The 3rd International Conference on

COMPSAFE2020

Computational Engineering and Science for Safety and Environmental Problems

8th-11th December 2020, Kobe, Japan

Virtual Conference

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Elasto-plastic collapse analysis of steel building frames modeled with solid elements

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Under the current Building Standards Law, it is stipulated that the stress level of each member and interlayer story drift angle of each story of the building should be set below the reference value, and the horizontal load bearing capacity should be set above the reference value. Since seismic motion does not always occur on the assumed scale, it is desirable to verify in advance on which member the load is concentrated due to the seismic motion exceeding the expected value. The author's research group[1] has developed a detailed finite element analysis system (E-Simulator) that can reproduce the damage and collapse processes of buildings and civil engineering structures during earthquakes. E-Simulator faithfully reproduces and models the 3D shape of the target structure using solid elements. The use of E-Simulator for evaluation of seismic performance of building structures and structural design is an important research subject.

In this study, we conduct elasto-plastic collapse analyses of a steel building frame using E-Simulator. Then the results are compared with results from conventional method based on beam elements. The target structure is a five-story steel building which has been designed according to the current codes and standards. Using the pre-processer developed by authors (E-Modeler)[2], the target structure is discretized with hexahedral solid elements. Incremental loading analysis will be performed for the static earthquake force of medium-scale, large-scale and surpassing-scale earthquake force, and the conventional analysis results will be compared with the analysis results using E-Simulator.

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Behavior of air conditioning ducts during earthquakes using a detailed FEM simulation

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Abstract. The purpose of this study is to clarify the behavior of an air conditioning duct installed in a clean room during earthquakes by a detailed simulation. The detailed simulations here are performed after modeling the actual dimensions, joints, and material strength.

1. Introduction

Seismic resistance is usually qualitatively considered when installing ducts. However, the details of the dynamic behavior during an actual earthquake are not known like the building structure[1]. Factory cleanroom equipment often has large amounts of air supply and exhaust, and the ducts are often large. In some cases, the routes of the ducts do not have a linear arrangement in order to avoid interference with building structures. In these cases, we use a curved duct for these sections (Fig. 1). It is not difficult to imagine that the influence of the load on the support members during an earthquake is not uniform.

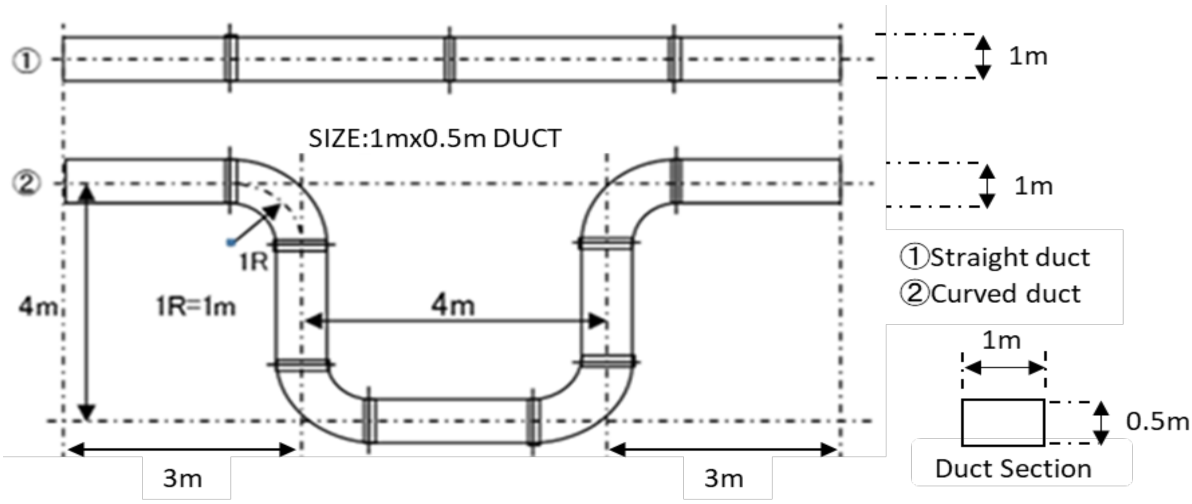

Fig. 1 Reference duct image diagram

The ducts installed in the clean rooms are large and heavy. Generally, there is enough space in the ceiling, and the supports tend to be long. By simulating the behavior of the duct in the ceiling during an earthquake, it is possible to confirm in detail the current earthquake-resistant construction methods and the behavior of the ducts that are earthquake-resistant supported during the earthquake.

We visualize not only the deformation of the duct during an earthquake but also the stress, and both the force and the deformation occurring during an earthquake.

2. Simulation software used for analysis

The nonlinear response FEM software “LS-DYNA” Ver.R11[2][3] was used for the seismic response analysis. This software is widely used in impact simulation and has excellent suitability for calculating large deformation behavior, fracture behavior, and contact problems. A supercomputer owned by University of Hyogo was used for the calculation.

3. Duct model used for analysis

As a research model this time, a duct with a bent portion is adopted. It is common for the duct to have a bend on the duct route in order to install it away from other buildings and equipment. The steel material is fixed by a suspension member from the upper part, and the duct is placed on the steel material, which is the normal construction method. This model is created using existing duct construction drawings (Fig. 2).

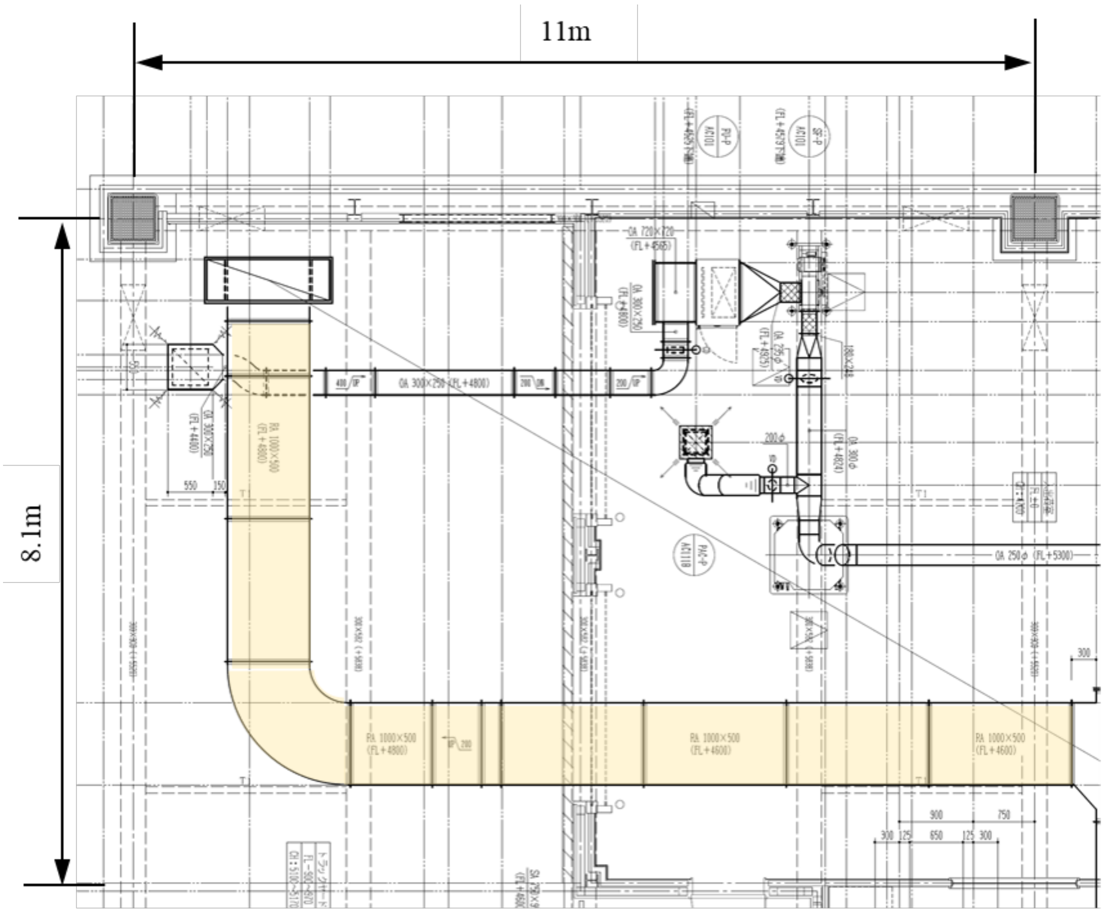

Fig. 2　Existing duct construction drawings

4. An Example of dynamic analisys

The Ojiya seismic wave is adopted as the seismic wave (Fig. 3).

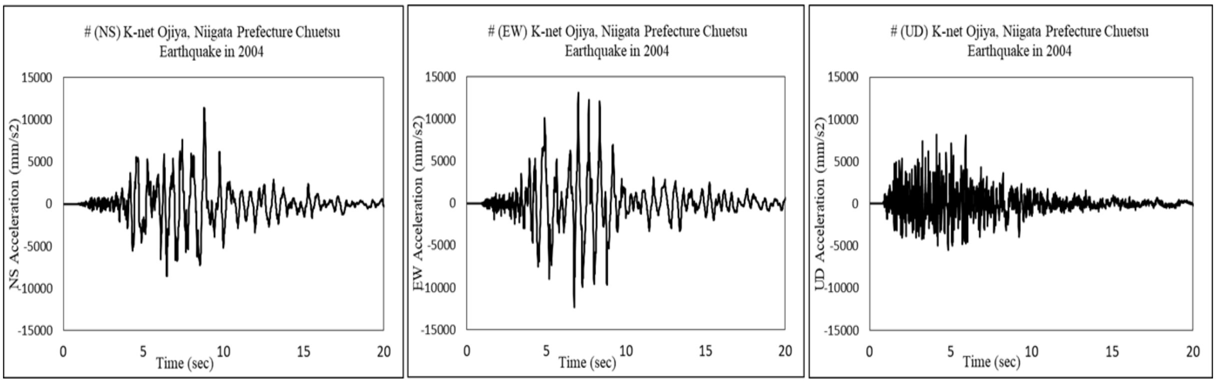

Fig. 3 Ojiya seismic wave

5. Overview of the simulation model

The simulation model uses the duct shown in Fig. 3. The setting values of the model are described below.

Duct size 1,000mmHeight×500mmWidth, Thickness 0.8mm, FL+4600mm-4800mm, Common board clip joint Building floor height H = 6600 mm Ceiling height = 2700 mm

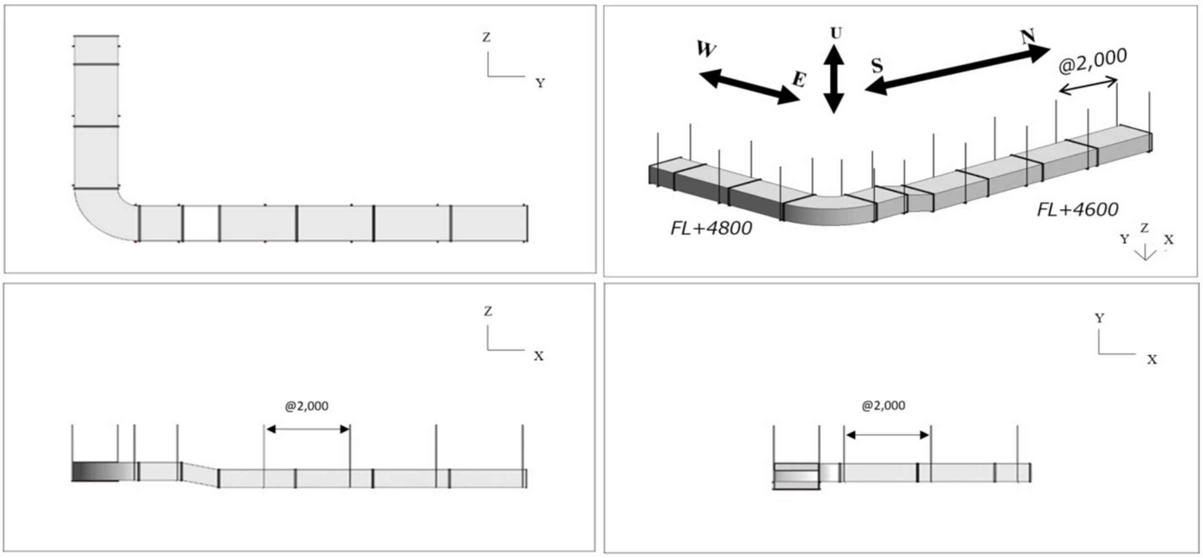

Fig. 4 FE Model Overview

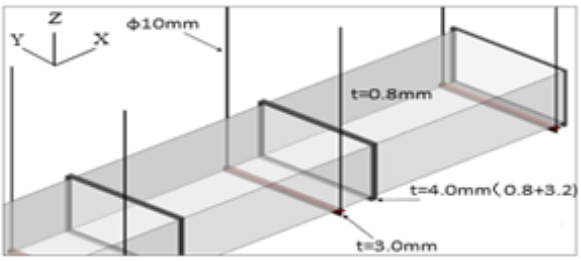

Fig. 5 Common plate flange clip fixing model

All ducts materials assume Mild Steel. The clip part uses *CONSTRAINED_NODAL_ _RIGID_BODY to restrain the nodes facing each other. Each plate is defined only for surface contact (coefficient of friction is 0.2), only the clip part is joined (Fig. 5).

The direction of the duct shown in Fig. 4 will be described. The duct W end and the duct W direction are fixed. Conversion to NS and UD directions is possible. The N-terminus of the duct is not fixed. The top of the hanging bolt is completely fixed.

6. Simulation result by FE model

In Fig. 6, the stress distribution applied to the duct model due to seismic motion was confirmed. In Fig. 7, it can be confirmed that the duct is separated from the support member due to seismic motion. In Fig. 8, the buckling status of the bending duct can be confirmed. In Fig. 9, it can be confirmed that the support members are displaced due to the earthquake motion.

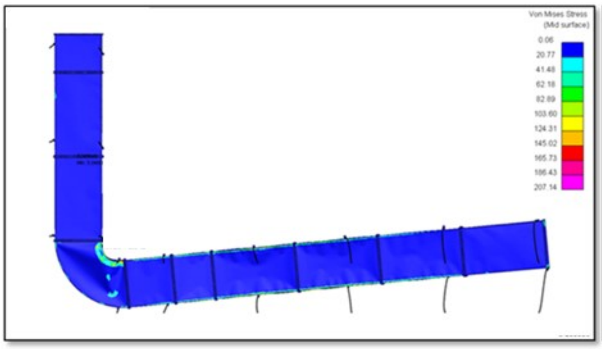

Fig. 6 VM Stress distribution

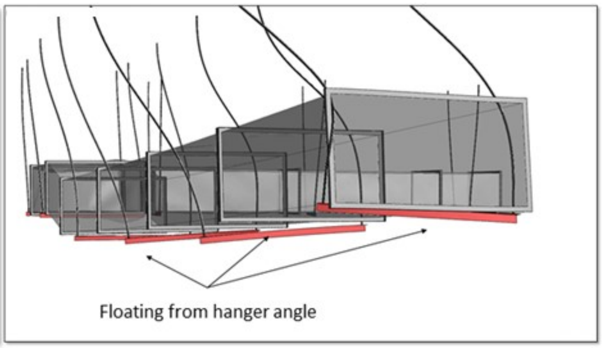

Fig. 7 Lifting from the hanger angle

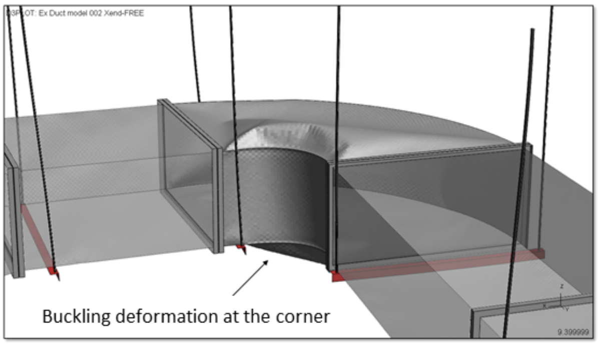

Fig. 8 Buckling deformation state of corners

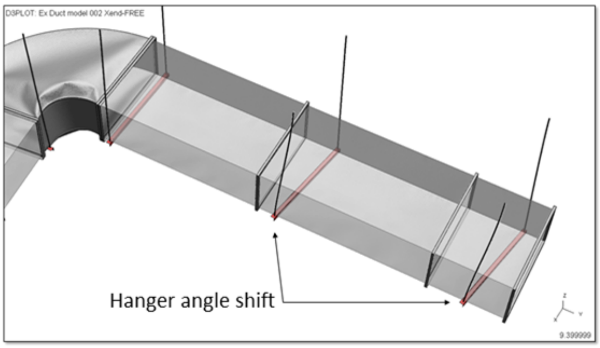

Fig. 9 Hanger angle misalignment

7. Conclusion

Since the duct is installed in the ceiling and cannot be seen, its behavior during an earthquake is unknown. Through this simulation, we were able to visualize the behavior of the duct during an earthquake and the damage estimation by animation.

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Seismic response analysis of a ceiling using a reinforcement member corresponding to a large duct route

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1. Introduction

The clean room air passes through the air conditioning ducts and intermittently through high performance filters to maintain the cleanliness. Therefore, in order to maintain the cleanliness of a clean room, it is most important to plan the air conditioning ducts first. However, in the current clean room design, the ducts are bypassed due to interference between the ceiling reinforcement members and the duct routes, because the seismic components are planned before the equipment. The ducts are bypassed, which may cause thermal efficiency and cost loss, as well as combustion accidents, so a new in-ceiling reinforcing member that facilitates the securing of large duct routes (called "new proposed reinforcement") has been proposed [1].

The purpose of this study is to evaluate, through examples, both the seismic performance and the cost of using the new Proposed Reinforcement for the entire ceiling and the conventional reinforcement for the entire ceiling.

2. Time Response Analysis of a Ceiling with Reinforced Members

First, the arrangement of reinforcement members is set up. The assumed architecture is a rectangular clean room of 24m × 18m and the ceiling dimensions are 150cm [2]. For this clean room, either conventional or new proposed reinforcement is used for the ceiling. In the normal specification [3], about three conventional reinforcements are used in a 30 m^2 room, but since one reinforcement is sufficient to satisfy the rigidity of the room, one conventional reinforcement is used to support about 30 m^2 in this case. The area supported by the in-ceiling reinforcement is assumed to be 28.8 m^2 (3.2 m × 9.0 m), which is one grid. The model of the in-ceiling reinforcement is shown in Figure 1 and the arrangement of the in-ceiling reinforcement members is shown in Figure 2.

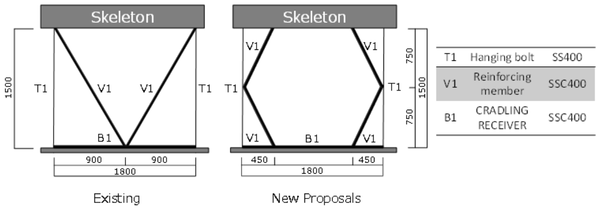

Figure 1 The model of the in-ceiling reinforcement

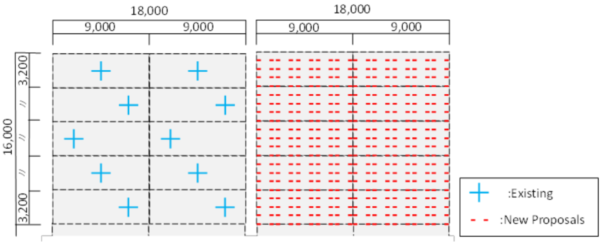

Figure 2 The arrangement of the in-ceiling reinforcement

The stiffness was calculated using the quotient of the horizontal load of 1.0 kN divided by the load displacement [2]. The single mass model of the ceiling is shown in Figure 3, and their ceiling pocket size, area, weight and stiffness are also shown in Table 1. The weight was calculated using a unit area mass of 20 kg/m^2.

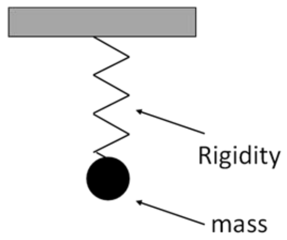

Figure 3 One-quality point system model

Table 1 Conditions for setting the ceiling

	Existing type	New Proposals	
Ceiling pocket	150		cm
Support area	3.2×9.0		m2
Weight	5.64		kN
Rigidity	90.9	1.72	kN/cm
Number of parts	1	20~25	pcs

This time history response analysis is performed using a general-purpose elastic-plastic seismic response analysis program (Dynamic Pro ver.7.15). The EL CENTRO (1940) NS and JMA Kobe (1995) NS, which are short-period seismic waves of inland seismic waves, and an expected Nankai Earthquake which will be a long-period seismic wave of trench-type seismic waves, were used in the analysis.

The maximum inter-story displacement of the EL CENTOR (1940) NS is about 0.08 cm for one conventional reinforcement, about 0.16 cm for 20 new proposed reinforcements, and about 0.10 cm for 25 new proposed reinforcements. The results of the seismic analysis confirmed that the dense installation of the new proposed reinforcement would reduce the displacement close to that of the conventional reinforcement. Figure 4 shows the maximum interlayer displacement on the vertical axis and the results of the time history response analysis with one conventional reinforcement and 20 to 25 new proposed reinforcements on the horizontal axis.

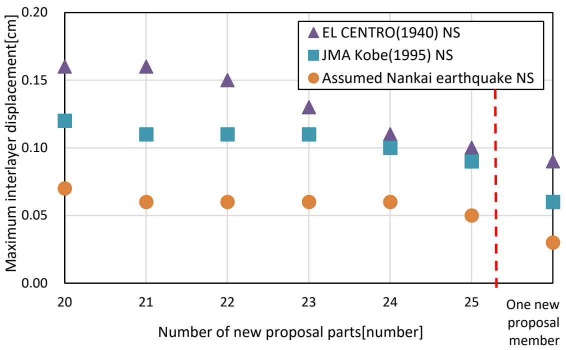

Figure 4 Relationship between maximum interlayer displacement and reinforcement methods

3. An examination of costs

To verify the cost, an example is set up. The cross section of the air-conditioning duct is 1,000 mm × 1,000 mm. It is assumed that the duct is surrounded by a heat insulator with a thickness of 50 mm. Two duct models with a linear equivalent distance of 10 m are made. The model-01 is a straight pipe duct route with 25 new proposed reinforcements, and the model-02 is a duct route with an elbow duct to bypass one conventional reinforcement. The assumed duct route is shown in Figure 5.

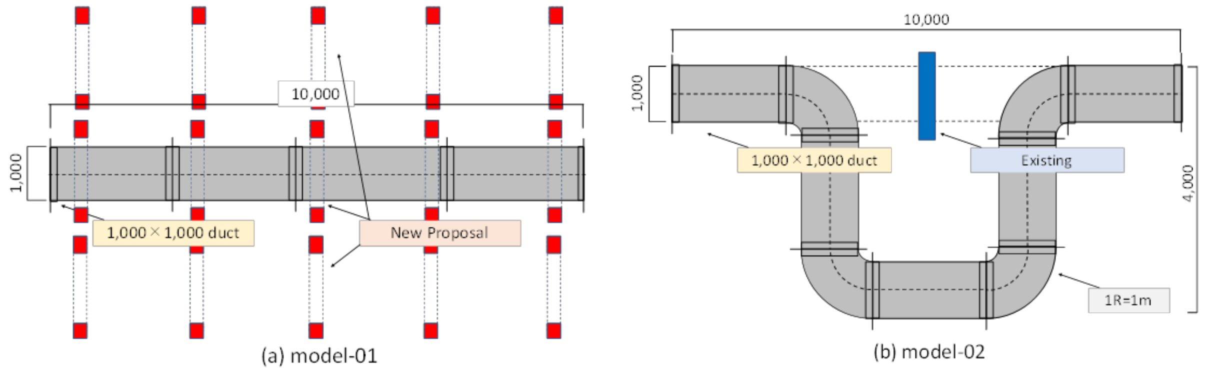

Figure 5 The assumed duct model

The unit price of the ducts is a combined unit price of 3,420 yen/m^2, and the insulation work is to cover the glass-wool ceiling, and the unit price is 5,750 yen/m^2. 31,200 yen for the duct suspension steel of model-01, and 15,000 yen for transportation and other costs. In addition, the price of the duct suspension steel in model-02 is 56,200 yen, and the transportation costs etc. are estimated to be 28,560 yen. The ductwork cost is the sum of these costs. The price of the ceiling reinforcement members is 100,000 yen per piece for the new proposed reinforcement and the conventional reinforcement, including material costs, construction costs, and miscellaneous expenses. The initial cost was the sum of the cost of ductwork and the price of the ceiling reinforcement member. The resistance of model-01 and model-02 are set at 100 Pa and 540 Pa, respectively [1]. When the expected power consumption is obtained from the fan selection graph [4], the power consumption of model-01 is 5.5kw/h and that of model-02 is 15kw/h. When considering the ducts assumed this time, it becomes 1/10, and model-01 becomes 0.55kw/h and model-02 becomes 1.50kw/h. The electricity charge is 15 yen/kw・h. The power charge is assumed to be 15 yen/kw・h. The assumed cost is shown in Table 2.

Table 2 The assumed cost

		Duct[/㎡]	Hanging[/㎡]	Area[㎡]	Duct Prices	Hanging	Charges	Reinforecements	Initial cost	Running cost[/month]
model01	yen	3,420	5,750	40	366,800	31,200	15,000	2,500,000	2,913,000	5,940
model02	yen			72	660,240	56,200	28,560	100,000	845,000	16,200

As a result of the cost calculation, the difference of the initial cost is 2,068,000 yen in the assumed example, therefore, model-02 is more cost-effective when the operation period is less than 201 months. On the other hand, the total cost of model-01 becomes cheaper when the clean room operation period exceeds 202 months. Figure 6 shows the calculation results of model-01 and 02 for the assumed duct route, with total cost on the vertical axis and operating time on the horizontal axis.

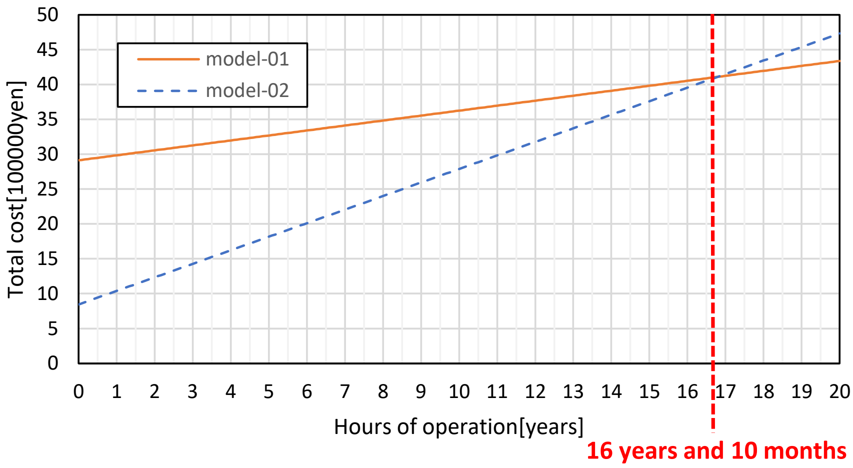

Figure 6 The relationship between cost and duct models

4. Conclusion

In this study, both the seismic performance and cost of the proposed new and conventional reinforcement were evaluated in terms of both cases. The results of the time response analysis showed that the dense installation of the new reinforcement was able to reduce the displacement close to that of the conventional reinforcement. As a result of the cost evaluation, it was found that the total cost of the new proposed reinforcement model-01 is lower than that of the conventional reinforcement model-02 when the expected operating period of the industrial clean room is more than 16 years and 10 months. Hence, when the operating period of the clean room is longer, the total cost of the ducts with the proposed new reinforcement tends to be cheaper than the ducts with the conventional reinforcement, which has better air conditioning efficiency.

By using the new reinforcement, not only can the total cost be reduced during long-term operation, but also the initial cost of the air blowing fan can be reduced due to lower power consumption. In addition, it is possible to reduce the risk of combustion accidents by adopting a linear duct design. In the future, since the initial cost is higher than that of the conventional reinforcement, we will aim to reduce the initial cost by improving the shape of the new proposed reinforcement to improve its rigidity and changing the materials used.

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Evaluation of seismic resistance on new ultra-lightweight suspended ceilings from the steel beams of the roof

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In recent years, large-scale earthquake disasters have occurred frequently, causing human damage due to the collapse of ceilings. In 2014, the seismic standard of the Ministry of Land, Infrastructure, Transport and Tourism Notification No. 771 was presented, and the ceiling that could cause a serious disaster at the time of fall was designated as "specific ceiling". In addition, many facilities that have a corresponding ceiling are designated as evacuation sites in the event of a disaster, and countermeasures against them are important.

The purpose of this research is to pursue the seismic resistance of the new ultra-lightweight earthquake-resistant system ceiling during a large earthquake.

Traditionally, the main building material of the steel roof purlin has been used as a ceiling suspension source. Although the self-weight of the ceiling is taken into consideration in the design, sufficient consideration has not been given to the bearing capacity when installing braces that resist seismic forces. The ultra-lightweight new earthquake-resistant system ceiling is extremely lightweight, with the weight of the ceiling surface components being less than 2 kg/m^2. Therefore, by strengthening the ceiling suspension part where the purlin and brace are installed, it can be expected to have strength for receiving horizontal force during an earthquake. When the suspended ceiling and braces are installed on the main building material of this steel-framed roof, the static strength test results of the main building material, the reinforced joint metal parts, and the detailed FEM analysis are compared. Then the earthquake response analysis is applied to the ceiling. It is then possible to determine the proper arrangement of the brace material that can withstand the horizontal force.

In the future, the ultra-lightweight new earthquake-resistant system ceiling suspended from the main building material of the steel-framed roof will not collapse even in the event of a large earthquake and can be provided as a safe and secure evacuation space.

1. Overview of ultra-lightweight new seismic system ceiling

As shown in Fig. 1, the ceiling of the ultra-lightweight new seismic system consists of aluminum frames suspended by hanging bolts assembled in a grid pattern of 1000 mm x 1500 mm, and a lightweight decorative glass wool panel is installed. The weight of the ceiling surface components is less than 2 kg / m^2. C-100 x 50 x 20 x t2.3 steel material supports the roof at a pitch of about 606 mm as a roof purlin material for the S roof base. It is common to use the roof purlin material as a hanging source for the ceiling. Fig.1.2 shows the shape of the suspended ceiling when a brace material that supports the horizontal force applied during an earthquake is installed and the shape of each joint hardware.

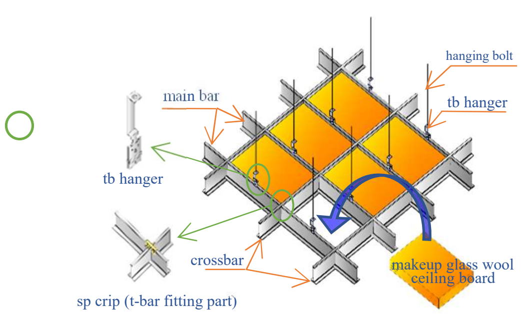


Fig. 1 Overview

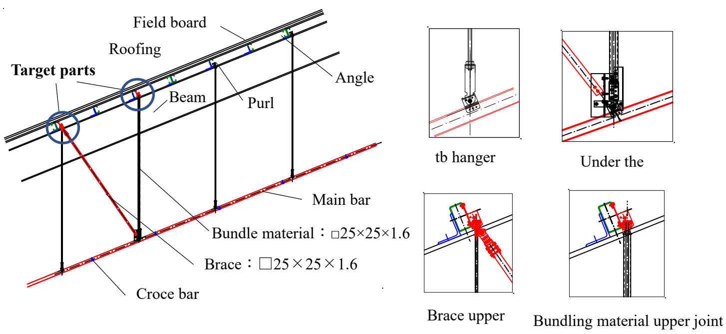


Fig. 2 Cross Section

Although the roof purlin material has been studied for the wind pressure resistance applied to the roof surface, it is permissible to suspend the ceiling from there, but regarding the installation of brace material that supports the horizontal force applied to the ceiling surface during an earthquake. It has been considered impossible. Ultra-lightweight new seismic system Ceiling has a ceiling surface component weight of 2 kg / m^2 or less, so the value of horizontal force applied to the ceiling surface during an earthquake is small, so it may be possible to support even if brace material is installed on the roof purlin material.

2. Strength test of reinforced joint hardware that also reinforces roof purlin materials

The shape is shown in Fig. 3, and the result of the test piece with the lowest value among the strength tests of the same hardware is shown in Fig. 4.

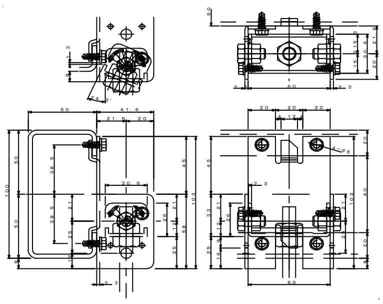


Fig. 3 Purlin reinforcement hanging bracket

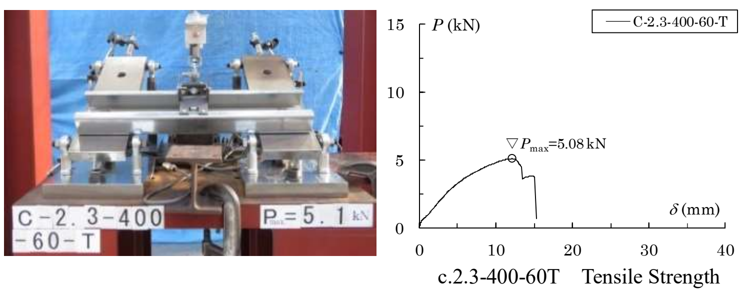
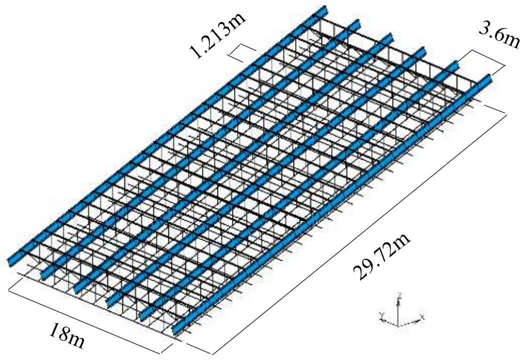


Fig. 4 Part of the strength test result

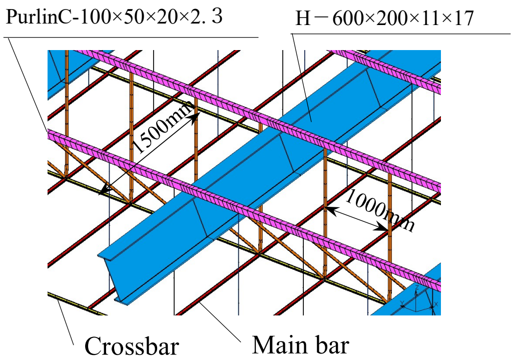
From this result, it was confirmed that the reinforcing joint hardware has sufficient strength. This makes it possible to support the shaking of the ceiling surface during an earthquake if seismic brace materials are installed at appropriate intervals.

3. Deformation due to the mounting position of the brace material and bundle material of the steel roof base main building

However, the roof purlin material is installed on the steel beam at a large interval. It is conceivable that the transmission of the bearing force will differ greatly depending on the position where the brace material that supports the normal force is attached. Here, Fig. 5 shows an analysis model when the distance between the roof purlin materials supported by the beams is assumed to be 3600 mm, and the analysis was performed in consideration of the deformation of the roof purlin material.



(a) Overall shape 18m x 29.72m Beam pitch 3.6m Purlin pitch 1.213m



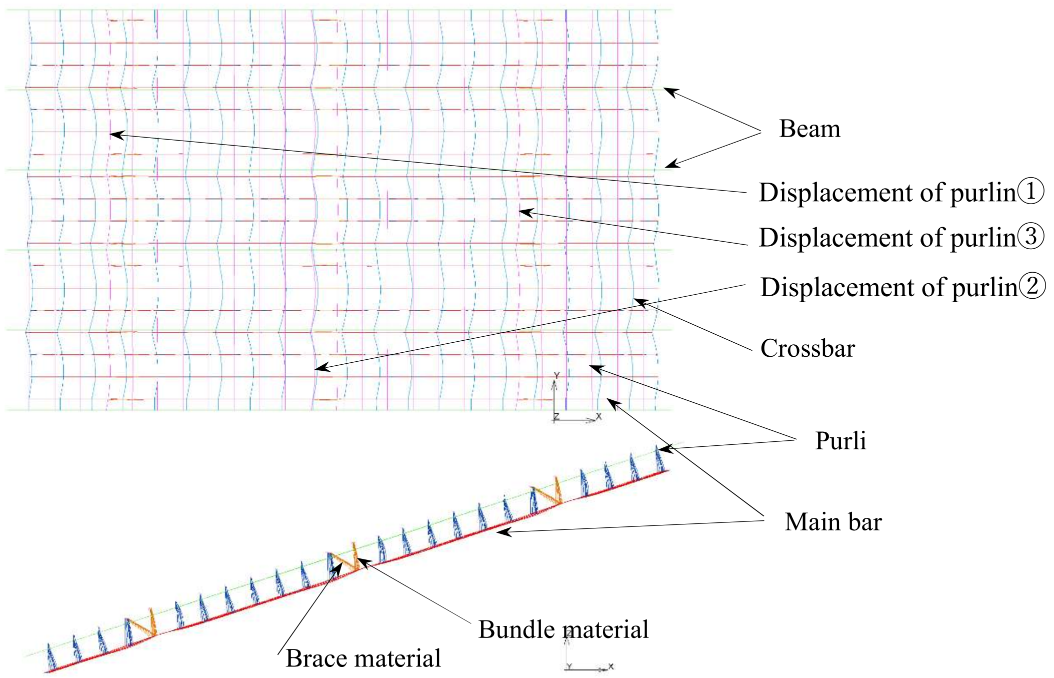
(b) Lattice dimensions 1000mm x 1,500mm details

Fig. 5 Analysis model

4. Analysis result

Deformation of the roof purlin material that receives the horizontal force of the ceiling during an earthquake through the brace material and bundle material changes in a complicated manner depending on the installation position (distance from the beam) with the brace material, the number and the interval. As a result of several types of analysis, such as 2 places at both ends in the length direction of the ceiling surface (29.72 m), 2 places evenly divided, and 3 places in the same way, brace material was used to suppress deformation of the roof purlin material. Good results were obtained with an analysis model installed at approximately 9.6 m[3] locations in the length direction at approximately equal intervals.

Fig. 6 shows the horizontal (X-axis positive) acceleration assuming a large earthquake and the deformation status at the time of applying up to 3.67G.（The deformation is shown magnified 10 times.) The main bar is not buckled, and the horizontal force and horizontal displacement acting on the node at the lower end of the brace are almost equal at three points. At this time, the horizontal displacement of the roof purlin material that receives the most horizontal force is 20 mm or less.



Purlin① : Dx=19.2mm Purlin② : Dx= 19.7mm Purlin③ : Dx= 18.7mm

Fig. 6 Deformation status when horizontal acceleration is applied up to 3.67G

Next, Fig. 7 shows the moment distribution generated in the roof purlin material to which the central brace is attached, which was obtained by the same analysis model. The numbers show the maximum values for each span, but the difference between roof purlin materials is small and the distribution is even.

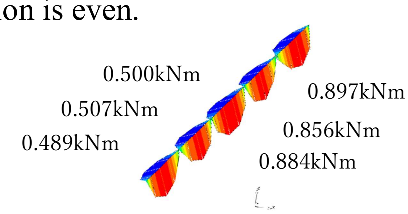


Fig.7 Bending moment distribution of purlin

5. Conclusion

Even if the suspension source of the ultra-lightweight new seismic system ceiling is the S roof main building material, the brace material and bundle material that support the horizontal force applied to the ceiling surface during an earthquake are reinforced with metal fittings at appropriate positions. By installing it in, it is possible to prevent the ceiling from collapsing in the event of an earthquake. As a result, it is possible to provide safe and secure ceilings to many facilities such as S gymnasiums such as schools, martial arts halls, and community halls that are used as evacuation centers in various places.

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Advances in Computational Design Techno-Press Vol,4/No,4/October2019
Tests of integrated ceillings and the construction of simulation models (P381-P395)

Earthquake simulation of the urban model by earthquake response analysis based on structural calculation document

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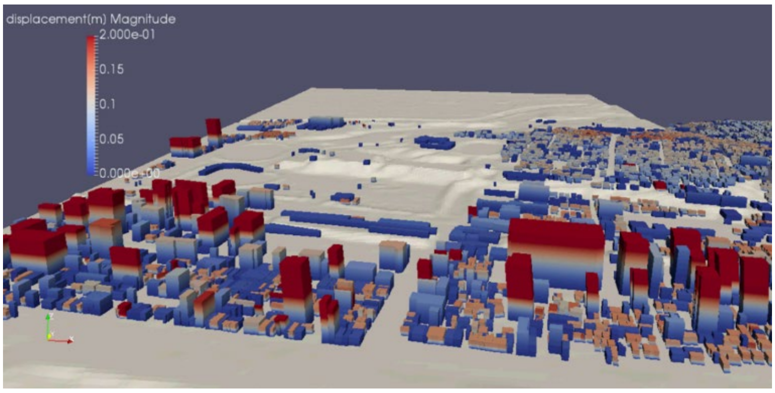
1. Background and purpose

IES[1] (Integrated Earthquake Simulator) is an earthquake simulator of the urban model, and an earthquake response analysis by the MDOF (Multi Degree of Freedom) model is possible in it. As one example, Fig. 1 shows visualization of the result of earthquake response analysis in the area around Akashi Station in using IES.



*(Attention)
In case of the larger displacement of the building model by earthquake response analysis, it is visualized in red color.

Fig.1 Visualization of analysis result in the area around Akashi Station in using IES

IES information of structural type, number of floors, build time, and building area are accurate, but floor height, building weight, and story stiffness are not accurate because of being assumed based on a defined calculation. Thats why, it cannot be said that IES reflects actual building-specific information and analysis result. In this study, we focused on structural calculation document etc. carried out surveys and studied it for the purpose of advance improving the urban model.

2. Approach to building-specific information by structural calculation document[2]

Originally, it is desirable for building-specific information to utilize BIM in point of view from digital data network, but it is difficult in BIMs current situation. Therefore, we focused on the structural calculation document as a practical method. Structural calculation document is a paper document that we can confirm the structural safety, and it had possibility to get more actual building-specific information than one assumed by IES.

In this study, we decided steel structure buildings in Hyogo Prefecture as the target, and got browsing permission by Hyogo Prefecture Office. There was 8876 buildings data in public property, and 2503 were constructed with steel structure. Then we listed 16 buildings with 3 or more floors in them. Finally, we could succeed to get 5 buildings structural calculation document with officers' cooperation.

3. Comparison of building-specific information in structural calculation document and assumed one by IES

Table 1 shows the main building-specific information described in the structural calculation document. We compared floor height, layer weight, and story stiffness which is important factor between in the structural calculation document and one assumed by IES.

Table 1 Main building-specific information described in structural calculation document

・Calculation condition
・Number of floor
・Floor height
・Layer weight
・Layer shear force
・Interlayer displacement (interlayer displacement due to layer shear force)

(1) Floor height

In case of IES, floor height is simply assumed by dividing building height by number of floors. But floor height information in the structural calculation document is more exactly. We do not have to evaluate which is exactly, but their difference was not so big.

(2) Layer weight

In case of IES layer weight is calculated by multiplication of unit area weight (8kN / m^2, fixed value) with building area. But we can know the accurate layer weight by structural calculation document directly. Fig. 2 shows comparison of layer weight between assumed values by IES and building-specific information of structural calculation document. It was confirmed that there was large variation and difference between building-specific information of structural calculation document and assumed value by IES.

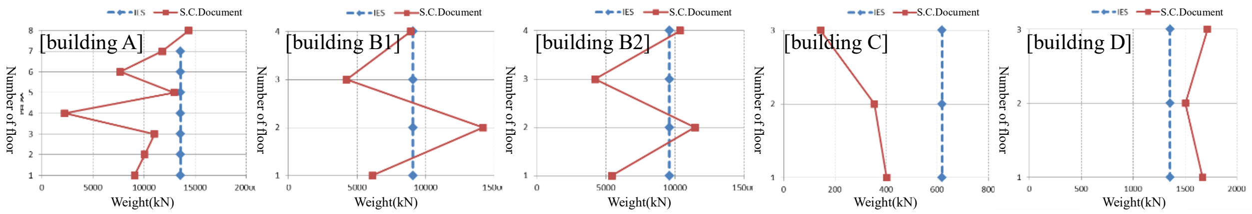


Fig.2 Comparison of layer weight between IES and structural calculation document

(3) Story stiffness

In case of IES, each story stiffness is calculated with ratio to story stiffness of the first floor. In the case of structural calculation document, since layer shear force and interlayer displacement are described, story stiffness of each floor can be easily calculated (story stiffness = layer shear force / interlayer displacement). Fig.3 shows a comparison of story stiffness between assumed value of IES and building-specific information of the structural calculation document. There is a large difference between them.

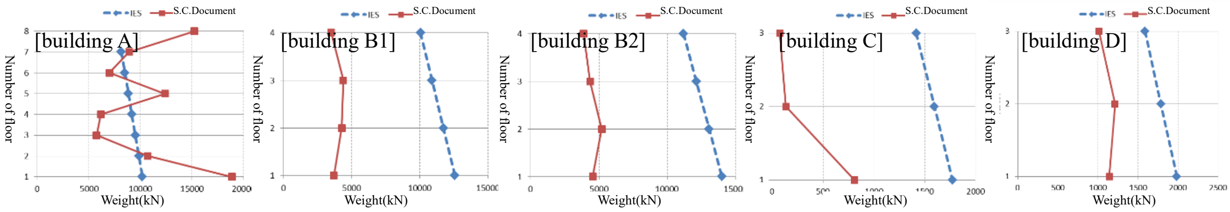


Fig.3 Comparison of story stiffness between IES and structural calculation document

4. Comparison of earthquake response analysis results of assumed values by IES and analysis by building-specific information of the structural calculation document

We created "IES' earthquake simulation model" and "structural calculation document's earthquake simulation model" by each parameter, and performed earthquake response analysis with Dynamic PRO Ver.7.14. EL Centro 1940 NS was used as the input earthquake wave. Maximum acceleration of this earthquake wave is 341.7 cm/s2, maximum velocity is 33.4 cm/s, duration is 53.76 seconds, and number of data is 2688. We adjusted the maximum velocity of this earthquake wave to 50 cm/s, and performed time history earthquake response analysis.

Fig.4 shows comparison of the maximum interlayer displacement angle and the maximum layer shear force in building A as one sample. In the maximum interlayer deformation angle, the IES assumed value model was smaller than structural calculation sheet model. In the maximum layer shear force, assumed value model by IES was larger than the structural calculation sheet model in building A.

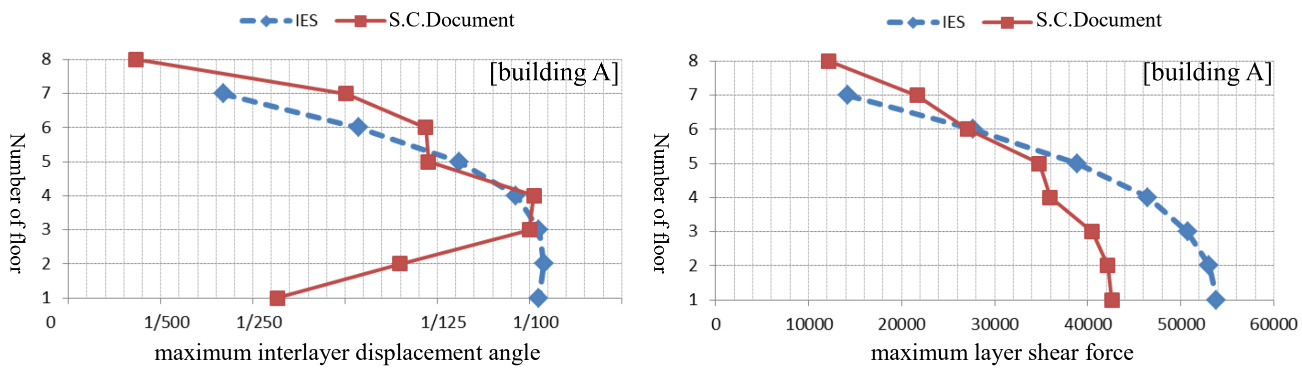


Fig.4 Comparison of analysis result between IES and structural calculation document

5. Expansion to building under construction in IES

(1) Some other points for the purpose of advance improving the urban model in IES

Earthquake response analysis based on structural calculation document is useful for advance improving the urban model in IES. However there are some other points for the purpose of advance improving the urban model in IES. General modeling method of special structures and modeling to target for buildings under construction is some of them.

Special structures mean seismic isolation structure, skyscraper structure, damper structure, pilotis structure, atrium structure, expansion structure and mezzanine floor structure etc. They are not assumed in IES. Mr. Yoshioka proposed a calculation method in seismic isolation structure with the information based on building performance evaluation sheet[3].

And IES targets to not buildings under construction but buildings after completed construction. However, to protect human life and property are required in both the building under construction and the building after completed construction. The urban model should include building under construction based on this concept.

(2) Expansion to building under construction in IES

The building construction takes more than half one year to two years from the start of construction to the completion of the building. The building model under construction changes in time. Mr. Ushio studied the earthquake response of various models in a building under construction[4].

If we can show the modeling methods in each case of installation of steel elements in detail and reflect to IES, it may called the ultimate advance improving the urban model. Fig.5 shows the construction stages and the steps of installation of steel elements. We will be able to make models in each stage and step in detail.

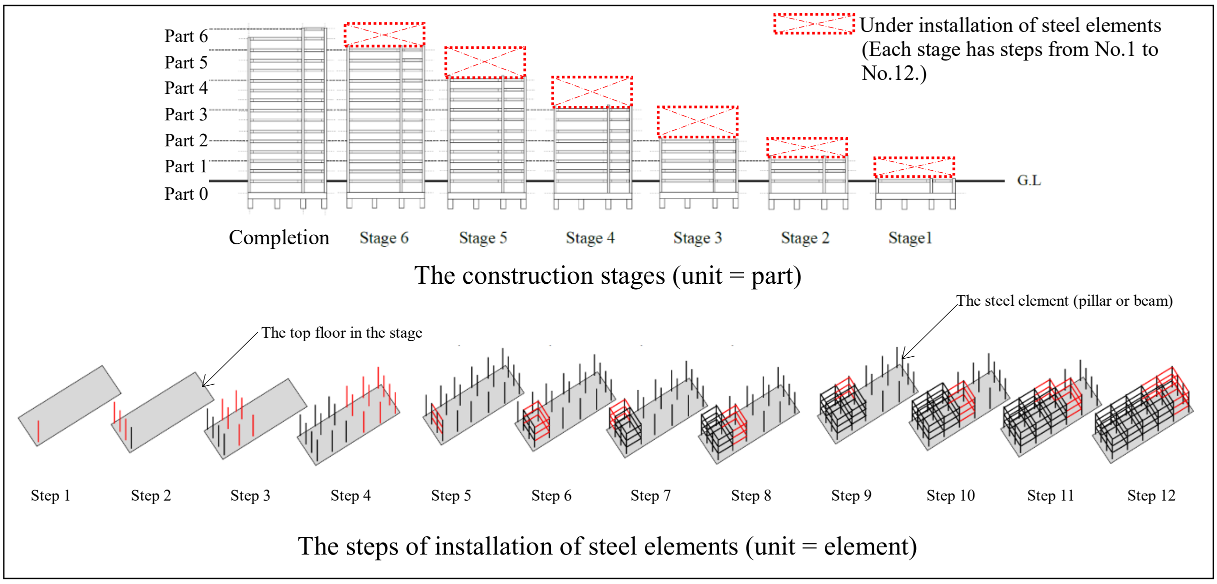


Fig.5 The stages and steps of installation of steel elements

6. Conclusion

In this study, for the building model group constructed by assumed value by IES, the modeling method of the building group according to the reality by using the structural calculation sheet was shown.

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Prediction of collapse during earthquake considering the condition of concrete block walls

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1. Background and purpose

The northern Osaka earthquake that occurred in June 2018 is classified between medium and large scale [1]. Therefore, the problems that were overlooked in the big earthquake were highlighted by the accident. That is a child fatal accident caused by the collapse of a concrete block wall. From this, a collapse simulation of a concrete block walls ware performed [2]. In last year's model, the analysis was performed considering the presence or absence of rebar arrangement. As a result, it did not collapse in a small earthquake even without reinforcement. This suggested that there are concrete block walls that did not collapse in the small earthquake and could be dangerous. In this paper, we made a detailed model and simulated the collapse of the concrete block wall by pushover analysis, and clarified the key part of the earthquake resistance of the concrete block walls.

2. FEM Model

We created a model of a concrete block wall using the impact / structural analysis software LS-DYNA[3]. Fig1 shows the model diagram of this time. This model is a finite element analysis model. This time, the model was detailed and examined for "length of vertical rebar, cross-sectional defects due to corrosion of rebar, and mortar filling rate". In this model, the external dimensions of each

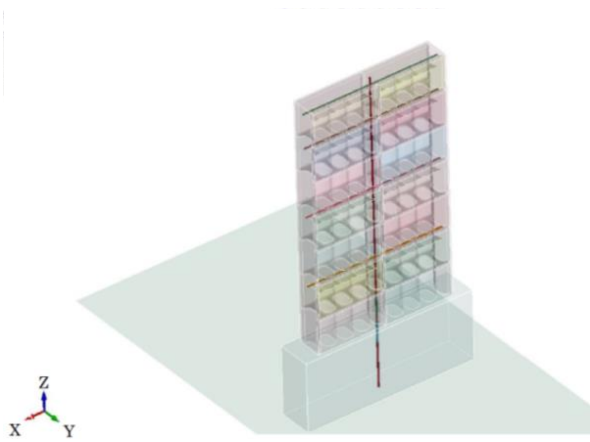


Fig. 1 model diagram

Table 1 Calculation result

level	standard	rebar length1	rebar length2	rebar length3	corrosion1	corrosion2	corrosion3	mortar1	mortar2	mortar3
rebar length (mm)	400	100	200	300	400	400	400	400	400	400
rebar diameter (mm)	9.530	9.530	9.530	9.530	2.383	4.765	7.148	9.530	9.530	9.530
Adhesive stress (N/mm^2)	4.903	4.903	4.903	4.903	4.903	4.903	4.903	1.226	2.452	3.677
Fall start time	0.34	0.36	0.32	0.34	0.26	0.28	0.30	0.30	0.32	0.32
load (%)	0.7252	0.8365	0.6200	0.7252	0.3414	0.4299	0.5214	0.5214	0.6200	0.7252
result	Break	Pull out	Break	Break	Break	Break	Break	Break	Break	Break

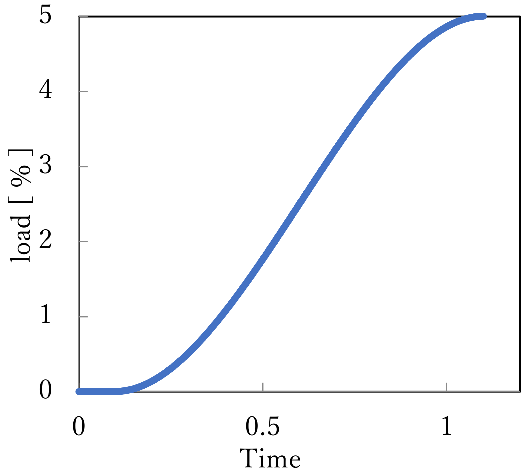


Fig. 2 Load graph

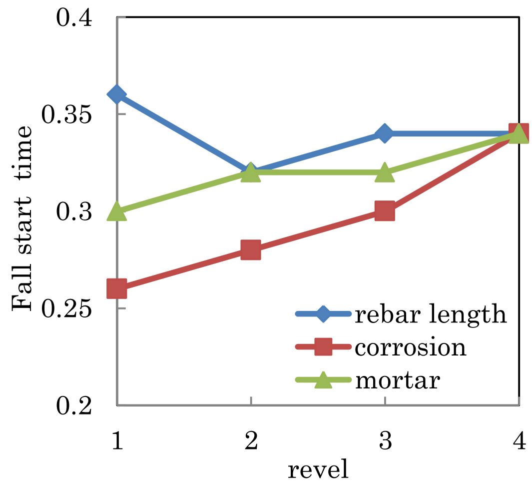
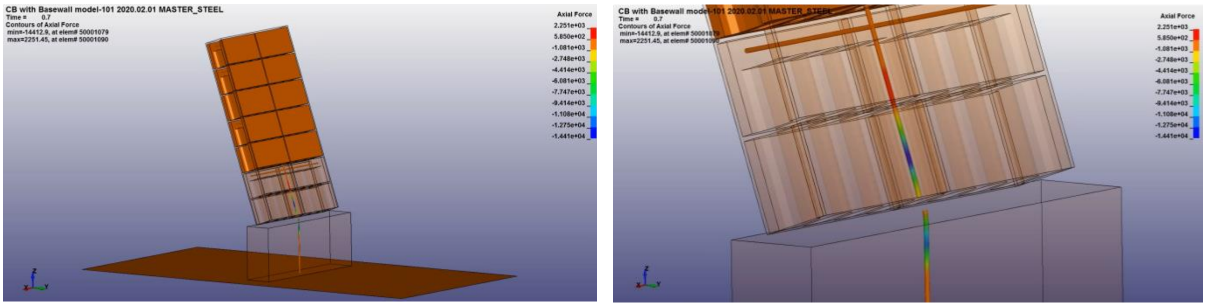


Fig. 3 Level and fall start time

block (L: X axis, W: Y axis, H: Z axis) are L390 x W150 x H190 [mm] [4]. The concrete block wall has 2 rows horizontally and 7 steps vertically, and is L800 x W150 x H1400 [mm]. The base part was L1000 x W200 x H400 [mm]. Since the concrete block wall can only fall in the Y-axis direction in Fig1 when an earthquake occurs, this model has two rows in width. For the same reason, pushover was done in the Y-axis direction. In addition, the load was evenly distributed over the entire wall and applied in the -Y direction. In accordance with the Building Standards Law, one reinforcing bar is arranged vertically and four reinforcing bars are arranged horizontally as shown in Fig1. For this fall, consider a fall caused by pulling out the reinforcing bar and a fall caused by breaking the reinforcing bar. The concrete block is class C, and the concrete strength is 30MPa[5] and the mortar strength is 18MPa. The adhesive stress was multiplied by 0.163444167, and the adhesive stress of concrete and mortar was set to 4.90 N / mm2 and 2.94 N / mm^2, respectively. The relationship between the adhesive stress and the amount of slip was set as two break points based on the study on the adhesive strength of deformed reinforcing bar by the pull-out test of Murata and Kawai [6]. SD295A was used for the reinforcing bar, and the yield point was set to 295N/mm^2 and the tensile strength was set to 440N/mm^2. The diameter of the reinforcing bar was 9.53 mm. In this model, the adhesion and friction between the block and the foundation are not taken into consideration, and the foundation and the ground are not connected and are independent of each other. The



(a) Standard overall (b) Standard Focus

Fig. 4 Fall figure

foundation is fixed and set so that it does not move. The ground is just an expression. In the pushover analysis, the analysis was performed with a force up to 5 times its own weight. Fig2 shows the load graph entered this time.

3. Analysis result

Table1 shows the various setting values this time. Fig. 3 shows a graph of the levels in Table 1 and the fall start time. The photographs of the fall are shown in Fig4. Pulling out occurred only when the length of the reinforcing bar was 100 mm, but everything else broke. All of the fractured parts were at the boundary between the foundation part and the block part.

From this, it can be seen that the weakest point of the concrete block wall is the boundary between the foundation and the block. In addition, the fall start time was the longest when the reinforcing bar in the foundation was shortened. It is considered that this is because the axial force applied to the reinforcing bar is dispersed as the reinforcing bar is pulled out and does not break, and the fall start time becomes longer. As a result of changing the length of the reinforcing bar, the longer the reinforcing bar, the longer the fall start time except for the rebar length 1. From this, it can be judged that the longer the reinforcing bar is, the better the seismic resistance of the concrete block wall is. In addition, since the fall start times of the rebar length 3 and the rebar length 4 do not change, it is considered that the load capacity does not change much if the reinforcing bar length is longer than a certain length. As a result of changing the diameter of the reinforcing bar, it was found that the fall start time became shorter as the reinforcing bar became thinner. This is larger than the result of changing the other two parameters (reinforcing bar length and mortar adhesion). From this, it can be seen that the cross-sectional defect is the most important point among the three points that we paid attention to in order to improve the seismic resistance of the concrete block wall. Since many reinforcing bars were actually rusted on the concrete block wall that fell due to the Northern Osaka Earthquake, we believe that rusting of reinforcing bars can be an important factor in achieving earthquake resistance. As a result of changing the adhesive stress of the mortar, the larger the adhesive stress, the longer the fall start time, but the amount of change was smaller than the other two (reinforcing bar length, cross-sectional defect). The results of changing the adhesion stress of the mortar this time were all fractures. In addition, no slippage of the reinforcing bars was confirmed. Therefore, it is considered that the seismic performance of concrete block walls is mostly determined by the tensile strength of the reinforcing bars. From this, it can be seen that the adhesive stress of the mortar is related to the seismic resistance, but the length of the reinforcing bar and the cross-sectional defect due to rust contribute more.

4. Conclusion

In this study, an analysis model of a concrete block wall was created and pushover analysis was performed. In creating the model, we focused on the above three points: "reinforcing bar length, cross-section defect due to rust, and mortar adhesion". As a result of the pushover analysis, pull-out occurred only when the length of the reinforcing bar was shortened, but all other reinforcing bars broke. The fall start time was the longest when the pullout occurred.

As a future issue, will seismic response analysis give the same results as pushover analysis? In addition, it is necessary to model the parts that may be weak points that we have not focused on this time. The length of the reinforcing bar is short, and there are complex settings such as when it is rusted. From the above, it is considered that even if the standard is met at the time of construction, it will be a guideline for the time when it becomes dangerous due to aging deterioration, which will lead to the safety evaluation of the existing concrete block walls.

Acknowledgments

This research was supported by the Kobe Municipal Water Fire Safety Association "2019 Safety and Security Town Development Research Grant System". For this research, we received advice from Associate Professor Yoshihiro Okumura of Kansai University, who is the chairman of the Takatsuki City School Block Wall Earthquake Accident Investigation Committee. I would like to express my gratitude here.

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