuoka city.

From these values the interstory displacement is obtained by dividing them by the number of stories.

$$\delta_i=(1.3\sim 2.0)/6=0.22\sim 0.33\ \text{cm}\ ,$$

or expressing them by an angle

$$\theta_i=\delta_i/h_i=1/1600\sim 1/1000\ .$$

Where $h_i$=story height of the building in $i$-th story.
The results are shown in Table 2.

## 5. Discussions

From the estimated deflection and the observation of damage, the cause of damage to window glass in each building will be discussed below.
*Shida Hospital*—It can be said from the measured period that the frame of this building is not flexible, and twisting would not easily occur because of well balanced wall arrangement. The estimated displacement is only about 0.5 cm and the damage might have been avoided if a small clearance existed between window glass and steel sash. Actually the putty which fixes the glass in the sash was hardened excessively, and this must be the main reason of the glass failure.
*Shimizu City Hall*—The estimated displacements in the old building are 1.0 to 2.0 cm. This is larger than that in Shida hospital, but still is not large enough to expect such a large percentage of damage in ordinary glass with some clearance between glass and sash. In the new building the estimated displacements are 1.1 to 2.3 cm which are larger than those in the old building, but there was almost no glass damaged by this earthquake. This difference in the degree of damage must be attributed to the difference in the degree of hardening of the putty, because the putty in the new building was observed to be still soft.
*Ihara Middle School*—The estimated displacement is almost the same as that in the Shida hospital. The reason of the glass failure is also attributed to the hardening of putty.
*The Watch tower attatched to Hamamatsu City Hall*—Although there is no measurement of natural period of this building, this towery structure consists of open frame rested on the wall construction, and apparently this part vibrated severely due to whipping phenomenon during the earthquake. The interstory displacement is estimated to be much larger than those of other buildings from the fact that many cracks were found in beams and columns. Damage to window glass would be mainly due

to large interstory displacement rather than to other factors considered in other buildings, but damage to glass in the "fixed", "steel sash" type window is more severe than that to other types of window glass.

Summarizing the above observations and considerations it is concluded that the glass with high percentage of failure has something in common with "steel sash", "fixed" and "hardened putty". This means that because of "fixed" the deformation of structure was directly transmitted to the sash, and because of "steel sash" glass could not encroach into the sash, and because of "hardened putty" there was no clearance between glass and sash. It was considered that the failure occurred because the large amount of interstory displacement due to long natural period caused the large displacement to window glass. However, the period measurement revealed that the buildings did not have a very long natural period, and the estimated story displacements are small except the watch tower in Hamamatsu. It seems that the elastic deformation of the glass itself can be expected to be very little. Although this is suggested in the paper by Meehan and Bouwkamp[2)] more extensive experiments must be carried out.

## Acknowledgments

The authors wish to express their sincere thanks to Professors K. Kanai and H. Umemura for their kind advice, and also to Dr. M. Izumi of the Building Research Institute and R. Kenmochi of the Architectural Department for their kind cooperation in inspecting the damage to window glass. Their thanks are also due to the Port and Harbour Technical Research Institute and the Railway Technical Research Institute for putting their earthquake records at the authors' disposal.

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2) J. G. BOUWKAMP and J. F. MEEHAN, "Drift Limitations Imposed by Glass", *Proceedings of the Second World Conference on Earthquake Engineering* (1960), 1763.

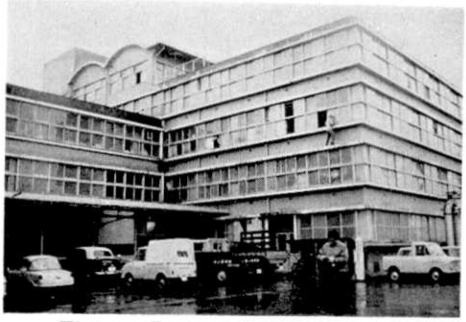

Fig. 4. Broken window glass is being repaired in Shida Hospital. (by courtesy of Mr. M. Shibano)

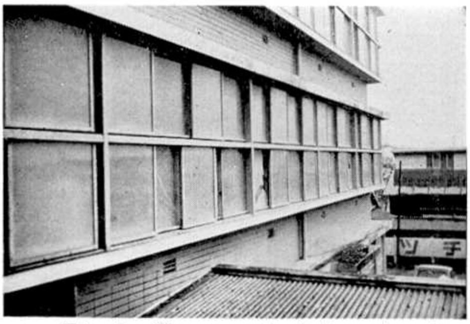

Fig. 5. Close-up of window glass in Shida Hospital. (by courtesy of Mr. M. Shibano)

Fig. 6. Outside view of Shimizu City Hall after repairing the broken glass.

Fig. 7. Front view of old building of Shimizu City Hall. (by courtesy of Mr. M. Shibano)

Fig. 8. Front view of Ihara Middle School in Shimizu City. (by courtesy of Mr. T. Matsuda)

# 52. 1965年4月20日の地震による鉄筋コンクリート建物窓ガラス被害に関する一考察

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昭和40年4月20日静岡県下におこつた地震により2, 3の鉄筋コンクリートビルに窓ガラス被害が生じた．この地震は静岡その他で震度 IV の中程度のもので，木造建物では全壊・半壊ともに皆無，壁のきれつなどの小被害が多少あつた程度で，道路その他の被害も軽微であつた．そこでなぜこの程度の地震で近代ビルの窓ガラスが割れたかを考察してみた．

はじめガラス被害のあつた建物は骨組の柔らかい長周期のもので，地震時大変形をおこしてそれが窓ガラスに伝わり被害をおこしたと考え，建物の微動を測定して周期を求め，同地方の強震計記録を用いて地震応答解析により地震時の最大層間変位を推算した．その結果藤枝と清水にある3つの建物はいずれもそれほど長周期ではなく，層間変位も角度にして最大 1/1000 程度の小さなもので，サッシュまわりにわずかの「逃げ」があれば破損するはずのない量であつた．ただ被害率の大きい窓ガラスはいずれも (1) スティールサッシュ，(2) はめころし，(3) パテが硬化，の共通点があつて「逃げ」がないものであり，これにはずれたものはほとんど被害をうけていない．よつて被害は骨組の大変形によるのではなく微少変形ながら上の3つの条件が重なつて生じたものと考えられる．