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Development of W-Truss System

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Abstract

The authors propose a new concept of space truss system with using an arc plate for its connection detail. The detail is aimed to have stable performance that would not be controlled significantly by welders' qualities, for an important part of the structure. This report is focused on the development of the W-truss System through some experimental studies of its connection.

1. Introduction

For any steel pipe truss construction in building & construction applications, special consideration is necessary for engineering and construction of steel pipe joints because the component members are closed sections. In a spatial truss construction where steel pipe joints are branched, that is, where steel pipes are joined at a solid angle of incidence, the incidence of angle, the pipe diameter and the pipe thickness work as parameters to influence on the over all strength of the joints. Design strength values of steel pipe branch joints, established on the results of many parametric experiment, are published in the steel pipe structural design and construction manual[1)] and have been widely used in practice.

On the other hand, there is a type of system truss structure comprising various spherical joints, known as a structural subsystem[2)] intended for utilizing the flexibility of space truss structures. The advantages of constructing a space structure by using it include, firstly, the capability of dividing a 3D structure into many component units at many nodes and designing and producing many unit members in same ways. Secondly, an excellent reproducibility in performance and quality of such component members for any frame geometry because the component member production processes will naturally be mechanized and equipped with data processing capabilities. However, if applied to a frame of simple geometry, the joint structural mechanism may have the disadvantages of being too redundant and expensive. If the truss system should be easily used in no awareness of its characteristics, the system mechanism will only be redundant, unable to exhibit its potent superiority.

Therefore, a steel truss system was proposed and developed to specialize for unidirectional truss structures, as a preferred structural subsystem for space structures. For the verification of the joint performance which is most important in steel pipe truss structures, an aim was to achieve superiority in the performance of conventional branch joints[3,4)].

2. General Description of W-Truss

This newly developed steel truss system is called "W-truss". W-truss is composed of a set of identical units, each unit consisting of a chord member (a cylindrical steel pipe), two gussets attached to both sides of the chord member, and diagonal members connecting the unit with adjacent chord members. Lateral connection of these units in a plane builds up a space structure. Considering the importance of quality reproducibility and energy saving at gusset plate joint fabricating workshops and construction sites, an object was to formulate a system of unidirectional truss frames with almost constant spans and truss intervals, namely, frames of nearly rectangular geometry in a plane, unlike a system truss, by standardizing the design and parts.

The W-truss joint (**Fig. 1**) is an assembly where an arciform steel node block ("arc plate") is welded to the surface of the chord member only at both sides of the arc plate, with a clearance kept in the central area between the arc plate and the chord member. These two gussets are fixed to the arc plate. Either end of each connecting steel pipe is flattened and tied by friction fastening to the gusset with high strength bolts. Each gusset bears the load of two diagonal pipes.

Generally, the axial force of a diagonal member of a truss frame

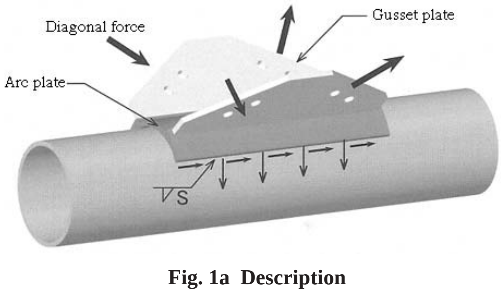

Fig. 1a Description

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[1] Building Construction Division

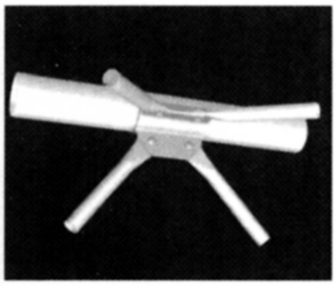

Fig. 1b W-truss connection

subject to deflection is alternately compressive and tensile. The resultant force of four diagonal members is divided into (1) force perpendicular to the main pipe axis (T stress) and (2) force parallel to the main pipe axis (K stress), and K stress usually works in the main. At each W-truss joint, the angle of circumference of the arc plate is set at 120°, as a rule, to provide sufficient yield strength mainly against T stress, and the intersection point of the axes of the four diagonal members is aligned with the arc plate weld line level to preclude stress which is nonparallel to the weld line when there is K stress. As a result, the intersection point of the diagonal members and the main pipe axis are evenly eccentric by a distance of D/4.

In conventional branch-joint steel pipe truss structures, stress tends to concentrate in the vicinity of intersection welds under axial force of diagonal members. The structure performance therefore tends to be affected by weld quality variation, and performance reproducibility often depends on the skills of welders. Moreover, for gusset joints, welding to the main pipe is made at many portions including diaphragm reinforcement, often leading to the dependence of structure performance, again, on the skills of welders. For the purpose of eliminating such uncertainties as far as possible, the W-truss joints use the intermediation by thick arc plates to minimize welding to the main pipe, to reinforce the main pipe wall, and to disperse local stress. The joint design is also intended to enable explanation and evaluation of fluctuations in diagonal pipe diameter and the angle of incidence by plain mechanisms.

The W-truss structure as designed above was developed. The following sections will describe a series of static loading tests performed to verify the yield strength of the truss joints.

3. T-Joint Test

3.1 Outline of the test

A T-stress application test was conducted on the W-truss joint as a basic test to examine joint behavior. For this test, only one gusset was attached to the arc plate top, and static force was applied orthogonally to the axis of the main pipe to examine the combined behavior of the arc plate and the main pipe.

The specimen (**Fig. 2**) is a Circular Hollow Section (CHS) for general structures (STK 490), having an arc plate and a gusset along its centerline. The length of each of the two equal pipes between the support point at either end of the pipe and either end of the gusset is 1.0D. The arc plate and the gusset are formed by steel casting (SCW 480) into one piece, which is welded to the main pipe by fillet welding with a sufficient size. The angle of circumference is 120°, and a clearance of approx. 3 mm is given between the arc plate and the main pipe surface to help easier visual understanding of the specimen behavior.

A specimen having the main pipe size ϕD by thickness T of 216 × 5.8 (mm), and an arc plate thickness t = 20 mm, was used as a standard specimen, and parameters were used for changed main pipe size (TN), arc plate size (TS), and axial force applied to the main

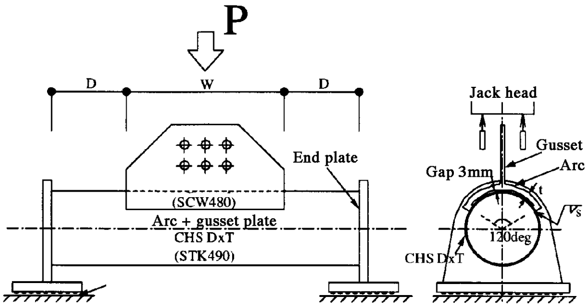

Fig. 2 T-joint test set-up

Table 1 T-joint test specimen

								Results
ID	CHS			Arc plate		CHS force	Note	Max P
	D (mm)	T (mm)	D/T	W (mm)	t (mm)	(kN)		(kN)
TN165	165.2	4.5	37	400	20	0		510
TN216-1	216.3	5.8	37	450	19		Std.	780
TN216-2		8.2	26		19			1050
TN267-1	267.4	6.6	41	500	20			830
TN267-2					19		60deg	650
TA165	165.2	4.5	37	400	20	0.3 AFy		450
TA216	216.3	5.8	37	450	20			740
TA267	267.4	6.6	41	500	20			780
TS216-1	216.3	5.8	37	450	10	0		520
TS216-2					14			670
TS216-3				350	20			680
TS216-4				550	20			820

pipe (TA), (**Table 1**). By material tensile tests, it was previously confirmed that the arc plate and the cast gusset steel had an approximately 60 percent yield strength to the main pipe.

3.2 Test results

The cut section of the specimen after the test loading (**Photo 1**) shows arc plate deformation, broken at its top and evenly pressed open and wider, as a bird spreads its wings. The flexural deformation of the main pipe concentrated on its 3 o'clock and 9 o'clock positions, and shows flattening in its area ranging between 11 o'clock and 1 o'clock positions, figuratively. The arc plate of the specimen is uniformly deformed in the axial direction of the pipe, and the clearance between it and the main pipe remains unchanged in the central portion but is lost at its both side edges along the main pipe axis where the loading force was maximal, showing the two being in contact with each other.

In terms of the general behavior of the specimens, their yield strength gradient gradually declined after entering in the elasto-plastic region and drew long-hanging yielding curves after reaching their maximum yield strength levels (**Fig. 3**). The maximum yield strength levels are nearly 3.3 times higher than those estimated of the steel pipe branch joints having the same diagonal tube and main pipe diameters shown in Reference 1).

By finite element analysis, the same specimen behavior was reproduced as given by the test, confirming that the rigidity and the yield strength of both the main pipe and the arc plate correlate with each other to decide the elastic and elasto-plastic behavior of the entire system. The following estimation equation was established for the maximum T-stress yield strength, P_y, using a mechanical model in which an arc plate and a main pipe are arranged in parallel, and also using parameters within the range of the parameters used in the test.

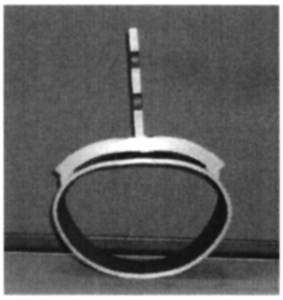

Photo 1 Cut section after loading

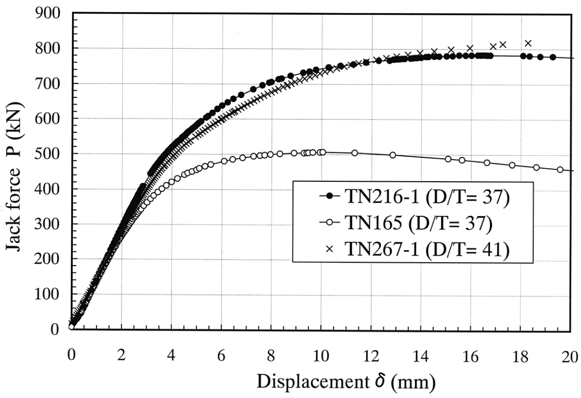

Fig. 3 T-joint test P-δ curve

$$P_y = C\,\frac{F_{yn} Z_{pn} + F_{yc} Z_{pc}}{D \cos(\pi/6)} \tag{1}$$

F_{yn}, F_{yc}: yield point of node, main pipe

Z_{pn}, Z_{pc}: plastic section modulus of main pipe

$$C = 32\,T/t\text{: } (0.23 \le T/t \le 0.58) \tag{2}$$

T, t: thickness of main pipe, arc plate

4. K-Joint Test

4.1 Outline of the test

In the next step, a K-stress applying tests was conducted using gusset joints whose field of stress is two-dimensionally simulated, to examine the unified behavior as in the T-stress test.

The test setup was as illustrated in **Fig. 4**, and the specimen parameters used were for the main pipe size (KE), arc plate size (KS), and eccentric distance (**Table 2**).

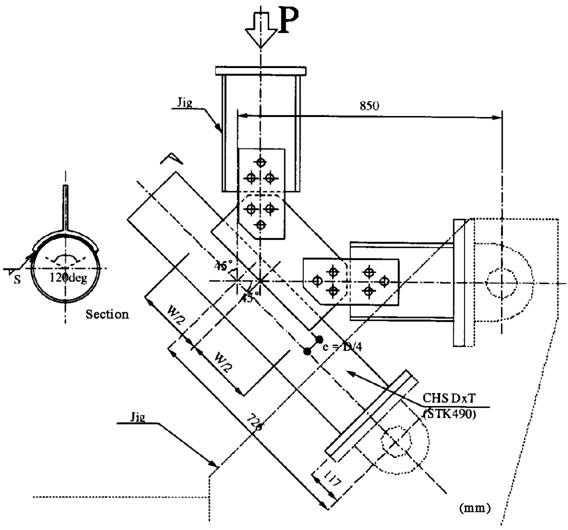

Fig. 4 K-joint test set-up

Table 2 K-joint test specimen

ID	CHS			Arc plate			Note	Results Max P
	D (mm)	T (mm)	D/T	W (mm)	t (mm)	e (mm)		(kN)
KE165	165.2	4.5	37	400	20	D/4		740
KE216-1	216.3	5.8	37	450			Std.	1140
KE216-2		8.2	26					1300
KE267	267.4	6.6	41	500				1355
KS216-1	216.3	5.8	37	450	20	0		1150
KS216-2						D/2		1075
KS216-3				350		D/4		1050
KS216-4				550				1160
KS216-5				450	10			1150
KS216-6					15			1170

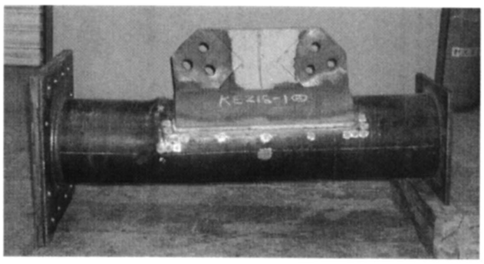

Photo 2 Typical specimen after loading

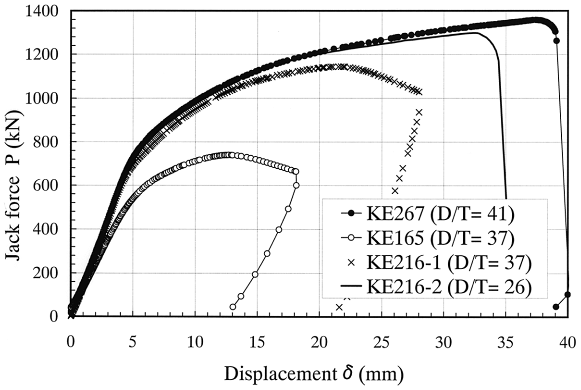

Fig. 5 K-joint test P-δ curve

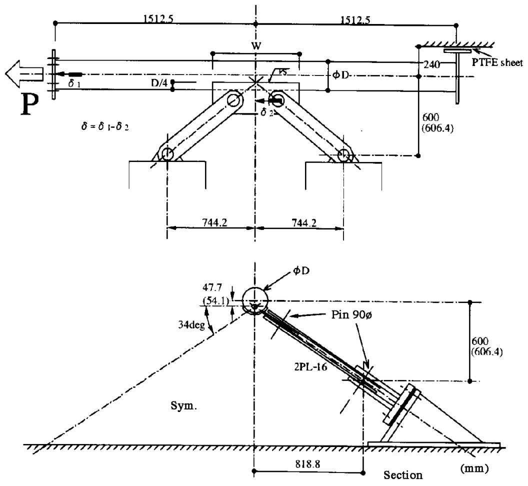

Fig. 6 X-joint test set-up

Table 3 X-joint test specimen

ID	CHS			Arc plate	
	D (mm)	T (mm)	D/T	W (mm)	t (mm)
A-1, 2, 3	190.7	5.3	36	460	13
B	216.3	5.8	37	460	11

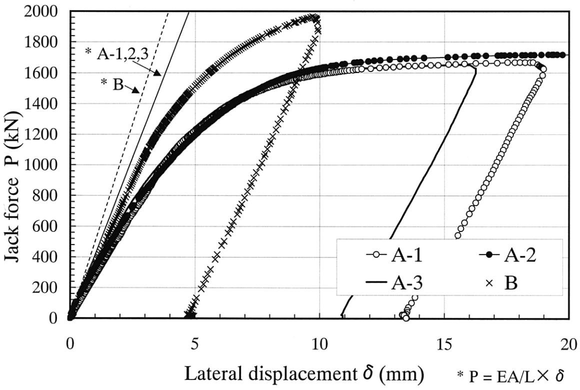

Fig. 7 X-joint test P-δ curve

4.2 Test results

In the standard specimen, its main pipe wall was noticeably deformed to show a bump-like swell, caused by axial compression and the eccentricity (D/4) of the axis of applied force, near the arc plate end on the restricted end side, reaching its maximum yield strength (**Photo 2**, **Fig. 5**). This maximum yield strength, like in the T-stress test, was approximately 3.3 times as high as the estimated strength of the steel pipe branch joints.

It was also found in this test that, as in the T-joint test, the rigidity and yield of the main pipe and the arc plate are jointly related with the behavior, and that the length of the arc plate was had little effect on it as far as the parameters used are concerned.

5. X-Joint Test

5.1 Outline of the test

In succession, an X-stress application tests was conducted to observe the properties of the main pipe and the arc plate when subjected to diagonal loading forces applied in four directions by simply pulling the main pipe axially. The gusset and the loading jig are connected with a 90mm-dia. pin to preclude possible effect of the gusset rigidity (**Fig. 6**).

5.2 Test results

The findings of the test confirmed that the specimen including the joints has sufficient elastic yield strength and that yield strength does not decline until it reaches the axial yield strength of the main pipe. The local deformation of the main pipe and the arc plate at the maximal yield strength was very small. It was also found that the rotational rigidity of the joints needs to be considered to some extent in the modeling of the truss (**Table 3**, **Fig. 7**).

Based on the verification by the series of the tests and FEM analysis, the standard thickness and shape of arc plates were determined for W-truss joints and thus a process of evaluating the yield strength of the joints against load was established.

6. Yield Strength of Gusset Ends

Subsequent to the verification of the main pipe and the arc plate, the ends of the gusset were examined with a view to finding the effect of the diagonal pipe ends upon it, since both ends of the diagonal pipe are flattened by cold press for connection with the gusset ends. The experiment results showed that the axial compression yield strength tended to decline with the pipe diameter/thickness (D/T) ratio. As a result of our examinations including working process analysis, it was determined that the flatness of the pipe end and the internal residual stress due to the cold rolling might have had an effect on the said strength declining tendency.

It is now a practice to set up yield strength reduction values for experimented pipe sizes in a certain range, and to take them into account when selecting, in designing, the thickness of pipes with flattened ends.

Tobata Chuo Elementary School Gymnasium, Kita-kyushu City.
Designed by: Takahashi Ueda Design Corporation.
Roof structure covers 24m (span) × 33m (longitudinal), and structure depth 1.2m.

Photo 3 W-truss example (Tobata Primary School Gymnasium)

7. Conclusion

In the foregoing sections, space W-truss was proposed that has new joints comprising arc plates. The verification of its structural properties were also outlined according to experiments and analyses. The Building Construction Division of Nippon Steel applied the W-truss to some buildings including the roof framing of the gymnasium at Tobata Primary School, Kita-Kyushu (**Photo 3**)

Acknowledgment

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