6.4 Damage to Steel Gymnasiums

6.4.1 Introduction

The damage to steel buildings such as offices and shops caused by the 2011 Tohoku earthquake in the areas of Ibaraki, Fukushima and Miyagi prefectures with JMA seismic intensity around 6 was investigated for two weeks after the earthquake. Structures of steel buildings are generally covered with exterior cladding and interior finishing. For this reason, the real situations of the damage to columns, beams and braces may not be correctly determined under the visual damage observation. Therefore, the damage investigation on steel gymnasiums whose structural members are generally exposed was considered and conducted. The damage investigation for such steel gymnasiums was carried out in the areas of Ibaraki prefecture with JMA seismic intensity around 6. This section describes the outline of the damage investigation of the steel gymnasiums.

6.4.2 Outline of damage investigation of steel gymnasiums

(1) Outline of damage investigation of high school gymnasiums in Ibaraki prefecture

Gymnasiums designed under the seismic code before June 1981 (hereinafter referred to as previous seismic code) were heavily damaged in the Mid Niigata Prefecture Earthquake in 2004, but most of gymnasiums designed under the current seismic code were not damaged[6.4-1)~6.4-3)]. Consequently, as the subject of the damage investigation, steel gymnasiums constructed under the previous seismic code were mainly chosen. The investigation covered a wide range of areas in Ibaraki prefecture where JMA seismic intensities 5 (+) to 6 (+) were recorded (Ooarai town, Shirosato town, Hitachi city, Mito city, Naka city, Hitachinaka city, Chikusei city, Kasama city, Hokota city, Tsuchiura city, Bando city, Koga city, Shimotsuma city and Joso city). The main purpose of the investigation is to determine what damage pattern was often observed in these areas and in which area the pattern was often distributed. A total of 44 gymnasiums in high schools were chosen and investigated.

(2) Outline of damage investigation of elementary and junior high school gymnasiums in Mito city

In general, building size (total floor area) of high school gymnasiums seems to be larger than the size of elementary and junior high school gymnasiums. In order to know an effect of building size on earthquake damage situation, damage investigation of elementary and junior high school gymnasiums was considered and conducted. The result of the damage investigation for the high school gymnasiums in Ibaraki prefecture showed that the areas around Mito city suffered relatively larger structural damage than other areas. Then, Mito city was chosen as the survey area of the damage investigation for

gymnasiums in elementary and junior high school. A total of 22 gymnasiums in elementary and junior high schools constructed under the previous seismic code in Mito city were investigated.

6.4.3 Results of damage investigation of steel gymnasiums

(1) Results of high school gymnasiums in Ibaraki prefecture

1) Outline of structure of investigated gymnasiums

A total of 44 gymnasiums were investigated in Ibaraki prefecture. The number of gymnasiums constructed under the previous seismic code is 41. There are 4 two-story gymnasiums, and 40 one-story gymnasiums. The number and percentage of structural types of the investigated gymnasiums are shown in Table 6.4-1. In general, the structural types of gymnasiums are classified into 3 classes as shown in Table 6.4-1, but the percentages of the types seem to strongly depend on the regions. For example, in the damage investigation[6.4-1)~3)] of the Mid Niigata Prefecture Earthquake in 2004, the percentage of the mixed structure consists of lower RC frame and upper steel frame was 75%, and the percentage of steel moment-resisting frames was 6%. From table 6.4-1, it is found that the percentage of the mixed structure in Ibaraki prefecture is smaller than Niigata prefecture, and the percentage of steel moment-resisting frames is larger.

Table 6.4-1 Structural types of investigated high school gymnasiums

Mixed structure consist of lower RC frame and upper steel frame		Steel frame structure		RC frame structure having steel roof frame	Unidentified
20(45%)		15(34%)			
Steel brace frame	Steel moment-resisting frame	Steel brace frame	Steel moment-resisting frame		
15(34%)	5(11%)	7(16%)	8(18%)	6(14%)	3(7%)

2) Structural damage

The types of observed structural damage in this investigation include a) buckling and fracture of brace member and fracture of its joint, b) buckling of diagonal member of latticed column, c) damage of connection (bearing support part) between RC column and steel roof, d) deflection, buckling and fracture of roof horizontal brace, and e) cracking of column base concrete. The a) and b) damage types are included as the type of severe structural damage based on the damage evaluation standard of earthquake damaged buildings[6.4-4)]. However, the number of these severe damaged gymnasiums is 2 and 1 corresponding to the damage type a) and b), respectively. Buckling of diagonal member of latticed column is damage to the column in span direction frames, and was not observed under the damage investigation of the Mid Niigata Prefecture Earthquake in 2004[6.4-1)~6.4-3)].

From the results of this investigation, it seemed that structural damage in Mito city, Hokota city and Naka city was relatively larger than in other areas.

3) Nonstructural damage

The types of nonstructural damage observed in this investigation include dropping of ceilings and exterior walls and breakage of windows, etc. In four of the investigated gymnasiums, ceiling materials were extensively dropped, which is classified into the severe damage category based on the damage evaluation standard[6.4-4)]. In five gymnasiums, breakage of many windows was observed.

4) Damage situations of seismic retrofitted buildings

Seismic retrofitting was performed in five of the investigated gymnasiums. One of the five retrofitted gymnasiums was constructed in the area where relatively severe damage was observed. Structural and nonstructural damage of this gymnasium were not observed.

(2) Results of elementary and junior high school gymnasiums in Mito city

1) Outline of structure of investigated gymnasiums

A total of 22 gymnasiums were investigated. 20 of the gymnasiums were constructed under the previous seismic code. All of the investigated gymnasiums are one-story. The structural types of the gymnasiums are shown in Table 6.4-2, as the case of the high school gymnasiums. The percentage of the mixed structure that consists of lower RC frame and upper steel frame is 19%, and the percentage of RC frame structure having steel roof frame is 41%.

Table 6.4-2 Structural types of investigated elementary and junior high school gymnasiums

Mixed structure consist of lower RC frame and upper steel frame		Steel frame structure		RC frame structure having steel roof frame	Unidentified
4(19%)		7(32%)			
Steel brace frame	Steel moment-resisting frame	Steel brace frame	Steel moment-resisting frame		
3(14%)	1(5%)	1(5%)	6(27%)	9(41%)	2(10%)

2) Structural damage

Five types of the structural damage, shown in the result of the investigation of high-school gymnasiums, were also observed in the elementary and junior high school gymnasiums. However, the degree of structural damage in the elementary and junior high school gymnasiums seems to be smaller than in the case of high school gymnasiums.

3) Nonstructural damage

Severe nonstructural damage in which ceiling members were widely dropped, as observed in the investigation for the high school gymnasiums, was not observed in the elementary and junior high school gymnasiums. However, 20 of the gymnasiums suffered some sort of nonstructural damage. The degree of nonstructural damage in the elementary and junior high school gymnasiums seems to be smaller than in the case of high school gymnasiums.

6.4.4 Classification and characteristics of damage to steel gymnasiums

During this earthquake damage investigation, a total of 66 gymnasiums in the high schools within Ibaraki prefecture and in the elementary and junior high schools within Mito city were surveyed. The damage to the gymnasiums was classified into the types of (1) to (7). The types of (1) to (6) and the type of (7) represent structural damage and nonstructural one, respectively.

(1) Buckling and fracture of brace member and fracture of its joint
(2) Buckling of diagonal member of latticed column
(3) Damage of connection (bearing support part) between RC column and steel roof frame
(4) Deflection, buckling and fracture of roof horizontal brace
(5) Cracking of column base concrete
(6) Other (Overturning of floor strut, etc.)
(7) Nonstructural damage such as dropping of ceilings and exterior walls and breakage of windows

Each damage photograph shows each damage type in the following pages.

(1) Buckling and fracture of brace member and fracture of its joint

Buckling of brace member (Photo 6.4-1) and fracture of brace joint (Photos 6.4-2 ~ 6.4-4) were observed. Angle section was often used for many brace members, but circular hollow section steel (Photo 6.4-3) was also used for brace members. Fractured sections include steel plate inserted into steel pipe, end of bracing member and section loss part by bolt hole. These types of the damage are classified into the severe damage category based on the damage evaluation standard[6.4-4)]. The number of the gymnasiums of this type is 3. The gymnasiums constructed under the previous seismic code that had been severely damaged by the Mid Niigata Prefecture Earthquake in 2004 had accounted for about 30% of the total[6.4-1)~6.4-3)]. It is impressed that a rate of the gymnasiums severely damaged by the 2011 Tohoku earthquake was lower than by the Mid Niigata Prefecture Earthquake in 2004.

Photo 6.4-1 Buckling of brace

Photo 6.4-2 Net section fracture at bolt hole

(a) Fracture at column top

(b) Fracture at brace crossing

Photo 6.4-3 Fracture of brace welded connection

Photo 6.4-4 Fracture of bolts

(2) Buckling of diagonal member of latticed column

In one of the investigated gymnasiums, buckling of diagonal members in some latticed columns was observed (Photo 6.4-5). Damage of column buckling caused in steel frames for span direction had not been observed under the damage investigations of the Mid Niigata Prefecture Earthquake in 2004[6.4-1)~6.4-3)].

(a) Latticed column

(b) Buckling of diagonal member

Photo 6.4-5 Buckling of diagonal member of latticed column

(3) Damage of connection (bearing support part) between RC column and steel roof frame

In the investigated gymnasiums, exposure of anchor bolts due to spalling of the concrete at connection (bearing support part) between the RC column and steel roof frame (Photos 6.4-6 and 6.4-7), spalling of finish mortars on the RC column at the roof bearing support part, and pullout of hole-in anchors (Photo 6.4-8) were often observed.

Photo 6.4-6 Spalling of concrete

Photo 6.4-7 Spalling of concrete

Photo 6.4-8 Pullout of hole-in anchors

(4) Deflection, buckling and fracture of roof horizontal brace

Roof horizontal braces were damaged in two high school gymnasiums and five elementary and junior high school gymnasiums. Such damage mainly occurred at horizontal braces with turnbuckles; obvious deflection of the horizontal brace (Photo 6.4-9) and fracture at thread and fracture of bolt connections were observed (Photo 6.4-10).

Photo 6.4-9 Deflection of horizontal braces

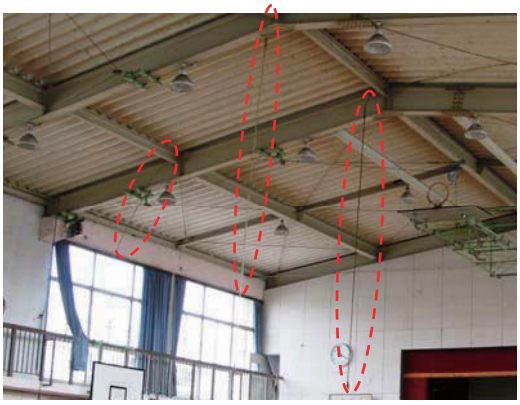

Photo 6.4-10 Fracture of horizontal braces

(5) Cracking of column base concrete

Damage of cracking of the column base concrete and mortar in the gallery of some gymnasiums was observed (Photo 6.4-11). Concrete and mortar of steel column base at a ground level was also cracked (Photo 6.4-12). However, almost all of these cracking are classified into minor or slight damage.

Photo 6.4-11 Cracking of column base concrete

Photo 6.4-12 Cracking of column base concrete

(6) Other (Overturning of floor strut, etc.)

As the other types of the structural damage, the following damage was observed; (a) overturning of floor strut (Photo 6.4-13), (b) tilting of concrete block self-standing wall and (c) peeling of paint of beam members which was observed near the top of the V-shaped roof beams or arch beams (Photos 6.4-14 and 6.4-15). In terms of the peeling of paint, it was uncertain whether yielding of the beams occurred or not.

Photo 6.4-13 Overturning of floor strut

Photo 6.4-14 Peeling of paint of beams

Photo 6.4-15 Peeling of paint of beams

(7) Nonstructural damage such as dropping of ceilings and exterior walls and breakage of windows

The types of nonstructural damage of gymnasiums included dropping of ceilings and lighting equipment (Photos 6.4-16 ~ 6.4-18), breakage of windows (Photo 6.4-19), dropping of exterior walls (Photo 6.4-20), dropping of interior walls and eave soffit (Photo 6.4-21). In particular, the severe damage such as dropping of extensive ceiling in the high school gymnasiums was observed more than in the elementary and junior high school gymnasiums.

Photo 6.4-16 Dropping of extensive ceiling components

Photo 6.4-17 Dropping of extensive ceiling components

Photo 6.4-18 Dropping of extensive ceiling components

Photo 6.4-19 Breakage of windows

Photo 6.4-20 Falling of exterior finish components

Photo 6.4-21 Falling of eave soffit

6.4.5 Conclusions

The damage to the steel gymnasiums constructed under the previous seismic code in the areas with JMA seismic intensity around 6 in Ibaraki prefecture was investigated, and the outline of the investigation was described in this section. The results of the damage investigation of the steel gymnasiums are summarized as follows.

a) Structural damage to the steel gymnasiums

1) The types of observed structural damage to the gymnasiums are classified into the following six categories. (1) Buckling and fracture of brace member and fracture of its joint, (2) Buckling of diagonal member of latticed column, (3) Damage of connection (bearing support part) between RC column and steel roof frame, (4) Deflection, buckling and fracture of roof horizontal brace, (5) Cracking of column base concrete, and (6) Other (overturning of floor strut, etc.).
2) In three among the 66 investigated gymnasiums, severe structural damage such as "fracture of brace member and joint" occurred. This rate of the damage seems to be smaller than that in the Mid Niigata Prefecture Earthquake in 2004.
3) Severe structural damage was observed in Mito city, Hokota city and Naka city than in other areas.

b) Nonstructural damage to the steel gymnasiums

1) The types of observed nonstructural damage include dropping of ceilings, dropping of exterior and interior walls, falling of eave soffit and breakage of windows.
2) In four of the investigated gymnasiums, ceiling materials were extensively dropped, which is classified into the severe damage category. In some of the gymnasiums, many windows were broken.
3) Severe nonstructural damage was observed in Mito city, Hokota city and Hitachi city than in other areas.

4) Severe structural and nonstructural damage seemed to have occurred in the high school gymnasiums rather than in the elementary and junior high school gymnasiums.

References

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6.4-2) Takashi Hasegawa, Akiyoshi Mukai, Kazuo Nishida and Tadashi Ishihara: Damage Investigation of Steel Gymnasiums Due to the Niigataken-chuetsu Earthquake (Part1 Study on structural damage), Summaries of Technical Papers of Annual Meeting, AIJ, B-2, pp.569-570, September, 2005 (in Japanese)

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