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Computer Aided Experiments for Truss Structures

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Abstract: It is quite difficult to investigate structural mechanical properties by full-scaled structure experiments. Consequently, an experiment using a reduced scale model is generally performed. In such an experiment, the resistance force becomes small in proportion to square of the model's reduction ratio and a higher accurate loading system is required. This paper aims to construct an automatic loading system to control the loads at multiple points independently and concurrently. By using this loading system, the experiments using reduced scale models of steel truss structures, that have non-buckling members for the compressive force, are performed.

Introduction

The social needs for large span structures, such as atria attached to tall buildings or baseball stadium roofs, are increasing. Such structures include shell structures using reinforced concrete and air-inflated membrane structures, but steel trusses are the most common. In Japan, a seismically active land, it is very important to ensure safety against earthquakes for steel truss structures as well as for general buildings.

In the seismic design of general buildings, plastic deformations are permitted for some structural members in order to absorb the large earthquake input energy. However, in steel truss structures, it is quite difficult to perform seismic design by allowing plastic deformation of members because of the brittle buckling behavior of compressive members. If such plastic deformation could be allowed for steel truss structures, a more rational seismic design method could be used.

By inserting an inner pipe into the pipe of a truss which is a brittle compressive member, the pipe is protected from buckling and enhanced ductility (Tada et al. 1991, 1992; Sridhara). Consequently, the whole structure should have a higher loading capacity and larger deformability. This double pipe member will be referred to hereafter as a "non-buckling member".

In this study, an experiment using reduced scale models of steel truss structures, which included the non-buckling members as mentioned above, was performed to investigate the structural mechanical properties. As the model becomes smaller, the

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strength is reduced and the load at each loading point becomes extremely small in the case of a distributed load. Therefore it is difficult to control all the load increments simultaneously, and the applied load has been substituted by the load specified by the tournament method so far. Here, we developed an automatic loading system which controls the loads at multiple points concurrently.

Method for Experiments

Specimens

Experiments were performed on three types of 6 grids statically determinate plane truss structures as shown in Figure 1. Truss-1 is a normal truss structure, Truss-2 is a truss structure with one non-buckling member installed in the central upper chord and Truss-3 is a truss structure with five non-buckling members installed in all upper chords. Overall truss dimensions were 120 cm span and 12.5 cm height.

The truss members were annealed stainless steel pipes, 7.0 mm diameter and 0.3 mm thickness for chord members and 5.0 mm diameter and 0.3 mm thickness for diagonal members. Joints are connected to truss members by silver blazing. The details of the non-buckling member are shown in Figure 2. The inner pipe has 6.0 mm diameter and 1.0 mm thickness. By setting the inner pipe very slightly apart from the outer pipe and both joints, the axial force will not be transmitted into the inner pipe. The sectional area is calculated so that the yield strength of the outer pipe (Py) will be lower than the Euler buckling load of the inner pipe ($P_E = \pi^2 EI/l^2$) and the safety factor (P_E/Py) will be about 1.5.

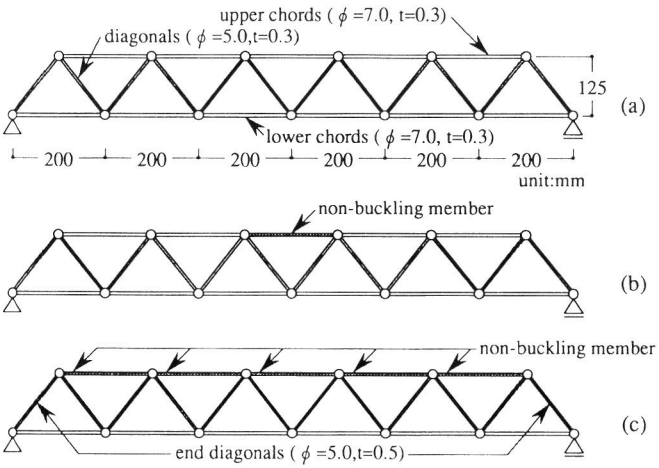

Figure 1. Specimens: (a) Truss-1; (b) Truss-2; (c) Truss-3

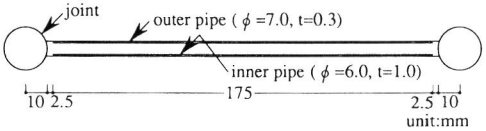

Figure 2. Detail of Non-buckling Member

Loading Apparatus

Photo 1 shows the loading apparatus. Loading is performed by pulling the rods which are installed at each joint of the lower chords. Controlling a stepping motor by a personal computer and rotating worm-gear (Photo 2), a tension force is provided to the rod. Two link-balls are attached to each end of the rod so that the bending moment does not act on the load-cell. Thus the loading point can move freely in accordance with the lateral and vertical deformation of each truss joint.

Loading is applied until the vertical displacement of the joint of the lower chords reaches 30 mm, and loading is controlled to be equal on all the load-cells attached to tensioned rods.

The deformations of the truss structure are measured by displacement transducers at each joint on the lower chords. The total applied load value is checked by load-cells attached to the right and left supports and the strains are measured by strain gauges attached to the center of each member.

Loading Control System

Figure 3 shows the loading control system. The personal computer is connected to the multi-axial controller through an RS232C and it is also connected to the measuring instrument through a GPIB. This system measures the load and the displacement values automatically and controls five stepping motors simultaneously. There is a displacement transducer and load-cell for each stepping motor. The computer compares the measured load and displacement values with the base control value and controls the stepping motors accordingly.

The flowchart for the stepping motor control is shown in Figure 4. The base control value is the load value of the load-cell corresponding to the base motor (P_3), and other load values are set in proportion to this base value. In the elastic region, the motor is controlled by the load value of the base point. Around the maximum strength region or in the plastic region, it is controlled by the displacement value of the base point.

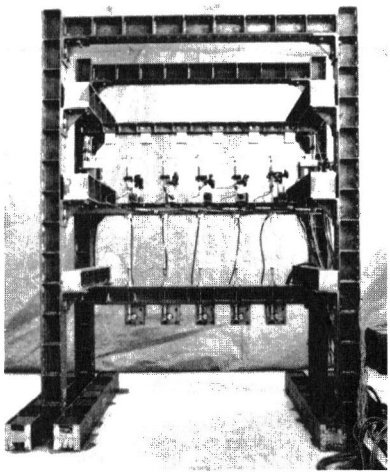

Photo 1. Loading Apparatus

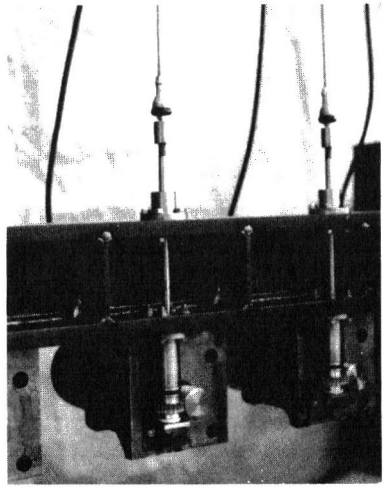

Photo 2. Detail around Stepping Motor

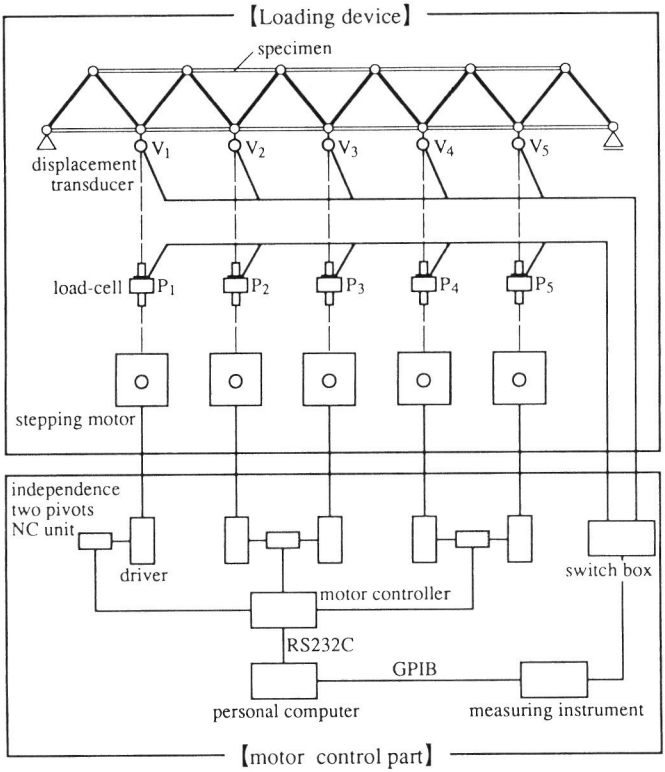

Figure 3. Loading Control System

ON/OFF for the motor is controlled as follows. The motor at the base point is set to be stopped when the value of the corresponding load or displacement becomes greater than the base control value. Other motors are stopped when the measured load value exceeds the load value of the base motor or the control value. And they are activated when the value is less than both values.

Experimental Result

Motor Control

Figure 5 shows the relationship between the load value of each load-cell and the vertical displacement of the central joint of the lower chords. P_1, P_2, ~, P_5 expresses the tensile force of each rod from left to right. P_3, the base load value, becomes less than other load values after the central member of the upper chords buckles. But, the five load values are nearly same.

Unlike a hydraulic pump, a stepping motor can easily control the displacement and it has a stiffness as a loading system about 100 times higher than the truss specimens. Furthermore the negative slope of the specimens after buckling is of the

same order as their elastic stiffness. Therefore the data in the negative slope region are easily measured even after the structure reaches an unstable condition.

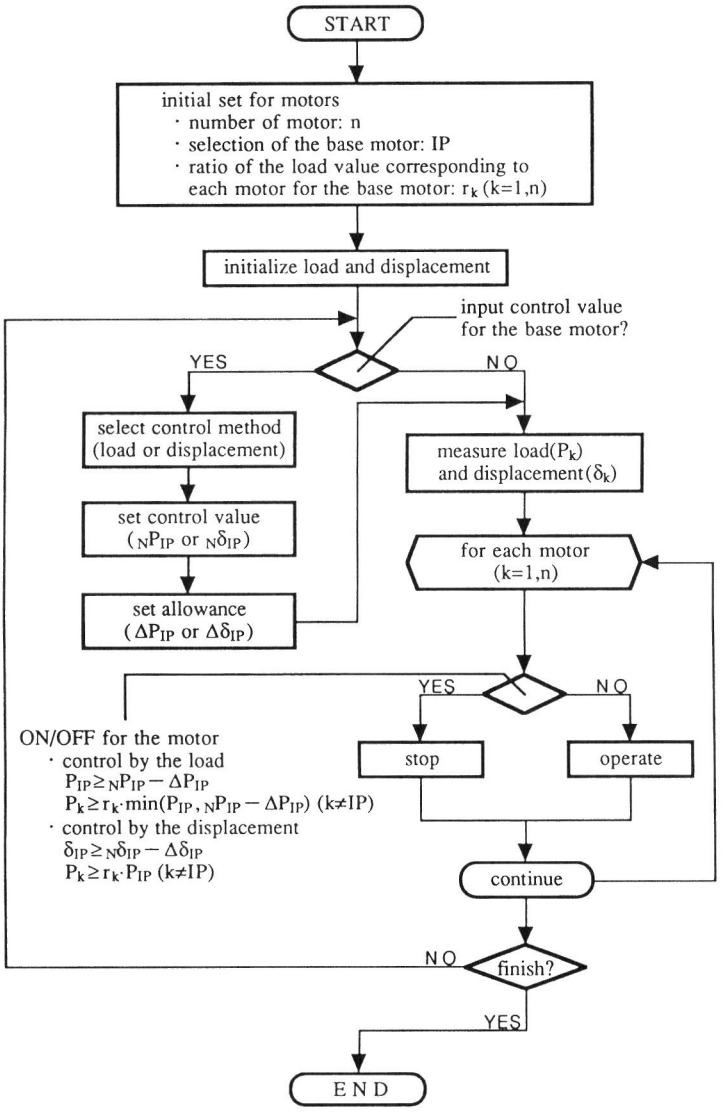

Figure 4. Flowchart for Stepping Motor Control

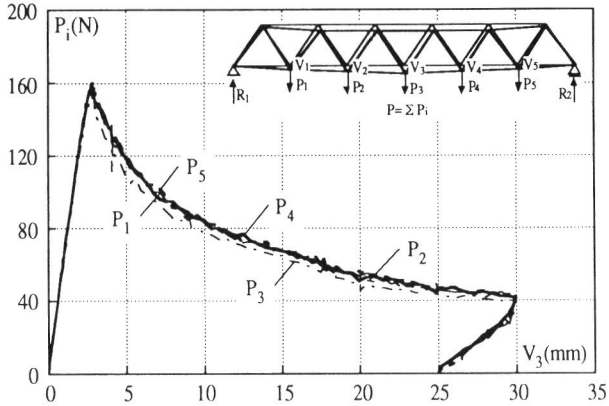

Figure 5. Load Value of Each Load-cell - Vertical Displacement of Central Joint of Lower Chords

Deformation of Each Truss Structure

Figure 6 shows the relationship between the total load value and the vertical displacement of each joint of the lower chords for each truss structure. (a),(b) and (c) indicate the cases for Truss-1, Truss-2 and Truss-3. V_1, V_2, ~,V_5 express the vertical displacement of each lower chord joint from left to right. Photos in figure show the final deformation state of each truss structure.

In Truss-1, the strength is drastically decreased by the buckling of the central member of the upper chords. In Truss-2, the strength of the early stage is relatively higher than Truss-1 because the central member does not buckle. But later the strength is reduced due to the buckling of an upper chord member next to the central non-buckling member. As a result, the deformability of the truss structure itself was not improved. This reason is explained as follows. The total load value which makes the central member yield is quite close to one which makes the neighboring members buckle. Thus the neighboring members buckled before the non-buckling member reached a stable yield. In both trusses, a hinge in the structure was formed at the buckling point in the upper chord members, then the structure became a 3-hinged mechanism, and finally the whole structure collapsed. From figures (a) and (b), the mode of the vertical displacements of the lower chord joints is obtained as follows. In Truss-1, the mode of V_1:V_2:V_3:V_4:V_5 is 1.00:1.99:2.94:1.99: 1.01. In Truss-2, the mode is 1.00:1.98:1.55:1.06:0.54. The V line is determined by connecting the lower joint under the buckled upper member to both right and left supports.

In Truss-3, the strength continued to increase even after the stiffness reduction around the point P = 941N and consequently a large deformability was obtained. The deformation is of a curved nature and it is found to be stabilized.

Conclusions

By controlling the stepping motors automatically using the personal computer, accurate load control is accomplished and a high stiff loading mechanism, which can catch negative slope data after the buckling of the chord member, was obtained.

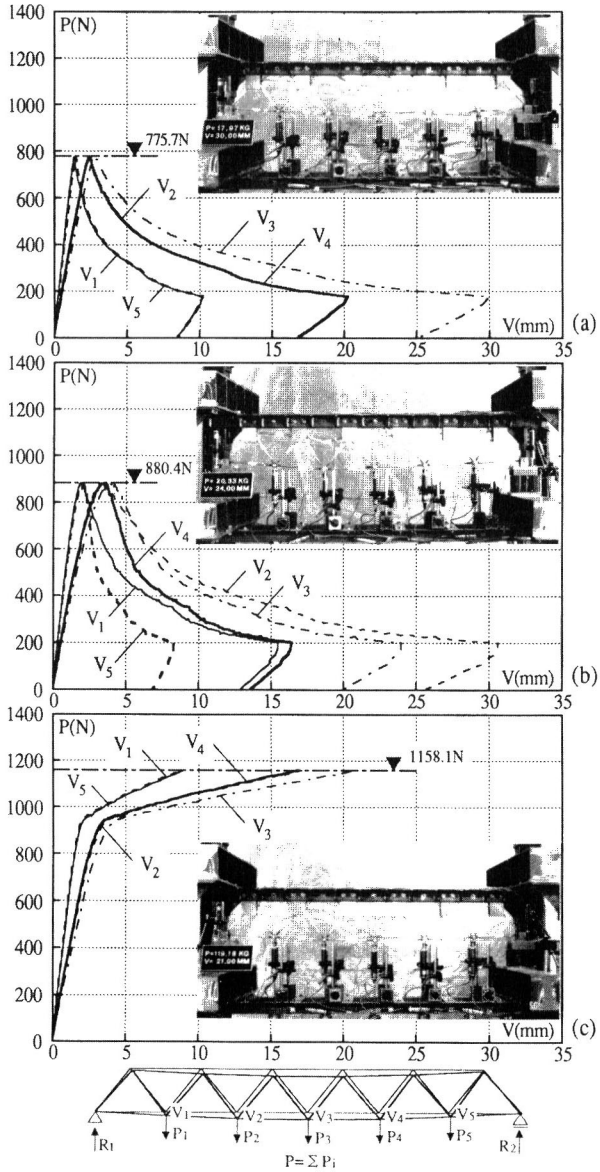

Figure 6. Total Load Value - Vertical Displacement of Each Joint of Lower Chords Relationships for Each Truss Structure: (a) Truss-1; (b) Truss-2; (c) Truss-3

Experiments for the three types of small scale truss structures using this automatic loading system were performed and conclusions were obtained as follows.

1) In a statically determinate plane truss structure, our proposed non-buckling member proved to work efficiently to protect buckling and enlarge the deformability. This non-buckling member is made by inserting an inner pipe into the truss pipe, and it is used for the members which are subjected to large compressive forces.

2) For the improvement of the load capacity and deformability of the truss structure, it is necessary to install this non-buckling pipe not only for the member with the largest compressive axial force, but also for members with a compressive axial force close to the largest one. But when the member with the largest compressive axial force is designed to be relatively small, we think that one non-buckling member placed in its position could be effective.

3) By using non-buckling members for compressive members, ductile truss structures could be created, where the plastic deformation were allowed during large earthquakes.

Acknowledgments

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