RESEARCH ON LIGHT-WEIGHT STAINLESS STEEL STRUCTURES IN JAPAN

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Abstract

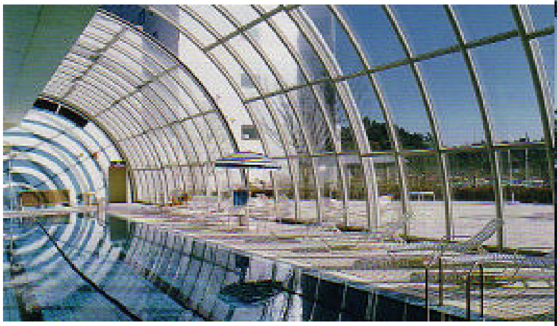
Stainless steel has a significance in corrosion resistance, which enhances the application of stainless steel in the form of thin-walled sections to light-weight structures. This paper introduces a recently established R & D program for utilizing thin stainless steel plates in building constructions. The organization of research committee, material specifications of stainless steel in the scope of the program, and topics of research subjects assigned in the program are briefly introduced. Since local buckling strength is one of the most important issues in the design of thin-walled structures, experimental results on stainless steel stub-columns are presented. Investigated sections are angle, channel, lipped channel, H-shaped, square box, and circular cylindrical sections, which are formed from two grades of austenitic stainless steels designated SUS304 and SUS301L 3/4H, whose specified yield strengths for design are 235 and 440 N/mm^2, respectively. Based on this experiment, effective width-to-thickness ratios of unstiffened and stiffened plate elements and limit diameter-to-thickness ratios of circular cylinders are established for design purposes.

1 INTRODUCTION

Stainless steel has a significance in corrosion resistance, while it has been scarcely used in structural skeletons of buildings due to high price. However, noticing the recent change in social thinking from mass production and abundant consumption to ecological coexistence with natural environment, the concept of sustaining a long life of buildings is of much importance in construction engineering. In that context, stainless steel is expected to be promising material for architectural construction of durable buildings.

The research for utilizing stainless steel in building structures was due to the advancement of cold-formed steel, especially in the USA, by G. Winter and his followers, which resulted in a design manual "***Design of Cold-Formed Stainless Steel Structural Members -Proposed Allowable Stress Design Specification with Commentary***" [1]. On the other hand, Japanese research on structural stainless steel for building use dates back only to the late 1980's growth of economy, when the researchers and engineers intended to use stainless steel in heavy steel constructions. This led to the establishment of specification of design and construction of heavy stainless steel structures published by Stainless Steel Building Association of Japan [2]. Typical structures which were built from relatively thick stainless steel plates are shown in Figure **1**, some of which were designed on the bases of the specification. They are a roof of swimming pool, a temple, a pinnacle, a canopy, a top light of atrium, a shelter of bus stop, a monument, and a walking bridge. These structures were designed with an intension to be maintenance free and of long-term duration.

The most promising use of stainless steel in ordinary buildings is obviously in the form of light-weight members relying on corrosion resistance, which may compensate for the high cost of fabrication as



Roof of swimming pool (Chiba pref. / Japan)
- SUS304 (10 ton)

Temple (Yamanashi pref. / Japan) - SUS304 (63 ton)

Pinnacle (Petronas Tower / Malaysia)
- SUS304, SUS316 (2,300 ton for one tower including exteriors)

Canopy (Hokkaido pref. / Japan)
- SUS304 (2 ton)

Bus stop shelter
(Yamaguchi pref. / Japan)
- SUS304

Monument of Atomic Energy Research Center
(Hyogo pref. / Japan) - SUS304 (4.5 ton)

Top light of atrium (Tokyo / Japan)
- SUS304 (8 ton)

Walking bridge (Aichi pref. / Japan)
-SUS304 (8 ton)

Figure 1 Examples of stainless steel constructions well as material itself. In Japan, thin stainless steel sections are particularly expected to be used in prefabricated steel houses. 150,000 houses are constructed per year of which about 80% are prefabricated houses. Thus, we need a design method for thin-walled sections of stainless steel preferably with a higher strength in order to reduce weight.

This paper introduces the outline of a research program which is now underway to develop an application methodology of thin-walled stainless steel products [3], and also introduces the state-of-the-art design method for taking account of local buckling which is the most important design consideration for light-weight steel constructions [4], [5], [6], [7]. Other recent achievements attained in the program can be found in the references placed at the end of this paper [8], [9], [10], [11], [12], [13].

2 Outline of R & D Program

2.1 Research Organization

In 1998 a committee, which is responsible for the R & D program of utilizing thin stainless steel plates in building construction was set up by the Stainless Steel Building Association of Japan. The committee was chaired by the author, and the members were selected from steel industries and universities. Nineteen companies from steel manufacturers, fabricators, and welding rod and bolt makers, and three universities, the University of Tokyo, Tokyo Institute of Technology, and Tsukuba University joined the program.

2.2 Stainless Steels in the Scope of the Program

Material

There are various types of stainless steels, from which two representative grades of stainless steels designated by SUS 304 and SUS 301L 3/4H were selected. The specified yield strengths for design, namely ***F***-values, of SUS 304 and SUS 301L 3/4H are planned to be 235 N/mm^2 and 440 N/mm^2, respectively. The former one is correspondent to mild steel, while the latter is to high strength steel in the conventional carbon steel constructions. Both stainless steels are austenitic types which are solution heat-treated after cold rolling, but SUS301L 3/4H is further thermal-refined and rolled to increase strength. Other secondarily-used stainless steels are also included in the scope of the Program, as shown in Table 1, on the understanding that martensitic and ferritic types of stainless steels without nickel (Ni) are less expensive than the austenitic type with nickel. These secondary grades of stainless steels are examined in tensile coupon test, but are not examined in the series of structural experiment on the assumption that the secondary grades are equivalent to the representative grades in structural behaviours. The assumption, however, should be verified by comparing their stress-strain curves.

Table 1 Stainless steels in the scope of the R & D program

Representative grades	***F***-value N/mm^2	Secondary grades	Remarks	
SUS304	235	SUS316, SUS301L	Austenitic	Ni+Cr+(Mo)
		SUS410S	Martensitic	Cr
		SUS410L, SUS436L	Ferritic	Cr
SUS301L 3/4H	440	SUS301L MT	Austenitic (hardening) Ni+Cr+(Mo) SUS301L MT is in JR Standards.	

Shape and Thickness

The shapes of stainless steel products were scheduled as shown in Figure **2** on the basis of currently used light-gauge sections of carbon steels. The selected shapes are angle, channel, lipped channel, H-shaped, square box, and circular cylindrical sections. The first three sections are formed only by cold forming, while the latter three sections need welding. The thickness is planned in the range of 1.0 to 6.0 mm with a focus of the most popular thickness ranging from 2.3 to 3.2 mm in light-weight steel structural buildings.

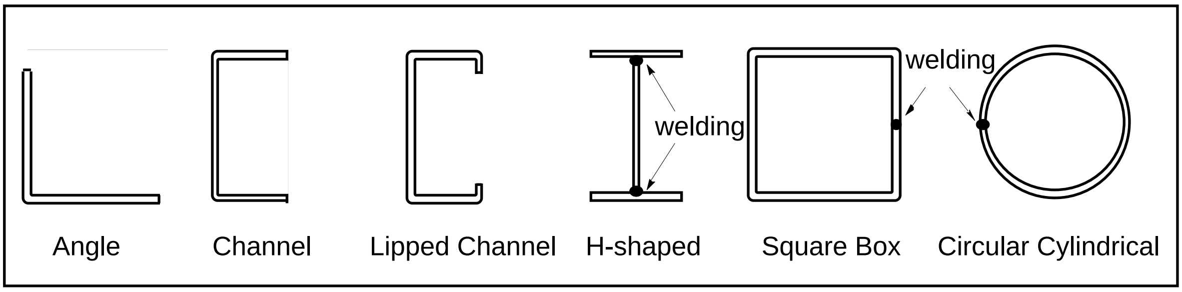


Figure 2 Shapes of thin-walled stainless steel in the scope of the R & D program

Table 2 Classification of structural steels in JIS

Form-ing	Carbon steel		Stainless steel	
	General use	Building use	General use	Building use
Hot	Rolled steels for general structure SS (JIS G 3101) Rolled steels for welded structure SM (JIS G 3106) Hot-rolled atmospheric corrosion resisting steels for welded structure SMA (JIS G 3114)	Rolled steels for building structure SN (JIS G 3136) Rolled bars for building structure SNR (JIS G 3138) Carbon steel tubes for building STKN (JIS G 3475)	Hot rolled stainless steel plates, sheets, and strip SUS-HP (JIS G 4304) Hot rolled stainless steel equal leg angles SUS-HA (JIS G 4317)	Stainless steel for building structure SUS-A (JIS G 4321) SUS304A SUS316A SUS304N2A SCS13AA-CF
Cold	Light gauge steels for general structure SSC (JIS G 3350) Welded light gauge H steels for general structure SWH (JIS G 3353) Carbon steel tubes for general structure STK (JIS G 3444) Carbon steel square pipes for general structure STKR (JIS G 3466)		Cold rolled stainless steel plates, sheets, and strip SUS-CP (JIS G 4305) Cold rolled stainless steel equal leg angles SUS-CA (JIS G 4320)	Light gauge steels for building structure (tentative) SUS-OO (JIS G xxxx) Light gauge steels, Welded light gauge H steel, Tubes, and Square pipes; Ni-Cr series and Cr series; Solution heat-treated, and Thermal-refining rolled

Table 3 Classification of design specifications of steel structures

Authority	Name of specification	Carbon steels		Stainless steels	
		within b/t limit	beyond b/t limit	within b/t limit	beyond b/t limit
Ministry of Land, Infrastructure, and Transport	Building code	SN400A (F=235) SN490B (F=325) etc.	SSC400 (F=235)	SUS304A (F=235) SUS316A (F=235) SUS304N2A (F=325) SCS13AA-CF (F=235)	
Stainless Steel Building Association of Japan	Design standard for stainless steel structures				
	Design standard for light weight stainless steel structures (Tentative)				SUS304 (F=235) SUS301L 3/4H (F=440)
Architectural Institute of Japan	Design standard for steel structures	SN400A (F=235) SN490B (F=325) etc.			
	Recommendations for the design and fabrication of light weight steel structures		SSC400 (F=235)		

Note : Unit of F-values is N/mm2. F-values for carbon steels are applicable to thickness not more than 40mm.

Relevant JIS Specifications

The stainless steels in the scope of the Program are expected to be newly placed in Japanese Industrial Standards (JIS) as shown in the shaded area of Table 2. This plan is under discussion in steel industries.

2.3 Joint Method

The method of joining thin-walled stainless steel members such as beam-to-column and column-to-base may not be the same as those of thick sections. Another techniques of welding such as laser welding and TIG welding, which are not common in heavy steel constructions, may be effective in thin-walled sections. High-strength bolts may be less applicable, while ordinary-strength bolts and screw bolts would be more effective in thin-walled stainless steel structures.

2.4 Design Method

Allowable Stress Design

There are three design methods in steel constructions, i.e., Allowable Stress Design (Elastic Design), Ultimate Strength Design (Plastic Design), and Limit State Design (Probability-Based Design), which appeared in this order in the history of structural design. The Committee adopted Allowable Stress Design in the light-weight stainless steel structures. This is because thin-walled stainless steel members are not expected to exhibit enough ductility required in Plastic Design due to premature failure caused by local buckling of thin plate elements, and also the data samples on structural resistance of the newly developed stainless steels are not enough to satisfy the process of statistical estimation which is required in Probability-Based Design.

Relevant Design Codes

The design specification which the Committee is planning to establish is put in the current group of design specifications as indicated by the shaded cell in Table 3. The new specification is devoted to the design of stainless steel structures in which width-to-thickness ratios of plate elements are beyond the ***b*** / ***t*** limits. The ***b*** / ***t*** limits are those within which the working stresses of plate elements in compression can reach the yield stresses of the materials.

Table 4 Topics of research in the R & D program

Subject		Experiment	Purpose	Institute in charge
Category	Item			
Material	Stress-strain characteristics	Coupon test	Collect stress-strain curves of all types of stainless steels in the scope of the R & D Program, and confirm that SUS304 and SUS301L 3/4 steels represent the other types.	Steel maker
Member	Plate element	Stub column test	Investigate local buckling behavior of angle, channel, lipped channel, H-shaped, square box, and circular hollow sections, and determine the effective width for design.	the Univ. of Tokyo
	Column	Long column test	Investigate Euler buckling behavior of angle, H-shaped, and circular hollow section columns, and determine column design curve incorporating the interaction of local buckling.	the Univ. of Tokyo
	Beam	Bending test	Investigate lateral buckling of channel and H-shaped beams, and determine design formula for allowable bending stress.	Tsukuba Univ.
	Beam-column	Bending test under compression	Investigate lateral-torsional buckling of H-shaped, square box, and circular hollow section beam-columns, and determine design formula for allowable stress in the combination of compression and bending.	Tsukuba Univ.
	Truss	Bending test	Investigate bending strength of pipe truss, and verify the design formula for compressive members and welded connections.	Tokyo Inst. of Tech.
Connect-ion	Fastener connection	Tensile test	Investigate slip, yielding, and fracture behavior of fastener connections, and determine the design formulae for allowable stress and ultimate strength.	the Univ. of Tokyo
	Welded connection	Crack sensitivity test and tensile test	Investigate weldability and determine the welding method and conditions for assuring 0-% crack occurrence, and confirm fully strengthened condition of welded joint.	Steel maker
	Pipe branch	Tensile and compressive test	Investigate joint strength of pipe branch welds, and determine design formula for tensile and compressive strength of pipe branches.	Tokyo Inst. of Tech.
Durability	Corrosion resistance of base and weld metal	Exposure test and corrosion accelerated test	Investigate corrosion of base metal and weld metal, and determine the interaction curve of corrosion rate and environmental condition.	Steel maker
	Corrosion resistance of fastener connection	Stress corrosion test	Investigate stress corrosion of bolted and high-strength-bolted connections, and determine the durability design formula.	the Univ. of Tokyo

2.5 Research Topics

The subjects of research assigned by the Committee are summarized in Table 4. Research topics cover all of the aspect of structural behaviours. It is noted, furthermore, that the problem of durability is newly included, because the corrosion resistance should be well quantified in comparison with the ordinary carbon steels.

3 Solution for Local Buckling

3.1 Tested Material

Stainless steels investigated for resolving the local buckling problem are SUS304 and SUS301L 3/4H as described above. Their chemical compositions and mechanical properties written in mill sheet are summarized in Table 5. It is observed that SUS301L 3/4H steel strips have higher yield ratios and less ductility than SUS304 steel strips.

Mechanical properties of coupons are investigated also in laboratory as shown in Table 6. It is known that stainless steels have following distinguishable mechanical properties in comparison with carbon steels : (1) proportional limits of stainless steels are fairly low and non-linearity appears at a low stress level, (2) strain hardening of stainless steels is considerable and thus yield ratios (yield strength /

Table 5 Material properties written in mill sheet

stainless steel	specification	thickness (mm)	chemical composition (%)							mechanical properties			
			C	Si	Mn	P	S	Ni	Cr	0.2%-offset strength (MPa)	tensile strength (MPa)	yield ratio	elongation (%)
SUS 304	JIS G 4305 cold-rolled strip	3.0	0.07	0.52	0.78	0.040	0.005	8.06	18.30	279	641	0.44	57
		1.0	0.05	0.38	1.00	0.036	0.004	8.10	18.26	—	633	—	55
		1.5	0.05	0.26	1.04	0.032	0.007	8.11	18.45	—	649	—	52
	JIS G 3459 pipe		0.05	0.53	0.98	0.034	0.005	8.33	18.12	312	583	0.54	53
			0.04	0.59	0.96	0.028	0.006	8.29	18.18	261	612	0.43	59
SUS 301L 3/4H	JIS G 4305 cold-rolled strip (thermal refining)	3.0	0.02	0.36	1.40	0.030	0.005	6.62	17.45	508	829	0.61	43
		1.5								511	832	0.61	41

tensile strength) are very low, and (3) initial Young's modulus of stainless steels is slightly smaller than carbon steels (nominal value of Young's modulus of stainless steels is 193,000 N/mm^2, while that of carbon steels is 205,000 N/mm^2). From the first item, yield strength of stainless steels for design is defined as 0.1%-offset yield strength of coupon test [2], while 0.2%-offset yield strength is generally used in material specification as in Japanese Industrial Standards. This study adopts the definition of 0.1%-offset yield strength.

3.2 Stub-Column Specimens

Sections of stub-columns are angle with equal legs, channel, lipped channel, H-shaped, square hollow, and circular hollow as shown in Figure **3**. Angle, channel, and lipped channel were cold-press-formed from 3 mm thick cold-rolled stainless steel strips, partly 1 mm thick for lipped channel. H-shaped sections were fabricated from 3 mm thick cold-rolled stainless steel strips by laser beam welding or partly by TIG welding. Square hollow sections were fabricated from two cold-press-formed channels by laser beam welding. Circular hollow sections were cold-press-formed from 1.5 mm thick cold-rolled stainless steel strips by means of TIG welding except 76.3-mm and 48.6-mm diameters of SUS304 which were formed from hot-rolled strips by automatic arc welding.

Table 6 Mechanical properties obtained from laboratory coupon test

stainless steel	shape		Nominal thickness (mm)	Measured thickness (mm)	0.1%-Offset strength (MPa)	Tensile strength (MPa)	Yield ratio	uniform elongation (%)	rupture elongation (%)	initail Young's modulus (MPa)
SUS 304	cold-rolled strip		3.0	2.92	249	—	—	—	—	203,000
			1.0	0.94	257	—	—	—	—	203,000
	pipe	D48.6	1.5	1.42	239	600	0.40	57	63	202,000
		D76.3		1.40	239	694	0.34	69	73	202,000
	press-formed pipe from cold-rolled strip	D101.6		1.38	331	737	0.45	55	60	222,000
		D139.8		1.38	318	750	0.42	58	62	222,000
		D165.2		1.36	301	742	0.41	57	61	222,000
SUS 301L 3/4H	cold-rolled strip		3.0	3.01	497	845	0.59	40	42	206,000
	press-formed pipe from cold-rolled strip	D48.6	1.5	1.51	496	932	0.53	45	51	150,000
		D76.3		1.50	458	928	0.49	46	53	177,000
		D101.6		1.51	451	904	0.50	45	51	185,000
		D139.8		1.49	420	902	0.47	48	54	187,000
		D165.2		1.49	420	889	0.47	53	59	188,000

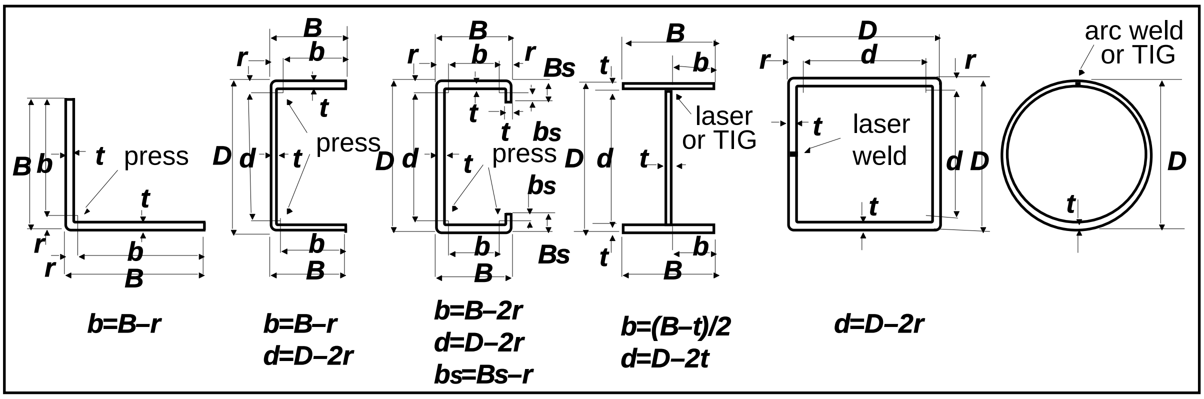


Figure 3 Sections of stub-column specimens

Width in this paper is defined as the width of a flat plate element excluding corners as shown in Figure 3. For example, the width ***b*** of an angle is equal to ***B*** − ***r***, in which ***B*** and ***r*** are the whole width and the outer radius of the corner, respectively, and the width ***d*** of a channel web is equal to ***D*** − 2***r***, in which ***D*** is the whole depth. For an H-shaped section, flange width ***b*** and web width ***d*** are determined by neglecting weld, because the fillet size by laser or TIG welding is very small. For circular hollow sections, outer diameter ***D*** is adopted in the calculation of diameter-to-thickness ratio. Length of each stub-column specimen is three times the whole width of the section, but for channel, lipped channel, and H-shaped sections, the length is the larger of 3***B*** and 3***D***. Seventy three specimens of stub-columns were scheduled as listed in Table 7. The section sizes in the table are nominal, while measured sizes are used in the buckling analysis.

Table 7 Schedule of stub-column specimens

section of stub-column	stainless steel	specified yield stress for design ***F*** (MPa)	nominal thickness (mm)	nominal width (mm)	nominal width-to-thickness ratio	number of specimens
angle	SUS304	235	3	B 25~60	b/t 6~18	6
	SUS301L 3/4H	440		B 25~60	b/t 6~18	6
channel	SUS304	235	3	B 2550 D 50~150	b/t 6~15 d/t 13~46	6
	SUS301L 3/4H	440		B 25~50 D 50~150	b/t 6~15 d/t 13~46	5
lipped channel	SUS304	235	3	B 50~75 Bs 20~25 D 100~200	b/t 13~21 bs/t 5~6 d/t 29~63	4
			1	B 17~25 Bs 7~8 D 33~67	b/t 13~21 bs/t 5~6 d/t 29~63	4
	SUS301L 3/4H	440	3	B 50~75 Bs 20~25 D 100~200	b/t 13~21 bs/t 5~6 d/t 29~63	4
H-shaped	SUS304	235	3	B 50~150 D 50~200	b/t 8~25 d/t 13~65	8
	SUS301L 3/4H	440		B 50~50 D 50~200	b/t 8~25 d/t 13~65	8
square hollow	SUS304	235	3	D 50~200	d/t 13~63	6
	SUS301L 3/4H	440		D 50~200	d/t 13~63	6
circular hollow	SUS304	235	1.5	D 48.6~165.2	D/t 33~110	5
	SUS301L 3/4H	440		D 48.6~165.2	D/t 33~110	5

3.3 Effective Width of Flat Plate

Application of Karman Equation

The onset of local buckling of a flat plate does not mean the failure, because post-buckling stability with an elevation of strength is usually expected. After overloading beyond the peak of post buckling strength, columns collapse as demonstrated in Figure **4**. This post-buckling strength is owing primarily to redistribution of stress in a buckled plate in which higher stresses beyond the buckling initiation stress are distributed in a section adjacent to its support edge as illustrated in Figure **5**. This redistribution of stresses is enough to compensate the release of axial stress at the middle of the bent plate. Since the out-of-plane deformation at the maximum strength is not serious, usually invisible, a thin plate can be economically designed on the basis of post-buckling strength. Here, the concept of effective width proposed by Karman is applied.

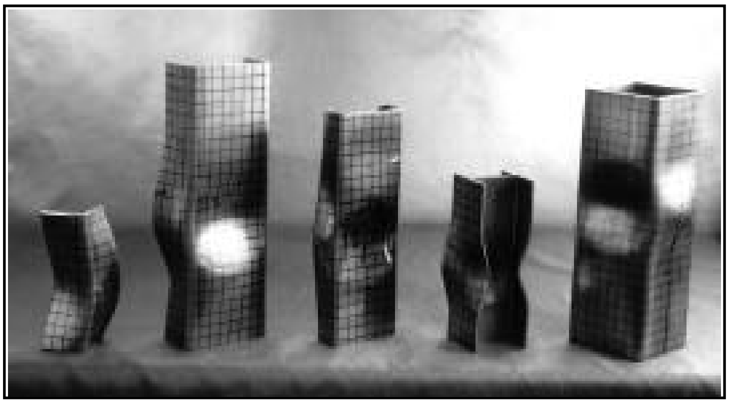


Figure 4 Local buckling of thin-walled stainless steel stub-columns

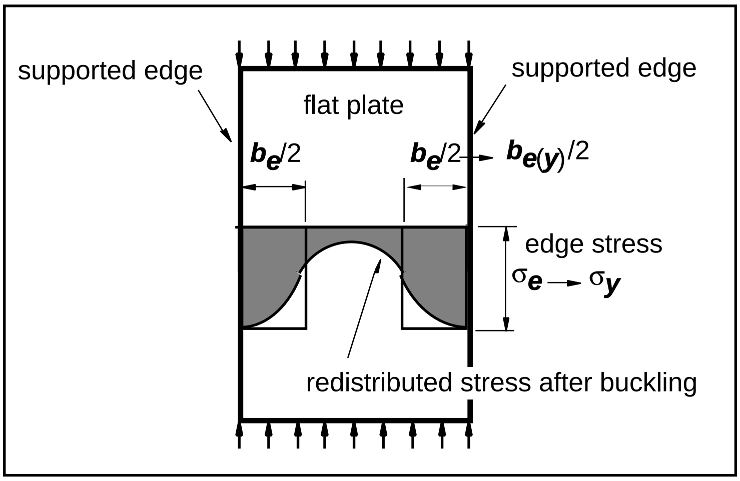


Figure 5 Karman's effective width

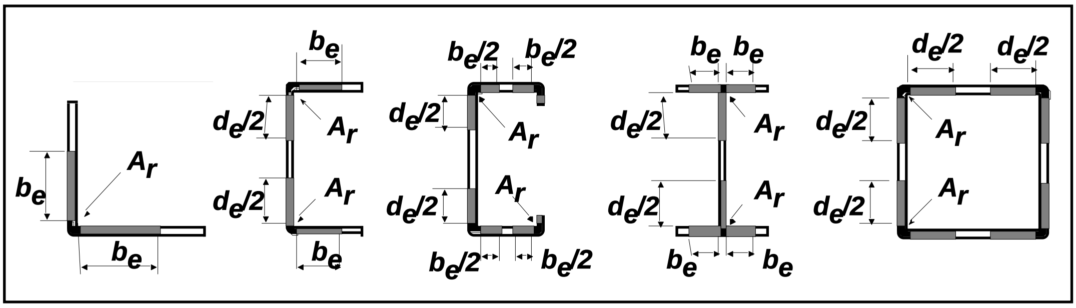


Figure 6 Effective width

According to the idea of Karman, following formula is commonly used in the allowable stress design of light-gage sections of steel, in which ***C*** is determined from experiment.

$$\frac{b_e}{t} = \frac{C}{\sqrt{\sigma_y}} \qquad (1)$$

The effective width denoted by b_e or d_e, as shown in Figure **6**, is a virtual width adjacent to its edge, over which edge stress equal to yield stress σ_y is uniformly distributed and the stress resultant is equal to the maximum compressive force.

Effective Width of Angle Sections

An angle section with equal legs is composed of two unstiffened plate elements each of which is pin-supported at one edge and free at the other. Now, we define an experimental effective width b_e^* as follows:

$$\left(\sum b_e^* t + \sum A_r \right) \sigma_y = P_{\max} \tag{2}$$

where the first $\sum$ means the summation of effective sectional areas of flat plates and the second is the summation of the corner areas A_r. For an angle section two flat plates and one corner are involved. The σ_y is the 0.1%-offset yield stress obtained from tension test, and $P_{\max}$ is the maximum compressive force of the stub-column.

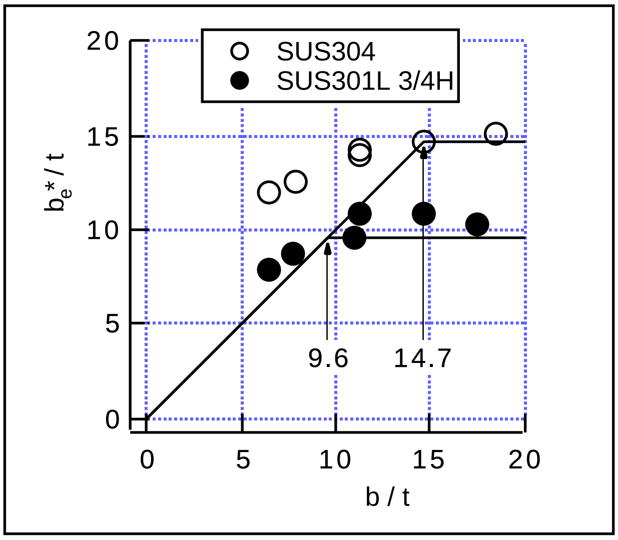


Figure 7 Effective width-to-thickness ratio of angle

Experimentally determined effective width-to-thickness ratios b_e^*/t which are calculated from Equation (2) are plotted against actual width-to-thickness ratios b/t in Figure **7**. It is noted that b_e^*/t-values of angles with small width-to-thickness ratios are greater than b/t-values, because strain hardening beyond full yielding of entire section can be attained. The observed limit value of b/t to assure full yielding is 14.7 for SUS304 and 9.6 for SUS301L 3/4H, beyond which experimental b_e^*/t-values tend to keep constant. The actual yield stresses of these plates are 249 and 497 N/mm^2, respectively. Substituting these values into Equation (2), the values of C of Equation (1) can be obtained with the following results:

$$\frac{b_e}{t} = \frac{230}{\sqrt{\sigma_y}} \quad \text{for unstiffened plates of SUS304} \tag{3a}$$

$$\frac{b_e}{t} = \frac{215}{\sqrt{\sigma_y}} \quad \text{for unstiffened plates of SUS301L 3/4H} \tag{3b}$$

It is noted that the same number is not assigned to $\boldsymbol{C}$ for the two grades of stainless steels. This indicates that the patterns of stress distribution at the maximum strength are not the same for the two grades of stainless steels. The reason why SUS304 has a higher $\boldsymbol{C}$-value than SUS301L 3/4H may be attributed to the fact that the former material has larger strain-hardening than the latter.

Effective Width of Square Hollow Sections

A square hollow section is composed of four stiffened plate elements each of which is pin-supported at both edges. As is the case of an angle, Equation (2) is applied to square hollow sections with a change of $\boldsymbol{b_e^*}$ by $\boldsymbol{d_e^*}$, from which $\boldsymbol{d_e^*}/\boldsymbol{t}$ vs. $\boldsymbol{d}/\boldsymbol{t}$ is plotted in Figure **8**. The observed limit value of $\boldsymbol{d}/\boldsymbol{t}$ to assure full yielding is 39.0 for SUS304 and 23.8 for SUS301L 3/4H which have actual yield stresses of 249 and 497 N/mm^2, respectively. Substituting these values into Equation (1), $\boldsymbol{C}$ is calculated and the following equations are established. In this case, too, different $\boldsymbol{C}$-values are given to SUS304 and SUS301L 3/4H.

$$\frac{\boldsymbol{d_e}}{\boldsymbol{t}} = \frac{615}{\sqrt{\sigma_{\boldsymbol{y}}}} \quad \text{for stiffened plates of SUS304} \tag{4a}$$

$$\frac{\boldsymbol{d_e}}{\boldsymbol{t}} = \frac{530}{\sqrt{\sigma_{\boldsymbol{y}}}} \quad \text{for stiffened plates of SUS301L 3/4H} \tag{4b}$$

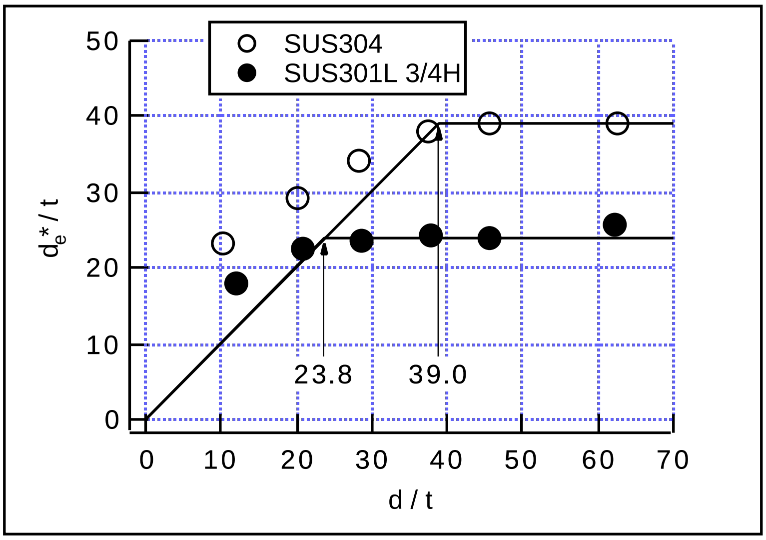


Figure 8 Effective width-to-thickness ratio of square box

Effective Width of Channel, Lipped-channel, and H-shaped Sections

The plate elements constituting channel, lipped channel, and H-shaped sections are not under the same stress condition after the moment of buckling. They may restrain each other at the state of post-buckling. Here, however, we assume that no interaction acts between the adjacent plates. For example, a channel is assumed to be composed of three independent plates such that a web plate is pin-supported at both edges and flange plates are pin-supported at one edge and free at the other. From this simplification, effective width can be calculated from Equation (3) for flange plates and Equation (4) for web plates. Effective width-to-thickness ratios predicted by this method are summed up over the entire section, which is denoted by $\left(\sum \boldsymbol{b_e}/\boldsymbol{t}\right)_{\mathrm{pred}}$. On the other hand, stub-column test gives the experimental effective width as follows:

$$\left(\sum \boldsymbol{b_e t} + \sum \boldsymbol{A_r}\right)\sigma_{\boldsymbol{y}} = \min\left\{\boldsymbol{A}\sigma_{\boldsymbol{y}}, \boldsymbol{P}_{\max}\right\} \tag{5}$$

From this equation, $\left(\sum b_e / t\right)_{exp}$ can be calculated. Both are compared in Figure **9**. The predicted width-to-thickness ratios on the assumption of no interaction tend to underestimate the actual ones in experiment. However, the error is less than 20% and conservative, which indicates that effective width of channel, lipped channel, and H-shaped sections can be calculated from Equations (3) and (4) on the assumption of no interactions between plate elements.

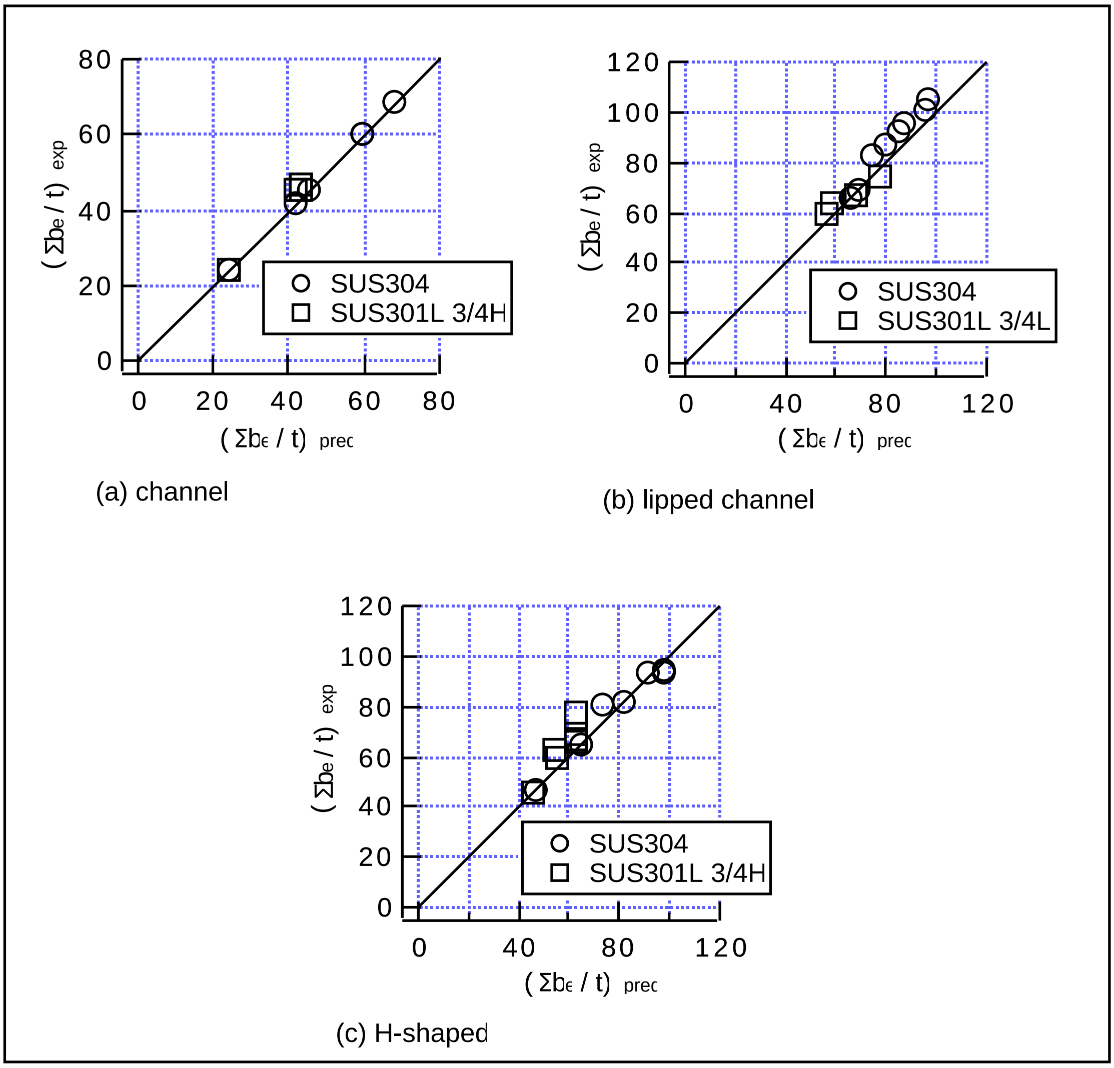


Figure 9 Prediction vs. experiment of effective width-to-thickness ratio

3.4 Limit Diameter-to-thickness Ratio of Circular Hollow Section

The buckling behaviour of a cylindrical shell is rather different from the buckling of a flat plate as shown in Figure **10**. The post-buckling strength which are commonly observed in flat plates is not expected in circular hollow sections.

Limit diameter-to-thickness ratio to assure full yielding of a thin circular cylinder for design is generally represented by following equation on the basis of Donnell's solution and the coefficient $\boldsymbol{C}_2$ is determined from experiment.

$$\left(\frac{\boldsymbol{D}}{\boldsymbol{t}}\right)_{\lim} = \frac{\boldsymbol{C}_2}{\sigma_{\boldsymbol{y}}} \tag{6}$$

All of the cylinders in this study can sustain full yield strength as shown in Figure **11**. Thus, the limit value cannot be obtained. However, from a conservative consideration, $\boldsymbol{C}_2$-values are tentatively assign as follows which are the maximum values verified in the test:

$\boldsymbol{C}_2 = 32{,}500$ for circular cylinder of SUS304 (7a)

$\boldsymbol{C}_2 = 46{,}800$ for circular cylinder of SUS301L 3/4H (7b)

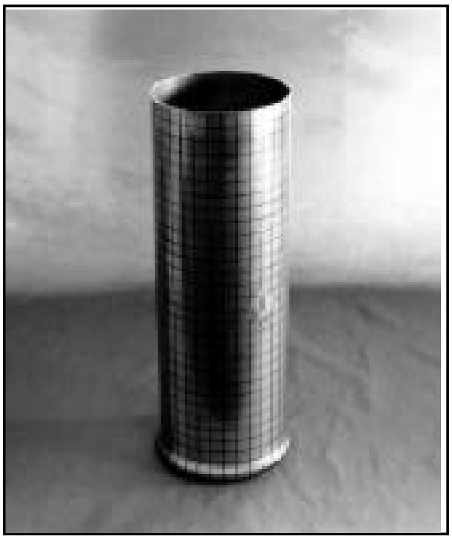


Figure 10 Local buckling of thin-walled stainless steel cylindrical stub-columns

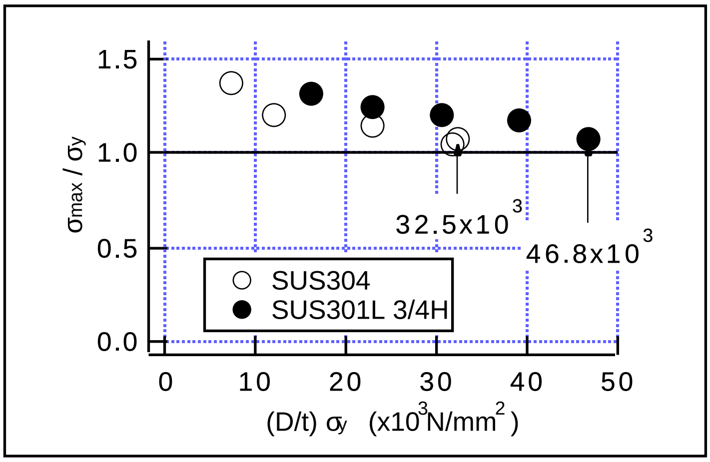


Figure 11 Maximum compressive strength of circular cylinder

4 Conclusions

A recently established R & D Program for utilizing thin stainless steel plates in building construction was outlined. The establishing of a committee by the SSBA, material grades of stainless steel, topics of research assigned in the Program are briefly presented. Since local buckling is the most critical concern in the design of light-weight steel structures, state-of-the-art design approach for taking account of local buckling of thin stainless steel members is reported here. Thin-walled stub-columns formed from two grades of stainless steels designated by SUS304 and SUS301L 3/4H are tested. Based on post-buckling strength, effective width-to-thickness ratios $\boldsymbol{b_e} / \boldsymbol{t}$ and $\boldsymbol{d_e} / \boldsymbol{t}$ are determined. The $\boldsymbol{b_e} / \boldsymbol{t}$ of unstiffened plates is derived from angle specimens, which is given by Equation (3). The $\boldsymbol{d_e} / \boldsymbol{t}$ of stiffened plates is derived from square tube specimens, which is given by Equation (4). The effective width of channel, lipped channel, and H-shaped sections can be calculated on the assumption of pin-supports between adjacent plates. The limit diameter-to-thickness ratios of circular cylinders are conservatively given by Equations (6) and (7).

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