Study on Compressive Deformation of Escalator Truss During Earthquakes Considering Large Deformation

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Abstract. Four fall accidents of escalators occurred utilized in three shopping centers during Greatest East Japan Earthquake in 2011.Based on the fall accidents, the quake-resistance standard of the escalator was reviewed in Japan. In the new quake-resistance standard, inter-story deflection assumed during earthquakes was set larger than before. It is conceivable that an existing escalator receives compressive load from a building. Therefore, it is necessary to investigate how the escalator truss behaves due to compressive load. From the above background, this study builds a model of the escalator truss that is subjected to compressive load based on results of a compression experiment of the escalator trusses of actual machine size. Elasto-plastic analysis was performed using the finite element method, and the state of deformation during compression was confirmed. The effectiveness of the analysis model was compared with the compression experiment of the escalator truss of the actual size. It is considered that the analytical model can reproduce the trend of the load-displacement curve.

1 INTRODUCTION

Escalators are generally installed by attaching L-shaped steels called support angle irons at both ends and hooking it on a building beam. The escalators have truss-structure that one end is fixed and the other end is unfixed to prevent breakage, when a building is deformed by an earthquake. However, four fall accidents of escalators utilized in three shopping centers occurred during Greatest East Japan Earthquake in 2011[3].The reason is that the non-fixed parts were detached due to large inter-story deflection than assumption. Based on the fall accidents, the quake-resistance standard of the escalator was revised in Japan. In the new quake-resistance standard, inter-story deflection assumed during earthquakes was set larger than before [4]. Therefore, it is possible to prevent fall accidents, but on the other hand it is conceivable that an existing escalator receives compressive load from a building. However, it is difficult to secure a sufficient clearance between the building beam and the escalator, and when the large inter-story deflection occurs, the escalator truss may be greatly deformed by compression load and may cause troubles in safety. Also, since the structure of the escalator truss has no fixed provision, it differs according to each company. Therefore, it is necessary to investigate how the escalator truss behaves due to compressive load. From the above background, this study builds a finite element analysis model of the escalator truss that is subjected to compressive load based on results of a compression experiment of the escalator trusses of actual machine size. In this study, a simple analysis model is created, welds are made as one body, and material properties are uniformly decided. The validity of the analysis model is investigate by comparing with the compressive experiment of the escalator truss of the actual size.

2 COMPRESSION EXPERIMENT OF THE ACTUAL SIZED ESCALATOR TRUSS

2.1 Outline of experiment

As part of the building standards development promotion project in 2014, a compression experiment of the actual sized escalator truss was carried out [1]. Experiments confirmed the deformation behavior of the escalator truss when receiving a compressive load from the building beam during the earthquake. In the structure of the escalator truss, it is conceivable that buckling will occur when subjected to enforced displacement in the longer direction. Therefore, it is considered that the truss members deform such as buckling, and the strength of the truss decreases greatly. Therefore, even after the member is deformed, it is necessary to confirm whether truss member can hold device weight and movable load or not.

2.2 Test body

In order to investigate the behavior of deformation due to the difference in the structure of the escalator truss experiments were conducted with 7 test bodies of 4 patterns. Differences in deformation behaviors due to differences in structure could be confirmed. In this report, three pattern of experimental results are reported. Table 1 and 2 show common specifications of each test body. Main material is Japanese Industrial Standard (JIS) SS400 [2]. The lift height of the escalator was 3 [m], and the test bodies close to practical use. Figure 1 shows the test body. Only the truss was included in the test body, not included the escalator's internal equipment (step, handrail, drive unit and so on). Weight of internal equipment is reproduced by hanging the dummy weights.

Table 1 Parameter of escalator

Height [mm]	Span [mm]	Truss width [mm]	Incline [°]	Main Material	Support
3000	9476	1500	30	JIS SS400 (carbon steel)	Top: Fixed Bottom: Non fixed

Table 2 Parameter of JIS SS400

Types of symbol	Yield stress [MPa] Thickness of steel [mm] t ≦ 16	16 < t ≦ 40	Tensile strength [MPa]
JIS SS400	245 and over	235 and over	400～510

Figure 1 Test body

2.3 Experiment method

Figure 2 shows the experimental outline. The top support angle and the top frame were fixed so that the escalator truss was prevented from floating up during compression. The bottom part of the escalator truss was constructed to slide in the longer direction so that it can be compressed in the longer direction. A load cell was installed at the bottom end and the reaction force was measured. Table 3 shows the experimental process. Compression and unloading were given step by step, and the influence by repeated load was confirmed. Finally, enforced displacement was given up to 200 [mm].

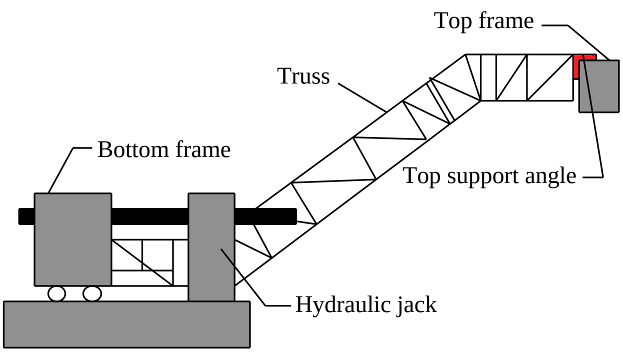


Figure 2 Experiment outline

Table 3 Experiment step

Step1	Press to 40 mm
Step2	Unloading
Step3	Press to 80 mm
Step4	Unloading
Step5	Press to 200 mm
Step6	Unloading

2.4 Experiment result

Figure 3 shows the appearance of deformation, Figure 4 shows the relationship between the enforced displacement and the reaction force of the truss. Immediately after the start of compression, all trusses underwent elastic deformation along with an increase in displacement. After that, it buckled and the load sharply decreased. However, there was difference in buckling load and transition of load. It is considered that there is no effect of repeated loads given to 40 [mm] and 80 [mm] for all trusses. Even if displacement was given up to about 200 [mm], all trusses were self-sustaining without falling.

Pattern A

Pattern B

Pattern C

Figure 3 Deformation of experiment

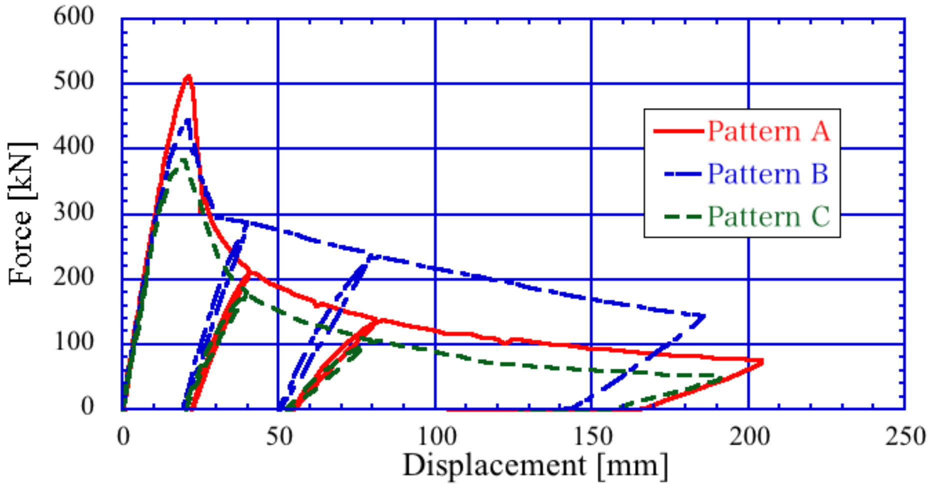


Figure 4 Reaction force of compression of experiment

3 FEM ANALYSIS

3.1 Analytical objective

An analytical model is created to simulate the compression experiment and elasto-plastic analysis is performed by using the the finite element method. In this report, the analysis model is made and it is evaluated by comparing load-displacement curve and deformation mode.

3.2 Analytical model

In this report, to create simple analysis model is aimed. Many escalator trusses are made of welded L-shaped steel, but analysis modelconsiders welded steel as one unit. Properties of steel are set uniformly regardless of the shape of member. In addition, analysis using bilinear models was performed and the same plastic factor were used. For the yield stress, two patterns were analyzed. Simulation 1 is yield stress of JIS standard. Simulation 2 is yield stress according to experimental result. In the experiment, the weight of the internal equipment was reproduced by hanging weights, but in the analysis, it is reproduced by applying the load to the member. Table 4 and 5 shows analysis conditions. ANSYS Workbench 16.0 was used as analysis software. It has a static structure and the solver is Mechanical APDL. The element used solid.

Table 4 Parameter of simulation

Truss	Incline	Element	Material property	support method	Load condition
Height : 3000mm Span : 9476mm width : 1500mm	30 °	Solid	Bilinear model Young's modulus:206GPa Plastic factor:1450MPa	Top: X,Y,Z fixed Bottom: Y,Z fixed	(1) Linear pressure (2) X 200mm (3) Unloading

Table 5 Parameter of yield stress

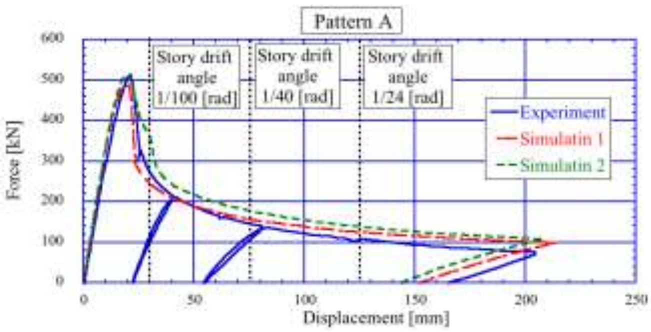
Yield stress [MPa]	Pattern A	Pattern B	Pattern C
Simulation 1 JIS standerd	245	245	245
Simulation 2 adjustment	290	285	195

3.3 Analytical method

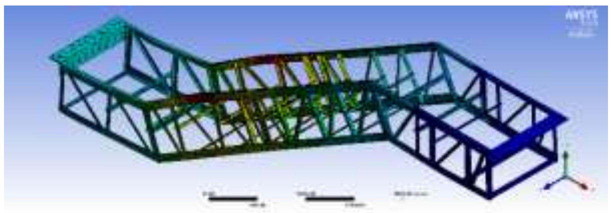
The analysis model simulates the experiment. The escalator truss was fixed the top end and enforced displacement of 200 [mm] was given. A story drift angle of the escalator at the time of the earthquake is determined by the quake resistance standard. the story drift angle includes 1/100 [rand], 1/40 [rad], 1/24 [rad], and so on. When not obtained by structural calculation, it is necessary to consider 1/24 [rad] or more. Analysis was done up to 200 [mm] beyond that values. The load-displacement curve is obtained by measuring the reaction force at the bottom end and deformation of the escalator truss.

3.4 Analytical result

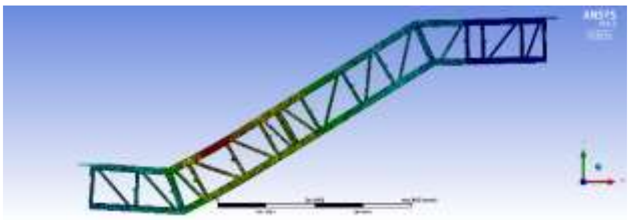
Figures 5, 6, and 7 show the analytical results. Upper left shows the load-displacement curve, the solid line shows the experiment result and the others show the analysis result. The upper right shows the whole figure, the lower left shows the side view, the lower right shows the top view. The yield stress of the material used in the experiment was higher than the JIS standard because the JIS standard indicates the lower limit value. Therefore, in Patterns A and B, the buckling loads of the analysis results using the JIS standard are smaller than the experiment results. However, in Pattern C, the buckling load of the analysis result using JIS standard is larger the experiment result. Pattern C might be influenced by the initial misalignment. In the three patterns, by adjusting the buckling load of the analysis results to the experiment result, the load transition after buckling can be reproduced roughly. The state of deformation focuses on the lower end, and it can be roughly reproduced.



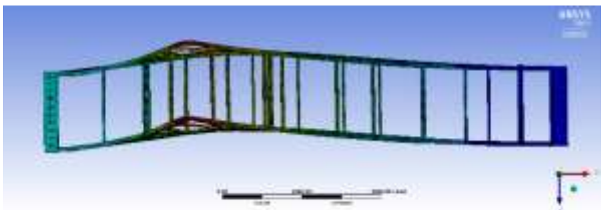
(a) Force-Disp. curve



(b) General view

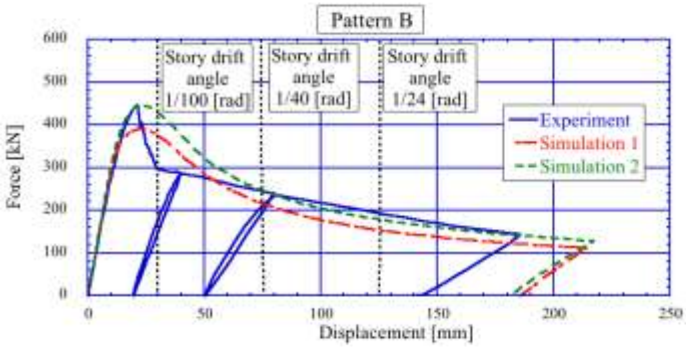


(c) Side view

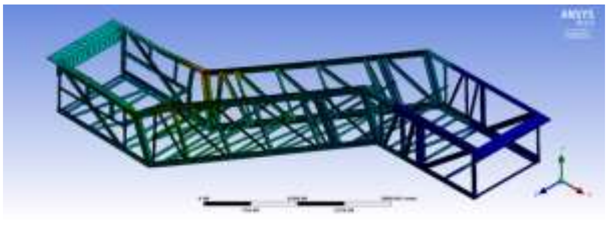


(d) Top view

Figure 5 Analytical results of pattern A



(a) Force-Disp. curve

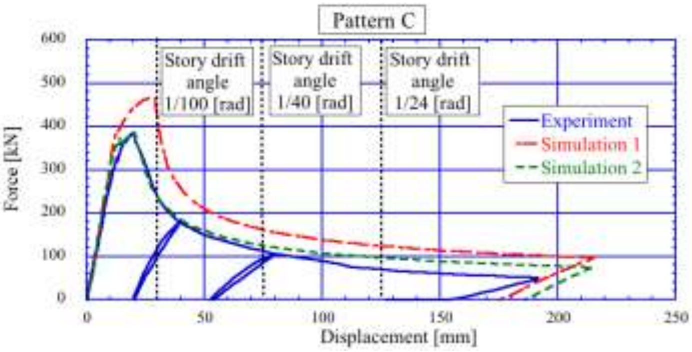


(b) General view

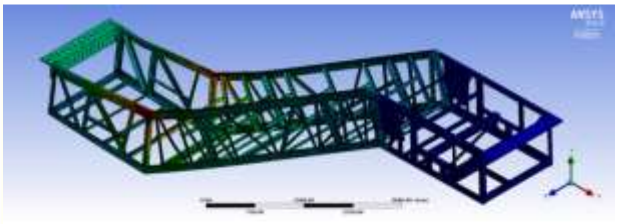
(c) Side view

(d) Top view

Figure 6 Analytical results of pattern B



(a) Force-Disp. curve



(b) General view

(c) Side view

(d) Top view

Figure 7 Analytical results of pattern C

4 CONCLUSION

In this study, a simple analytical model that considered welded steel as one unit and properties of steel are set uniformly regardless of the shape of member has been developed and analyzed, also the validity was compared with the experimental result. Even with a simple analysis models, they can analyze considering buckling and unloading. It is confirmed that the analysis model can reproduce the experiment roughly. In the analysis using the finite element method, results are often adjusted. Even the analysis result using the JIS standard in this analysis model is roughly reproducing the experiment result. It is considered that the analysis model can propose a thing sufficient enough for safety margin evaluation of escalator truss in advance.

ACKNOWLEDGEMENTS

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BIOGRAPHICAL DETAILS

Ryoto Matsuzaki is master's course student in mechanical engineering of graduate school of Tokyo Denki University. He researches compressive deformation of escalator truss.

Prof. Satoshi Fujita, a JSME (Japan Society of Mechanical Engineers) Fellow, has ten years of management experience as a director, a dean of school of engineering and a vice-president of Tokyo Denki University. He has been engaged in engineering research and development of seismic isolation systems and vibration control systems for buildings or key industrial facilities for over 35 years at both University of Tokyo and Tokyo Denki University. In recent ten years, he has been a committee member of the Panel on Infrastructure Development of Japanese ministry of land, infrastructure and transport (MLIT), and a chair of the Special Committee on Analysis and Evaluation of Lifts, Escalators and Amusement Facilities Accidents and Failures held in MLIT. In addition, he has been a chair of the ISO TC178 Japanese committee.

Miss Asami Ishii was received master’s degree in mechanical engineering from Tokyo Denki University, Tokyo Japan, 2006. She is now a doctoral course student of Tokyo Denki University. Her research interest includes seismic behavior of escalator and seismic behavior of lift ropes.