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Load Carrying Capacity of Steel Tubular Tower Structures

Résistance de tours en ossature d'acier tubulaire

Tragwiderstand von Stahlrohrtürmen

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SUMMARY

Stability and deformability of ordinary double-Warren truss structures were examined by experimental investigations. The test results show that premature buckling of the compressed members due to end constraints has been observed and the improvement of the durability of structures as a whole cannot be expected in the event of severe loading conditions. A newly developed knee-bracing system has been proposed and improvement in durability of the system was confirmed experimentally.

RÉSUMÉ

La stabilité et la déformation d'un contreventement à double grille ont été étudiés expérimentalement. Les résultats montrent un flambage prématuré des éléments comprimés. Une amélioration de la durabilité de l'ensemble de la structure sous un charge importante ne peut être attendue. Un nouveau type de renforcement aux angles est proposé et l'amélioration de la durabilité est confirmée expérimentalement.

ZUSAMMENFASSUNG

Stabilität und Verformungsverhalten von gewöhnlichen Doppelgitterbalken wurden experimentell erforscht. Als Ergebnis konnte das vorzeitige Knicken der unter Druck stehenden Teile aufgrund des Druckes auf deren Enden beobachtet werden. Weiter zeigte sich, dass im Falle intensiver Belastung keine Verbesserung der Dauerhaftigkeit der Bauten als Ganzes erwartet werden kann. Es wird ein neu entwickeltes Halbdiagonalverspannungssystem vorgeschlagen. Die Verbesserung der Dauerhaftigkeit des Systems wurde experimentell bestätigt.

1. INTRODUCTION

This paper refers to stability and deformability of typical double-Warren truss tower structures composed of circular hollow sections, which are widely used in constructing steel tower structures like as electric transmission towers and telecommunication towers. In current design practice, the structures are regarded as being collapsed as a whole, when buckling in a primary compressed member occurrs, strength and deformability of the structures are not taken into account in the post buckling range.
In order to improve the durability of the structure, it is desired to design so that buckling of the primary member does not lead to the collapse of the structure, since the structure can resist without the attainment of collapse mechanism, even if the structure would sustain unexpected external forces over the design load.
From this point of view, a method to improve deformability of the structure by adding bending resistant members is proposed. In order to make clear stability and deformability of the proposed structures in comparison with those of ordinary truss structures, an experimental investigation was carried out using subassemblages of truss sructure.

2. EXPERIMENTAL PROGRAM

2.1 Design of specimens

In order to make clear buckling behaviors and restoring force characteristics of ordinary double-Warren truss tower structures, four types of specimens were prepared for the experiment. They were composed of two panels of space truss structures with four legs, and were designed so as to be scaled down about 1/5 of prsumed actual truss tower structures rise to a height of over dozens of meters. The structural members were used circular hollow sections made of mild steel. Diameters and thicknesses were 60.5mm, 2.3mm for the leg members, and 27.2mm, 2.3mm for the diagonal members, respectively. Fig.1 shows the side view of the test specimens.

The Type-A specimen (Fig.1a) was designed so that four leg members were arranged parallel to each other and that the angle between the leg members and the diagonal members were 45°. The slenderness ratios of members were 58.25 in leg members and 96.42 in diagonal members, if regarding the distances between the intencity points of element longitudinal axes as the buckling lengths. The joint elements were designed so that all of the axes of members connected to the joint intersected at a certain point without eccentricity. Two types of connecting method, namely, welded and bolted connections, were prepared fot Type-A specimens, as shown in Figs.2 and 3. Connecting method of Type-AW was fillet weld, and two galvanized bolts were used for each connection of Type-AB.

Type-B specimens (Fig.1b) had 1/11.25 slant in leg members and the widths of structures were reduced to 80cm at the tops of the specimens. Type-C specimens (Fig.1c) were formed by adding horizontal strut members to Type-B specimens at the center of specimens. The horizontal members were identical to diagonal members. The connecting method of Type-B and C specimens were similar to the method of Type-AB, and all specimens applied bolted connections were galvanized to reflect a phenomenon of slippage as observed in the actual bolted connections. The slenderness ratio of the leg member was 59.22, and the ratio of diagonal member was 102.27. All compressive members were supposed to buckle in the inelastic range, because the slenderness ratios of the members were less than the critical slenderness ratio.

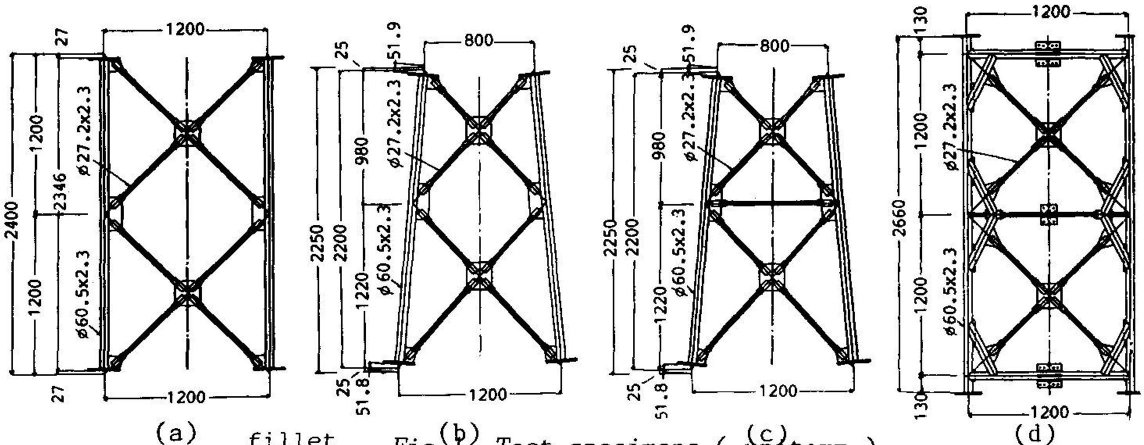

Fig.1 Test specimens (unit;mm)

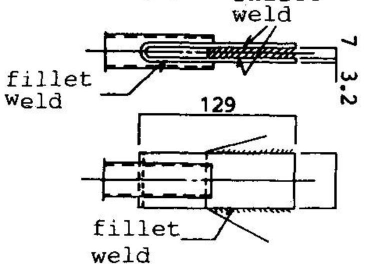

Fig.2 Welded connection

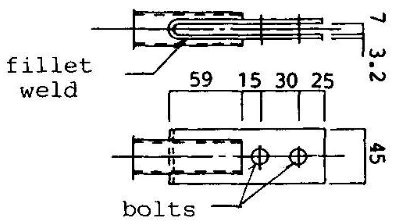

Fig.3 Bolted connection

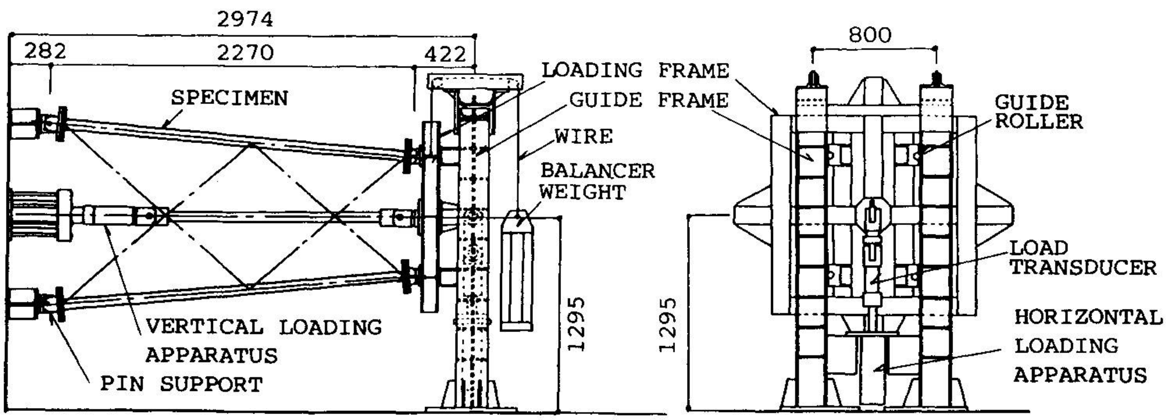

Fig.4 Loading apparatus (unit;mm)

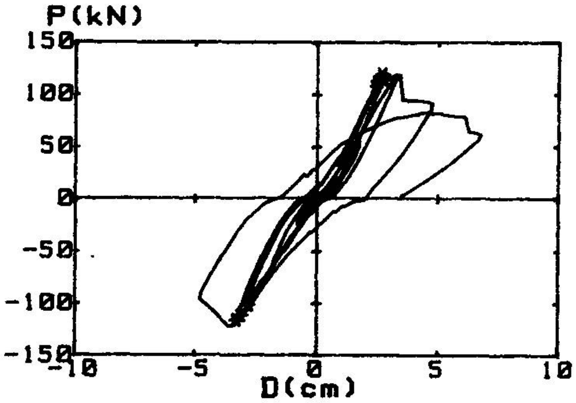

Fig.5 Type-AW P-D relation

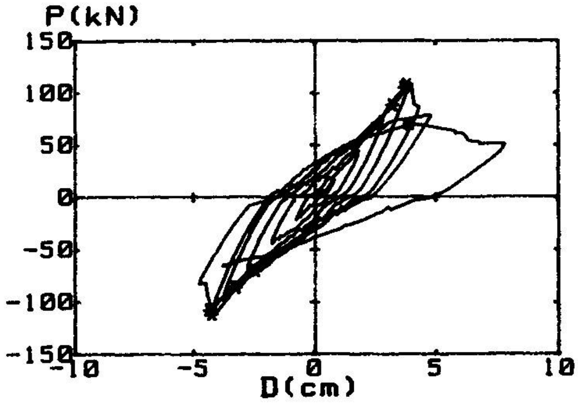

Fig.6 Type-AB P-D relation

Type-D specimen (Fig.1d) is an example of the improvement to prevent premature buckling of compressive members by adding bending resistant members called as 'Knee brace' to the ends of the diagonal members. The overall dimensions of the specimen were identical to Type-AB specimens except Knee braces. Knee brace members were same as leg members and fillet welded to leg and horizontal strut members. The section and length of Knee brace members were proportioned so that flexural yielding of Knee brace members preceded to buckling of the compressive members.

2.2 Testing Procedure

Fig.4 shows the testing apparatus for horizontal and vertical loadings and the set up of the test specimen. The test specimen was laid horizontally and pin-supported on a reaction wall at the ends of four legs. Rotations were allowed at the supported points. Loads were applied to the specimens by two hydrauric jacks. The horizontal load was applied in two different directions, 0° or 45° (the diagonal direction of the tower section). The applied load was controlled by monitoring the magnitudes of loads and the horizontal displacements of the applied points. Additionally, a constant vertical load was applied to certain specimens. The value N was kept constant at 0.2Ncr or 0.4Ncr. Ncr was four times the buckling load of each leg member which had been calculated from the result obtained by the horizontal loading test.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Effect of Connecting Method on Joints

Fig.5 and 6 show the relations between the applied horizontal load P and the horizontal displacement of the loading point D, obtained from the results of the experiments of Type-A specimens. In the experiments, only horizontal loads in 0° direction were applied. The symbols, '*', illustrated on the loci indicate the occurrence of buckling observed from the records of strains measured by wire strain gauges sticked on each compressive member.
Initially buckling occurred at the diagonal members of the lower panels, and at that time the structures had arrived at the ultimate states. Once buckling occurred, the rigidity and restoring force of subassemblages deteriorated rapidly, and after the subsequent buckling of leg members subassemblages collapsed. These phenomena were commonly observed in both Type-AW and AB.
However, inspite of buckling phenomena, the deformations were remarkably different from each other since the slippage occurred in the bolted connections. In order to assess such deformation characteristic of the bolted connections, the monotonic tensile test was conducted and the result is shown in Fig.7. From the figure, it can be observed that the connection can resist effectively only after the slippage, but the excessive distortion is inevitably generated.

3.2 Effect of Vertical Loads

Fig.8, 9 and 10 show load-displacement relations of Type-B specimens, which were subjected to cyclic loads in the direction of 0° as well as vertical loads in the constant level, namely, N=0, 0.2Ncr or 0.4Ncr.
In the case of no vertical loading, the overall load-displacement relations of Type-B are similar to those of Type-AB, as shown in Fig.8. As the vertical load increased, buckling of primary members occurred in lower level of horizontal load, while reduction of rigidity due to slips of the bolted connections occurred in higher level of horizontal load, and deformability of frame reduced. The experimental results of Type-C specimens indicated similar characteristics.

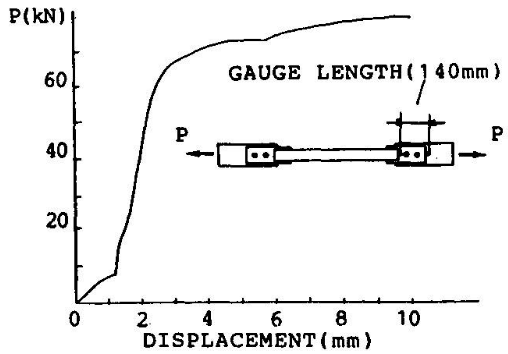

Fig.7 Slip characteristic of bolted connection

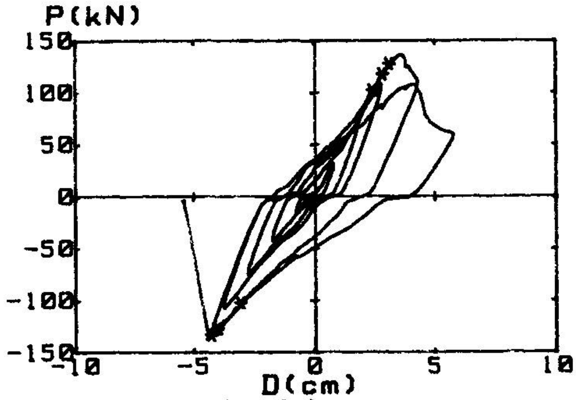

Fig.8 Type-B (N=0)

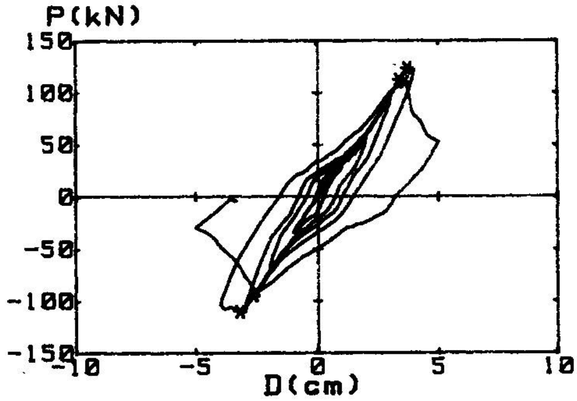

Fig.9 Type-B (N=0.2Ncr)

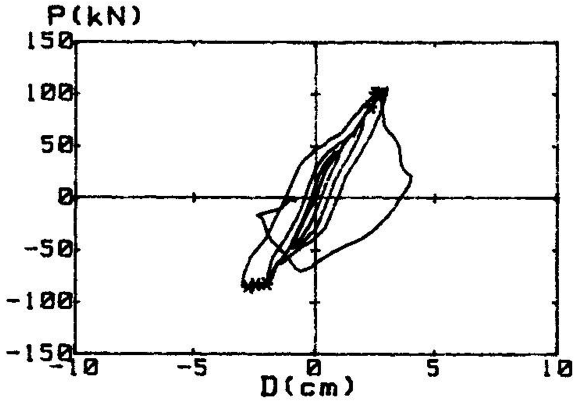

Fig.10 Type-B (N=0.4Ncr)

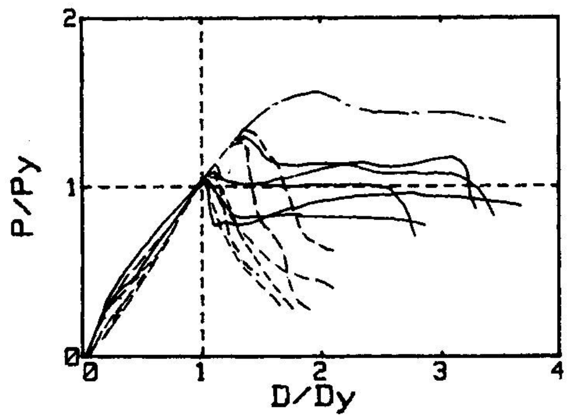

Fig.11 Normalized P-D relations

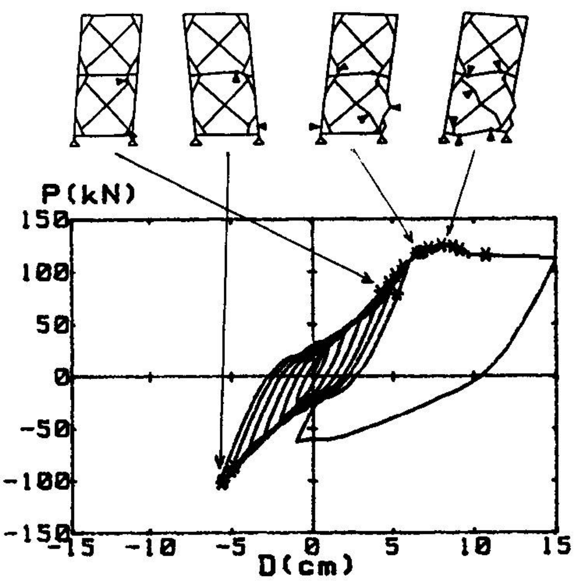

Fig.12 Type-D P-D relation

3.3 Effect of Direction of Horizontal Loads

Fig.11 shows the normalized horizontal load P/Py - displacement D/Dy relations, where Py and Dy are the specific load and the displacement corresponding to the initial buckling of each specimen. These lines indicate envelopes of hysteresis loops. Solid lines indicate the results loaded in 45° direction and dotted lines indicate the results of 0° direction loadings.
In the case of 45° direction loading, the primary members initially buckled at the compressive leg members, while the restoring force did not deteriorate so sharply, in comparison with the case of 0° direction loading. After buckling of compressive leg member, overturning moment was carried by other three leg members and capacity of the structure as a whole was kept constant at a certain level. From the results, it may be considered that stability and deformability of structures are unreliable especially in 0° direction loading.

3.4 Improvement on Stability and Deformability

Fig.12 shows the horizontal load-displacement relation of Type-D specimen, subjected to the horizontal load in 0° direction alone. The process of failure is illustrated. In the figure, the symbol, ▲, indicates buckling of compressive members and yielding due to tensile stress or bending moment.
Initially, the Knee brace member yielded and then the diagonal members buckled. As the result, the stiffness of the frame reduced, but the restoring force characteristic remained stable without distinct deterioration. The normalized load-displacement relation is showm in Fig.11 by a chain line to compare with other specimens, taking the critical load Py as the load at the time when a Knee brace member initially yields. From the figure, it can be remarkably observed that higher restoring force and fairly well deformability are exhibited and improvement in reliability and deformability of the structure is confirmed.

4. CONCLUSIONS

From the results of this study, the following mechanical properties of truss space towers subjected to horizontal and vertical loads have been revealed.
(1) The slippage of joint between the parts connected by bolts causes reduction of the rigidity and the influence of slippage can not be ignored, when considering restoring force characteristics of the structures.
(2) When horizontal force is applied in 45° direction, the structure can exhibit fairly well deformability, even after buckling primary compressive members. When the horizontal load is applied in 0° direction, load resistant capability deteriorates remarkably after buckling, and neither stability nor deformability of structure is reliable, especially under vertical loads.
(3) Contribution of newly developed 'Knee bracing system' toward improvement of deformability of truss structure has been confirmed experimentally, and improvement in reliability and durability of the structure is anticipated.

REFERENCES

1. J. Dario Aristizabal-Ochoa, Disposable Knee Bracing: Improvement in Seismic Design of Steel Frames. ASCE Journal of S.E., Vol.112, No.7, July 1986.