Chinese National Standards CNS

Specification for the Design of Crane Structures

General No. 6426 Catalog No. B 1216

1. Scope of Application: This standard applies to the calculation for the design of crane structures for general purposes. However, the specified formula and values below may not be used if proven applicable with appropriate theories or experiments.
   Note: In this standard the units and values shown in the {} are based on SI units and attached for reference.
2. Definition of terms: The terms used in this standard comply with the requirements specified in CNS 5510, CNS 5675, CNS 5677 and CNS 5678.
3. Materials: The materials used in the crane structures shall conform to the requirements in Table 1 or be of equivalent properties.
   In addition, the constants used in the materials shall conform to Table 2.

Table 1 Materials

Steel plates, steel shapes, flat bars and round bars	CNS 2800	Ductile steel for general structures	S(41)C
	CNS ____	Ductile steel for welded structures	S_____
Steel pipes	CNS ____	Carbon steel pipes for general structures	S___C(P)
	CNS ____	Rectangular tubes for general structures	S_____
Rivets	CNS 2800	Round bars for riveting	S(34)C(R
Pins and bolts	CNS 2800	Ductile steel for general structures	S(41)C
	CNS 2800	Carbon steel for mechanical fabrication	S20C1, S35C
High-strength bolts and nuts	CNS ____	The entire set of high-strength hex bolts, hex nuts and flat washers for friction connections	S_____

Table 2 Material Constants

Modulus of Elasticity, E	2.1×10^6 kgf/cm^3 (2.1×10^5 N/mm^3)
Shear Modulus of Elasticity, G	8.1×10^5 kgf/cm^3 (8.1×10^4 N/mm^3)
Poisson's ratio, 1/m	0.3
Linear expansion coefficient, α	1.2×10^{-5}
Specific weight, γ	7.85

4. Types of cranes: Based on the conditions of performance, cranes are categorized into Class I, II, III and IV. This categorization is based on the combination of operation frequency and work load of cranes. Table 4 shows the example of categorization in types and uses of cranes.

Table 3 Types of Cranes

Operation frequency		Little	Medium	Large	Extremely large
The number of times for load bearing		Irregularly used with long time of suspension	Regularly used with spaced frequency	Regularly used with intense frequency	Continuously used with intense frequency
Loading		Less than 10^5	10^5 ~ $6x10^5$	$6x10^5$ ~ $2x10^6$	Greater than $2x10^6$
Light	Seldom lifting rated loads, usually lifting less than 1/3 of rated load.	I	I	II	III
Medium	Sometimes lifting rated loads, usually lifting 1/3~2/3 of rated load.	I	II	III	IV
Heavy	Lifting rated loads on a regular basis.	II	III	IV	IV

Table 4 Examples of Crane Categorization

Type of crane	Uses	Category	Remark
Elevated mobile cranes	Manual cranes, cranes for power generation, cranes for disassembling and inspecting	I	
	Cranes for warehouses, material storages, mechanical and assembly shops and general industries	I or II	
	Elevated cranes for steel refineries	II or III	For servicing
		III or IV	For working
	Electromagnetic cranes with grab	III or IV	
	Forklifting cranes	III or IV	
	Casting cranes	IV	$\Psi^{(1)} = 1.25$
	Cranes for disassembling, furnace cranes	IV	
	Feeder cranes	III or IV	
	Forging cranes	IV	
Bridge cranes	Cranes for power plants, cranes for disassembling and inspecting	I	
	Cranes for assembly shops and material storages	II or III	
	Cranes for stacking products and containers	III	
	Electromagnetic cranes with grab	III or IV	
	Unloader	IV	
Extension cranes	Cranes for disassembling and inspecting	I	
	Cranes for assembly shops and material storages	II or III	
	Dock cranes (witch boom)	II or III	
	Electromagnetic cranes with grab	III or IV	
	Unloader	IV	

	Construction cranes	II	
	Cranes for heavy lifting	I	
Wire cranes	Cranes for moving heavy objects	II	
	Cranes for dam construction	IV	Ψ = 1.4
A-type derricks	A-type derricks for heavy lifting	I	
	A-type derricks for general construction works	II	
Others	Floating dock cranes with hook	II	
	Floating dock cranes with grab	III or IV	
	Racking cranes	I	

Note: Ψ is the impact factor. Refer to Table 7 in 5.2.1.

5. Loads:

5.1 Loads to be considered: The following loads shall be considered in the design of steel structures.

5.1.1 Lifting loads: Rated load plus hooked pulley, grab, hanger beam and electric magnet etc and the weight of wire when lift is greater than 50m.

5.1.2 Self weight: The weights of the parts that the crane consists of, excluding the weights mentioned in 5.1.1. For the self weight of mobile cranes, the weights of the miscellaneous parts in the hopper and built-in conveyer of the crane are considered part of the self weight of the crane.

5.1.3 Horizontal loads: The following loads are considered as horizontal loads:

(1) Inertial force: The inertial forces generated in accelerating and decelerating due to the longitudinal and transverse movement, horizontal shifting or spinning of the crane, usually considered as β times of the weight of moving parts and lift load, conform to the following requirements. However, when driven by wheels in longitudinal or transverse movement, the maximum is 15% of wheel moving load. In addition, when spinning, it shall be considered that the load is located at the tip of extension arm.

Horizontal shifting $\beta = 0.01\sqrt{V}$

Longitudinal and transverse movements $\beta = 0.008\sqrt{V}$

Spinning $\beta = 0.006\sqrt{V}$

Where V is the speed of movement (m/min)

(2) Centrifugal force: The force acting outward along the direction of radius due to spinning, which conforms to the following equation:

$$F = \frac{W \cdot V^2}{g \cdot R}$$

Where P: Centrifugal force (kgf) {N}

W: Lift load (kgf) {N}

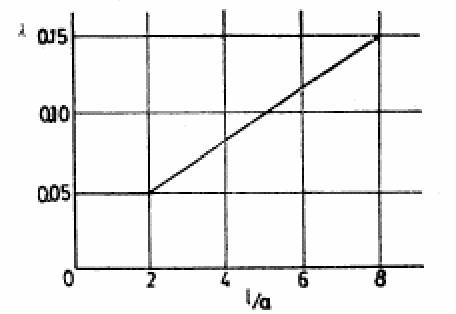
g: Gravitational acceleration (m/s^2)

R: Radius of spinning (m)

V: Tangential velocity of circumference (m/s)

(3) Lateral force on the wheels: The horizontal force acting perpendicularly to the advancing direction of wheels, which is proportional to the span and the effective distance between axes and determined from Fig. 1. The determination of the effective distance between axes can be found in Fig. 2(a), 2(b) and 2(c). Where there are 4 wheels on one track, it is the distance between the centers of outer wheels and the distance between the middle points of two outer wheels at the front and back if there are 4 to 8 wheels. If more than 8 wheels, it is the distance between the middle points of three outer wheels at the front and back [shown in Fig. 2(c)]. However, if horizontal guide wheels are present, the effective distance between axes is the distance the middle points of two outer guide wheels at the front and back.

Fig. 1 Lateral Force Coefficient of Wheels



$$S_r = \lambda \cdot R$$

Where

Sr: Lateral force of wheels (kgf) {N}

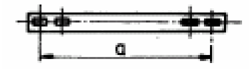
λ: Lateral force coefficient of wheels

R: Wheel load (kgf) {N}

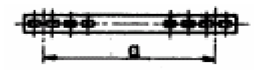
a: Effective distance between axes (m)

Fig. 2 The Determination of Effective Distance between Axes

(a) 4 wheels on one track



(b) Less than 8 wheels on one track



(c) More than 8 wheels on one track

5.1.4 Wind load: The wind load is determined using the following equation.

$$W = C \cdot q \cdot F$$

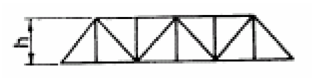
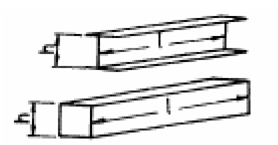
Where W: Wind load (kgf) {N}

q: Speed pressure (kgf/m^2) {N/m^2}

F: Pressure bearing area (m^2)

(1) Wind load coefficient: Wind load coefficient varies with the shape of structure and is determined using the values shown in Fig. 5. However, this does not apply to those proven by wind tunnel experiments.

Table 5 Wind Load Coefficient C

Type of wind bearing surface				C
Steel trusses		Ψ	Less than 0.1 Greater than 0.1 and less than 0.3 Greater than 0.3 and less than 0.9 Greater than 0.9	2 1.8 1.6 2
I-beams and box girders		l/h	Less than 5 Greater than 5 and less than 10 Greater than 10 and less than 15 Greater than 15 and less than 25	1.2 1.3 1.4 1.6
Pipes and cylindrical structures		$\alpha\sqrt{q}$	Less than 10 Greater than 0.1	1.2 0.7

Where Y: Solidity, which is the ratio between the area enclosed by the contour of wind bearing surface and the projection area.

l: The length of I-beam and box girder (m) h: The width of I-beam and box girder observed from windward direction

d: Diameter of pipe or cylindrical structure

q: Speed pressure (kgf/m^2) {N/m^2}

(2) Speed pressure: Speed pressure $q = \frac{V^2}{30}\sqrt[4]{h}$ V: wind velocity

When operating: $q = 8.5\sqrt[4]{h}$ (kgf/m^2) ($q = 85\sqrt[4]{h}$ {N/m^2})

When stopped: $q = 1000\sqrt[4]{h}$ (kgf/m^2) ($q = 1000\sqrt[4]{h}$ {N/m^2})

Where h: The height measured from the ground, min. is 16m

Note: The equations above were determined with wind velocity of 16m/s when operating and 55m/s when stopping.

(3) Pressure bearing area: This area is the projection area at the windward direction.

If the truss or part of the truss is blocked by other truss, the area of the overlapping part of truss shall be multiplied by the reduction ratio η given in Fig. 3. For the distance between opposite trusses, refer to Fig. 4.

Fig. 3 The Relation between Ψ and η

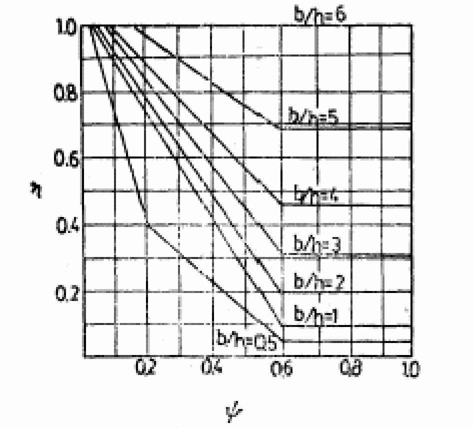
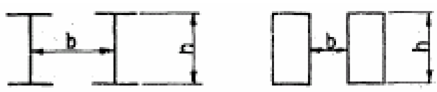


Fig. 4 The distance between opposite trusses, b



(4) Wind load on the lifted object: It shall consider the wind load of the lifted object when designing cranes in operation. But for the objects with no specific shape and less than 25t {250kN} of load, use the approximate values given in Table 6.

Table 6 The pressure bearing area of lifted object

Lifting loads	Pressure bearing area
Less than 5t {50kN}	$1m^2$ for every ton {10kN} of lifting load
Greater than 5t {50kN} and less than 25t {250kN]	$5m^2$ + [$0.5m^2$ for every ton {10kN} of lifting load greater than 5t {50kN}]

5.1.5 Heat induced load: The stress generated due to change of temperature. It shall be considered if the structure may be hindered when subject to thermal expansion. When designing, usually the range of temperature may consider +45°C~-25°C.

5.1.6 Seismic load: Whether it is a mobile or stationary crane, 20% of self weight shall be considered as horizontal seismic load. However, the seismic effect of a lifted object using steel wire may be neglected.

5.1.7 Impact load to a buffer: When installed with a buffer, the buffer shall be able to absorb the kinetic energy when impacted by a crane without lifting any object and traveling at 75% of rated speed, and the impact load is therefore determined with the deceleration at this moment. However, if automatic decelerating device is installed in front of the buffer, the impact load may be determined with the speed impact from such deceleration.

For the structure on which the lifted object of crane is guided from the lifting trolley as a rigid body, the effect of this lifted object shall be included.

In addition, if the lifted object or the guiding part is likely to impact to any object on the ground, it shall be considered that one side of the lifting trolley is loaded with a horizontal load.

5.1.8 Loads from catwalk and others: For catwalks and ladders, a concentrated load of 300kgf {3kN} shall be given and a horizontal movable concentrated load of 30kgf {300N} for the handrail during the design.

However, when the crane is operated without lifting (such as lubricating), the loads from catwalks, ladders and handrails may be half of the values mentioned above.

5.1.9 Others: Snow load and loads generated due to specific operations shall be considered where appropriate.

5.2 The increase of design load values

5.2.1 Impact factor ψ: The impact due to lifting may vary with the difference in lifting speed, deflection of truss or length of wire. However, generally it is determined with lifting load multiplies by the impact factor given in Table 7. But for the items in Table 4 marked with impact factors, such requirements shall be followed. If the stress induced from the lifting load and the stress from the self weight offset the stress in the structure, the effect of lifting load descending and impacting the ground, which is lifting load multiplied by (1-ψ)/2, shall be included in designing the structure.

Table 7 Impact Factor, ψ

Category of Crane	I	II	III	IV
ψ	1.1	1.25	1.4	1.6

5.2.2 Operation coefficient M: It shall be considered in relation with the operation conditions and the significance of crane as appropriate. The main loads shall be increased in accordance with the operation coefficients given in Table 8.

Table 8 Operation Coefficient, M

Category of Crane	I	II	III	IV
M	1.0	1.05	1.1	1.2

5.3 Load combinations: When calculating stresses, the worst scenario of load combination given in Table 9 shall be used.

Table 9 Load Combinations

Loading Condition	Load Combination
A	M{ψ(lifting load) + (self weight) + (horizontal load)} + (heat induced load)
B	M{ψ(lifting load) + (self weight) + (horizontal load)} + (wind load when operating) + (heat induced load)
C	(lifting load) + (self weight) + (seismic load or impact load) +(heat induced load), or (self weight) + (wind load when stopped) + (heat induced load)

Note:

1. For the structure in question, it shall be considered that the loads are taken as the maximum and placed at the most unfavorable locations. For example, if the maximum is reached without being multiplied by ψ, then ψ = 1.
2. For horizontal loads, the most unfavorable combination anticipated in 5.1.3, which may occur simultaneously, shall be considered. However, if most apparently the lifting is not likely to repeat, then ψ may be taken as 1.
3. When not in operation, the lifting trolley shall be placed at a certain location without being loaded. If unable to determine, such location shall be the location that gives the most unfavorable scenario.
4. For the cranes that can spin, the extension arm shall be placed at a certain

location without being loaded. If unable to determine, such location shall be the location that gives the most unfavorable scenario. Where the arm is subjected to wind and does not swing, the most unfavorable wind bearing direction shall be considered.

5. For equations applicable to heat induced loads and seismic loads, refer to 5.1.5 and 5.1.6.

6. Allowable stress:

6.1 Allowable stress: The allowable stress, σ_a, is the smallest value determined from the corresponding load condition in 5.3, in relation to the yielding point of material (or 0.2% of yielding stress) and tensile strength, divided by the factors of safety given in Table 10.

Table 10 Factor of Safety

Load Condition	Factor of Safety	
	In relation to yielding point	In relation to tensile strength
A	1.5	1.8
B	1.3	1.6
C	1.13	1.4

6.2 Structure members and welds: The stresses in structure members and welds shall not exceed the values given in Table 11.

Table 11 Allowable Stress for Structure Members and Welds

		Type of stress	Allowable stress	Cross section for design
Structure members		Tensile	σ_a	Pure cross section
		Compression	$\sigma_a/1.15$	Total cross section
		Bending	As per 9 & 10	Total and pure cross section
		Shear	$\sigma_a\sqrt{3}$	Total cross section
		Buckling	As per 8 & 12	Total cross section
		Compression bearing	$1.4\sigma_a$	
Welds	Butt welds	Tensile	σ_a	
		Compression	σ_a	
		Shear	$\sigma_a/\sqrt{2}$	
	Fillet welds	Tensile and compression at the direction of circumference	σ_a	

		Shear	$\sigma_a / \sqrt{2}$	Welding thickness

Note:

1. The effective cross section is the minimum cross section with rivet holes or bolt holes excluded.
2. The tests at the welds shall follow the requirements of CNS ____ (Methods of Radiographic Test and Classification of Radiographs for Steel Welds). When testing, the following conditions shall be met:
   (1) Type 3 defect is not allowed.
   (2) If Type 1 or Type 2 defect is present, it shall be below the allowable value of Class 2; if combination of Type 1 and Type 2 defects is present, it shall be below 1/2 of the allowable value of Class 2 respectively.

6.3 Rivets, bolts and pins: The allowable stress for rivets, bolts and pins shall conform to the requirements of Table 12.

Table 12 The allowable stress for rivets, bolts and pins

	Material	Type of stress		Allowable stress	Note: the diameters used in calculation, etc.
Rivets	Refer to Table 1	At shop	Shear	$\sigma_a \sqrt{3}$	Diameter of rivet hole
			Compression	$1.4\sigma_a$	
		At site	Shear	80% of the above	
			Compression		
High strength bolts		Visible Shear		$0.21\sigma_a$	Exterior diameter of bolt
High strength self-driven bolts		Visible Shear		$0.24\sigma_a$	Exterior diameter of bolt
Plugs		Shear		$\sigma_a \sqrt{3}$	Exterior diameter of bolt
		Compression		$1.4\sigma_a$	
Pin Joints		Shear		$\sigma_a \sqrt{3}$	If the pin can move slightly within the pin hole, the allowable compression stress is 50% of the value on the left.
		Compression		$1.4\sigma_a$	
		Bending		σ_a	
Anchor bolts	S(41)C	Tensile		$0.6\sigma_a$	Base diameter of thread
	S(20)C	Shear		$0.35\sigma_a$	

Note:

1. Visible shear is that the bolt is taking shear instead of the load transferred from the friction connection
2. The high strength bolts shall be fastened with the stress at the base diameter

of thread equivalent to 75% of yielding stress of material, and it is 85% for high strength self-driven bolts.

3. For joints using high strength bolts or high strength self-driven bolts, the friction surface of structure members shall be clean and free of grease and paint, etc, and the stains on the black coating shall be ground off with sand wheels.
4. When calculating the basic allowable stress of high strength bolts or high strength self-driven bolts, the criteria may use yielding strength instead of yielding point.
5. For allowable compression stress, the criterion is the smaller of the σ_a of fasteners and the supporting members.

6.4 Allowable fatigue stress: The steel structure shall be confirmed under the loading conditions given in 5.3 in relation with the safety of fatigue strength.

6.4.1 Structure members and welds: For the materials listed in Table 1, the safety against fatigue shall be confirmed with either stress ratio method or amplitude methods below.

(1) Stress ratio method: The maximum stress σ_{max} shall not exceed the values given in Fig. 5.1, 5.2 and 5.3.
The same applies to shear stress, where the maximum stress τ_{max} shall not exceed the S (base material) and S' (welds) given in those figures. The K value in the figures is the ratio of the minimum stress to the maximum stress (K = $\sigma_{min}/\sigma_{max}$ or τ_{min}/τ_{max}, and it is positive when vibrating under loads from both sides and it is negative when vibrating under loads from one side.)

(2) Amplitude method: The amplitude of stress fluctuation (σ_{min}, σ_{max}) shall be within the allowable stress and satisfy the following three equations.

$$(\sigma_{\max} - \sigma_{\min}) \le F_J \cdot F_L \cdot \sigma_d$$

When shear stress is in the base material,

$$(\tau_{\max} - \tau_{\min}) \le F_J \cdot F_L \cdot \tau_d / \sqrt{3}$$

When shear stress is in the weld,

$$(\tau_{\max} - \tau_{\min}) \le F_J \cdot F_L \cdot \sigma_d / \sqrt{2}$$

In the two shear equations, F_J and F_L shall be the values equivalent to those for Notch Type a.

In the equations,

σ_{max}: maximum stress (kgf/m^2) {N/m^2}

σ_{min}: minimum stress (kgf/m^2) {N/m^2}

τ_{max}: maximum shear stress (kgf/m^2) {N/m^2}

τ_{min}: minimum shear stress (kgf/m^2) {N/m^2}

F_J: Joint coefficient, which is the level of notch effect to joint and shall follow the requirements of Table 13 and Table 14.

F_L: Life coefficient, which is related to the number of stress fluctuations and shall follow the requirements of Table 15.

σ_d: Allowable fatigue stress: As per the requirements of Table 6 or taken as σ_d = 1000 kgf/m^2 {100 N/m^2}

However, each of the stress values shall fall within the values of allowable stress specified in 6.1.

6.4.2 Rivets and bolts: The shear stresses in rivets and bolts shall follow the S' curve in Fig. 5 or the equation in amplitude method for shear stress in welds.

It is permitted not to consider the fatigue strength of high strength bolts and high strength self-driven bolts

Fig. 5.1 The Allowable Stress for Category I Cranes

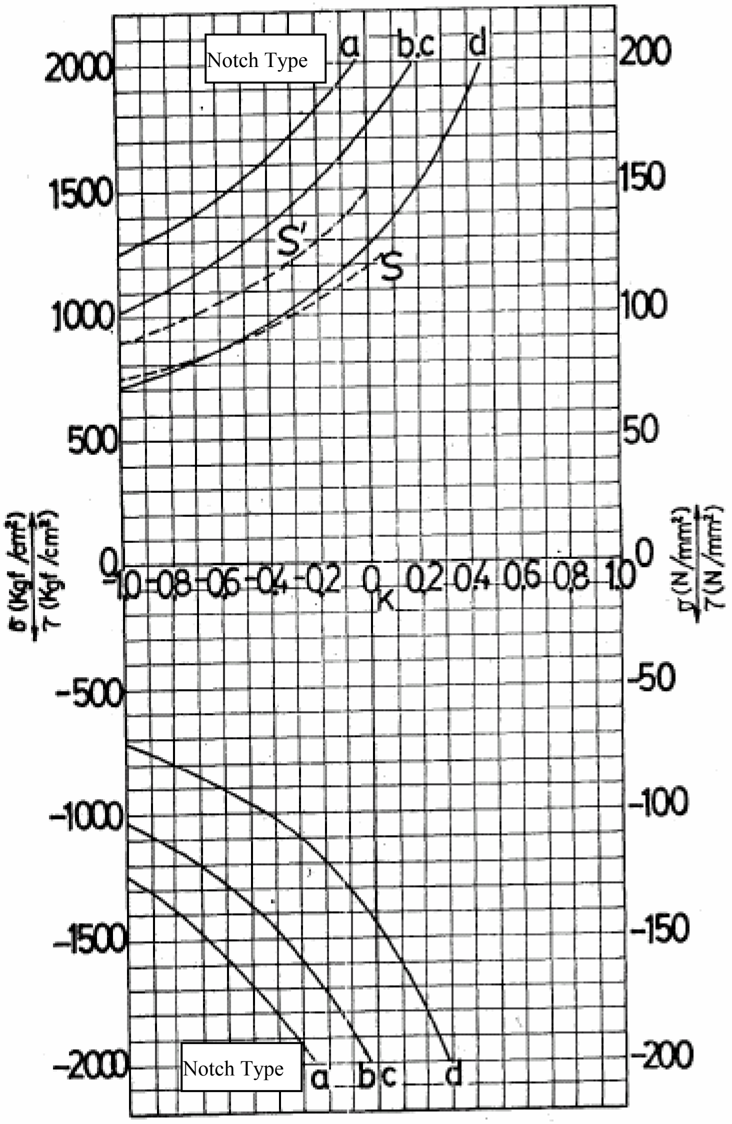


Fig. 5.2 The Allowable Stress for Category II Cranes

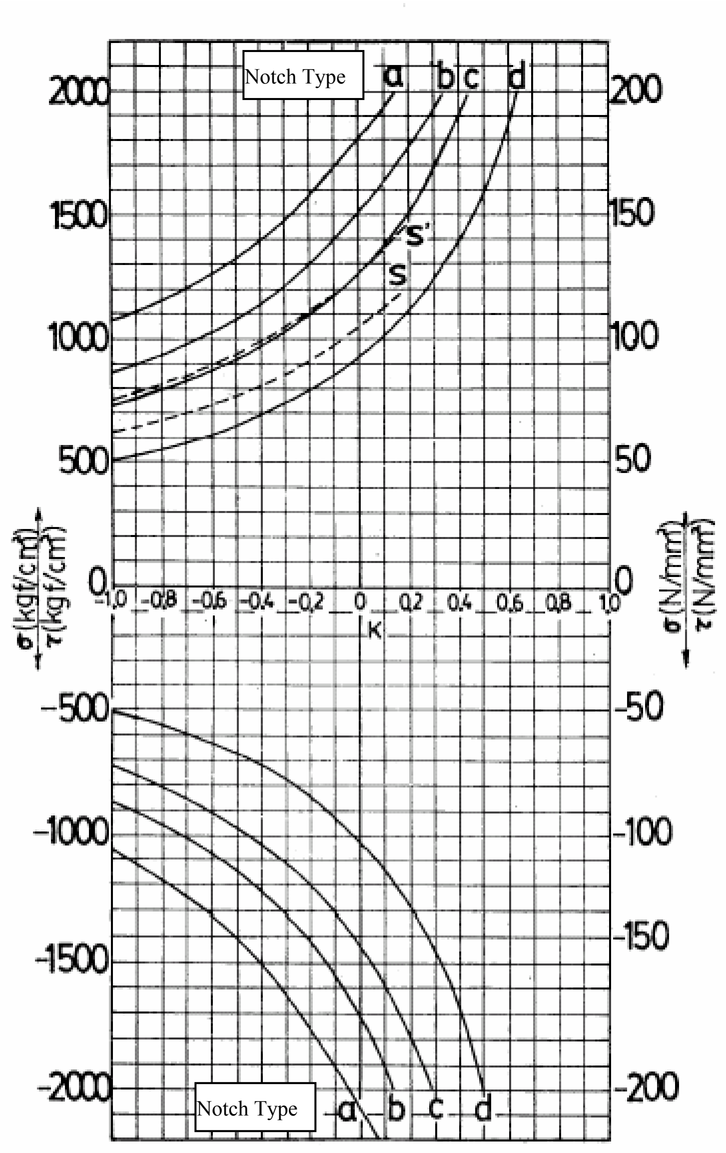


Fig. 5.3 The Allowable Stress for Categories III and IV Cranes

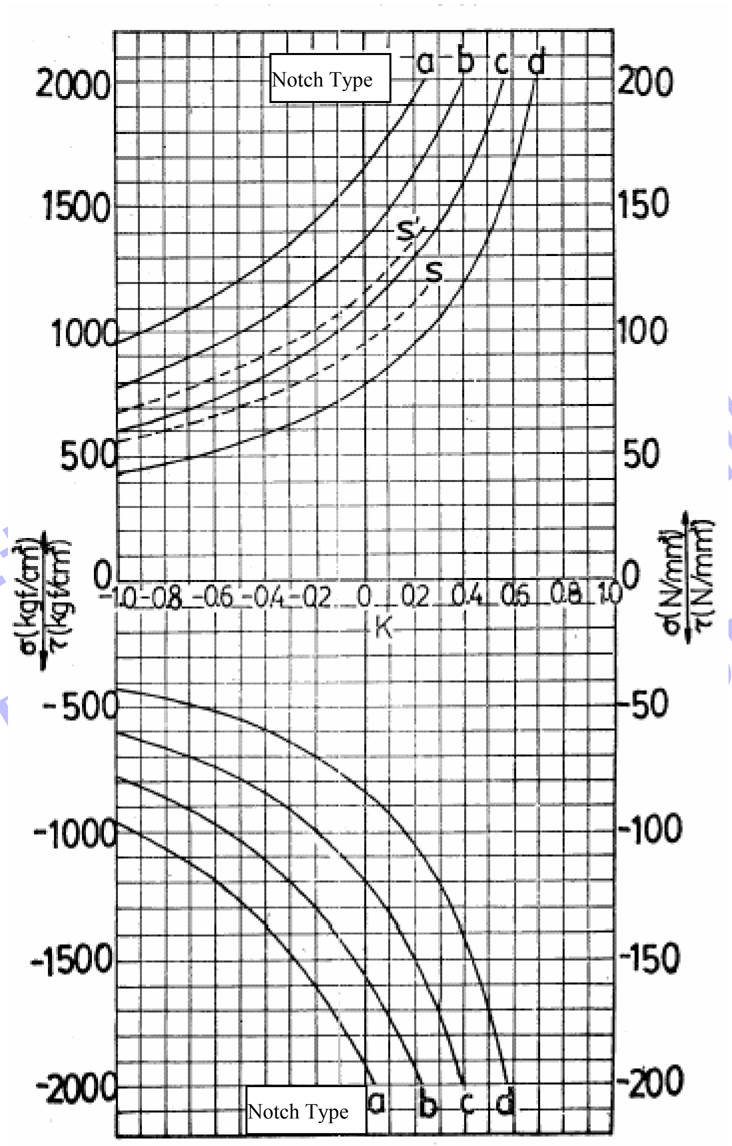
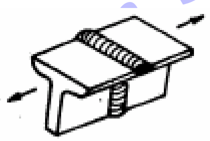
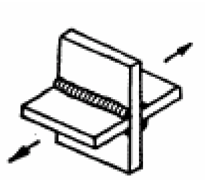
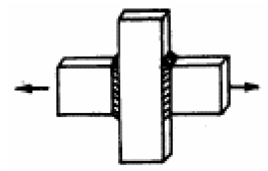
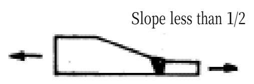
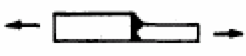
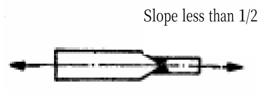
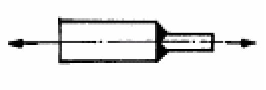
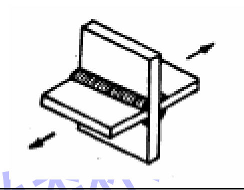
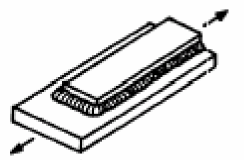
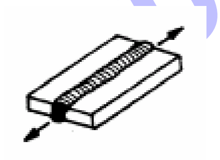
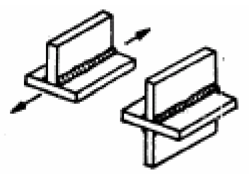
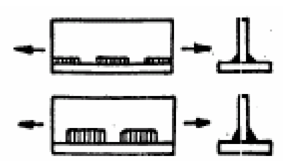
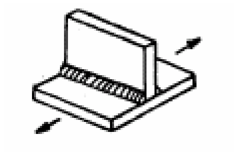
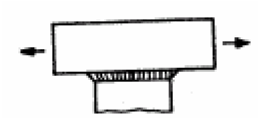
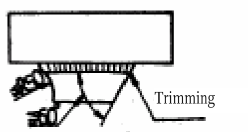
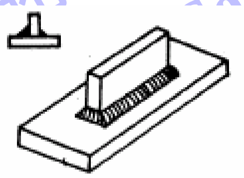
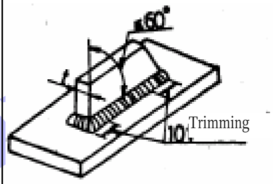
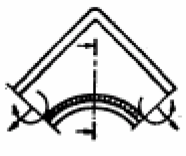
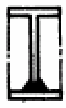
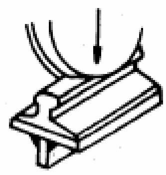
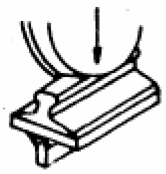
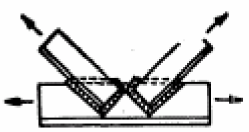
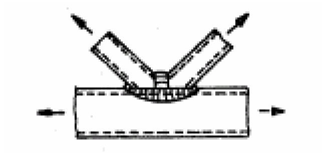
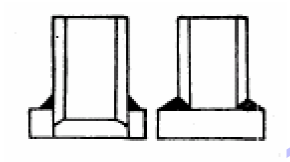
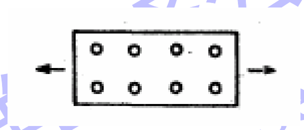
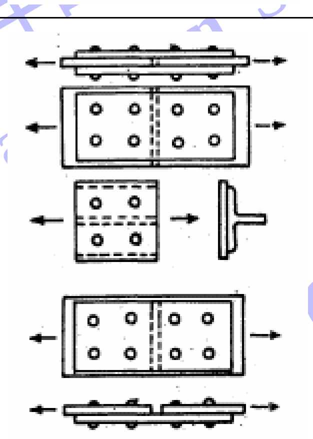


Table 13 Categorization in Notch Strength

Description	Illustration	Categorization in notch strength		Remark
		Not processed after welding	Processed after welding	
1. Base material		a		
2. Butt joints perpendicular to the force (with the same thickness of plate)	Butt joint with plates 2.1 	c	a	d for those with backing bars
	Butt joint with steel shapes 2.2 	c	b	Overlapped welding is strictly prohibited
	Cruciform joints 2.3 			
	2.4 	d	c	
3. Butt joints perpendicular to the force (with the different thickness of plate)	Non-symmetrical 3.1 	c	d	
	Non-symmetrical joints 3.2 	d	c	
	Symmetrical	c	b	

	3.3 			
	Symmetrical joints 3.4 	d	c	
4. Fillet joints perpendicular to the force	4.1  4.2 	d	c	Overlapped welding is strictly prohibited
5. Continuous Butt joints and fillet joints parallel to the force	Butt 5.1  Fillet 5.2 	b	b	
6. Pitched fillet joints parallel to the force	6.1 	c	c	
7. Joints with	Fillet, fillet (spot)	c	b	

attachment	7.1 				
	Butt 7.2 		d	c	
	Fillet 7.3 		d	c	
8. Bent corrugated joints of flange		8.1 Fillet 	c	c	
		8.2 Fillet (Full) (1) 	b	b	
9. Under the tracks		9.1 Fillet	d	d	
		9.2 Fillet (Full) (1)	c	b	
10. Structure frames	10.1 Fillet 		d	c	
11. Pipes	11.1 Fillet		d	c	

					
	11.2 Fillet V groove 				
12. Members with holes	12.1 	c			
13. Riveted joints, joints with high strength bolts and high strength self-driven bolts		12.1 Rivets			
		12.2 Bolts			

Note: Fillet (Full) means filling up the grooved opening completely.

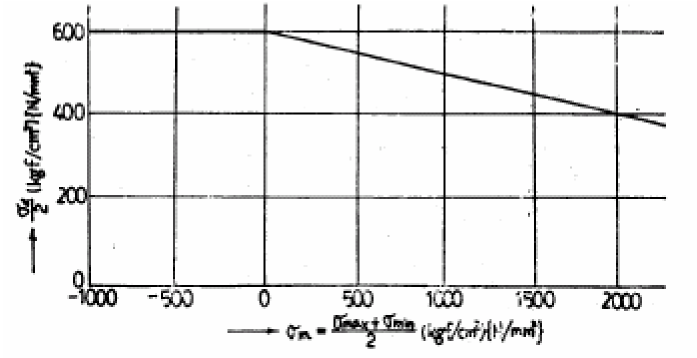
Table 14 Joint Coefficient, F_J

Type of Notch	a	b	c	d
Joint Coefficient, F_J	1.6	1.3	1.0	0.7

Table 15 Life Coefficient, F_L

Category of Crane / Type of Notch	I	II	III, IV
a, b	1.3	1.1	1.0
c, d	1.7	1.2	1.0

Fig. 6 Allowable Fatigue Stress, σ_d



λ: Slenderness ratio (refer to 14.2) Table 16-1 Buckling Coefficient, applicable to steel with yielding point lower than 24 kgf/mm^2 {240 N/mm^2}

λ	0	1	2	3	4	5	6	7	8	9	λ
20	1.04	1.04	1.04	1.05	1.05	1.06	1.06	1.07	1.07	1.08	20
30	1.08	1.09	1.09	1.10	1.10	1.11	1.11	1.12	1.13	1.13	30
40	1.14	1.14	1.15	1.16	1.16	1.17	1.18	1.19	1.19	1.20	40
50	1.21	1.22	1.23	1.23	1 24	1.25	1.26	1.27	1.28	1.29	50
60	1 30	1.31	1.32	1.33	1.34	1.35	1.36	1.37	1.39	1.40	60
70	1.41	1.42	1.44	1.45	1.46	1.48	1.49	1.50	1.52	1.53	70
80	1.55	1.56	1.58	1.59	1.61	1.62	1.64	1.66	1.68	1.69	80
90	1.71	1.73	1.74	1.76	1.78	1.80	1.82	1.84	1.86	1.88	90
100	1.90	1.92	1.94	1.96	1.98	2.00	2.02	2.05	2.07	2.09	100
110	2.11	2.14	2.16	2.18	2.21	2.23	2 27	2.31	2.35	2.39	110
120	2 43	2.47	2.51	2.55	2.60	2.64	2.68	2.72	2.77	2.81	120
130	2 85	2 90	2.94	2 99	3.03	3.08	3.12	3.17	3.22	3.26	130
140	3.31	3.36	3.41	3.45	3.50	3.55	3.60	3.65	3.70	3.75	140
150	3.80	3.85	3.90	3.95	4.00	4.06	4.11	4.16	4.22	4.27	150
160	4 32	4.38	4.43	4.49	4.54	4.60	4.65	4.71	4.77	4.82	160
170	4 88	4.94	5.00	5.05	5.11	5.17	5.23	5.29	5.35	5.41	170
180	5.47	5.53	5.59	5.66	5.72	5.78	5.84	5.91	5.97	6.03	180
190	6 10	6.16	6.23	6.29	6.36	6.42	6.49	6.55	6.62	6.69	190
200	6.75										200

Table 16-2 Buckling Coefficient for Cylindrical Material, ω [applicable to cylindrical material with yielding point less than 24 kgf/mm^2 {240 N/mm^2}]

λ	0	1	2	3	4	5	6	7	8	9	λ
20	1.00	1.00	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.02	20
30	1.03	1.03	1.04	1.04	1.04	1.05	1.05	1.05	1.06	1.06	30
40	1.07	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.11	40
50	1.12	1.13	1.13	1.14	1.15	1.15	1.16	1.17	1.17	1.18	50
60	1.19	1.20	1.20	1.21	1.22	1.23	1.24	1.25	1.26	1.27	60
70	1.28	1.29	1.30	1.31	1.32	1.33	1.34	1.35	1.36	1.37	70
80	1.39	1.40	1.41	1.42	1.44	1.46	1.47	1.48	1.50	1.51	80
90	1.53	1.54	1.56	1.58	1.59	1.61	1.63	1.64	1.66	1.68	90
100	1.70	1.73	1.76	1.79	1.83	1.87	1.90	1.94	1.97	2.01	100
110	2.05	2.08	2.12	2.16	2.20	2.23	2.27	2.31	2.35	2.39	110

Note: Where the ratio of the diameter of the cylindrical material and the thickness is less than 6 and λ = 120 or more, the requirements specified in Table 16-1 shall be met.

Table 17-1 Buckling Coefficient, ω [applicable to steel with yielding point greater than 30 kgf/mm^2 {300 N/mm^2}]

λ	0	1	2	3	4	5	6	7	8	9	λ
20	1.05	1.06	1.06	1.07	1.07	1.08	1.08	1.09	1.10	1.10	20
30	1.11	1.11	1.12	1.12	1.13	1.14	1.15	1.16	1.17	1.17	30
40	1.18	1.19	1.20	1.21	1.22	1.23	1.23	1.24	1.25	1.27	40
50	1.28	1.28	1.29	1.31	1.32	1.33	1.35	1.36	1.37	1.38	50
60	1.39	1.41	1.42	1.44	1.45	1.46	1.48	1.50	1.51	1.52	60
70	1.54	1.56	1.58	1.60	1.61	1.63	1.65	1.67	1.69	1.71	70
80	1.73	1.74	1.76	1.79	1.81	1.83	1.85	1.88	1.90	1.93	80
90	1.95	1.98	2.01	2.03	2.05	2.07	2.11	2.15	2.20	2.24	90
100	2.29	2.34	2.39	2.43	2.48	2.53	2.58	2.62	2.67	2.72	100
110	2.77	2.82	2.88	2.93	2.98	3.03	3.09	3.14	3.19	3.24	110
120	3.30	3.35	3.40	3.46	3.52	3.58	3.63	3.69	3.75	3.82	120
130	3.88	3.94	4.00	4.06	4.12	4.18	4.24	4.30	4.37	4.43	130
140	4.49	4.56	4.63	4.69	4.75	4.81	4.88	4.95	5.02	5.09	140
150	5.16	5.22	5.29	5.36	5.43	5.50	5.57	5.64	5.72	5.79	150
160	5.86	5.94	6.02	6.09	6.17	6.25	6.32	6.40	6.48	6.55	160
170	6.62	6.70	6.78	6.86	6.94	7.02	7.10	7.17	7.25	7.34	170
180	7.42	7.51	7.60	7.68	7.76	7.85	7.94	8.02	8.10	8.18	180
190	8.27	8.36	8.45	8.54	8.62	8.70	8.79	8.88	8.98	9.08	190
200	9.18										200

Table 17-2 Buckling Coefficient, ω [applicable to cylindrical material with yielding point greater than 30 kgf/mm^2 {300 N/mm^2} and less than 32 kgf/mm^2 {320 N/mm^2}]

λ	0	1	2	3	4	5	6	7	8	9	λ
20	1.02	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.04	1.05	20
30	1.05	1.06	1.06	1.07	1.07	1.08	1.08	1.09	1.09	1.10	30
40	1.10	1.11	1.11	1.12	1.13	1.13	1.14	1.15	1.15	1.16	40
50	1.17	1.18	1.19	1.19	1.20	1.21	1.22	1.23	1.24	1.25	50
60	1.26	1.27	1.28	1.29	1.31	1.32	1.33	1.34	1.36	1.37	60
70	1.38	1.40	1.41	1.43	1.45	1.46	1.48	1.49	1.51	1.53	70
80	1.55	1.57	1.58	1.60	1.62	1.66	1.70	1.73	1.77	1.82	80
90	1.86	1.90	1.94	1.98	2.03	2.07	2.11	2.15	2.20	2.24	90

Note: Where the ratio of the diameter of the cylindrical material and the thickness is less than 6 and λ = 100 or more, the requirements specified in Table 17-1 shall be met.

Table 18-1 Buckling Coefficient, ω [applicable to steel with yielding point greater than 34 kgf/mm^2 {340 N/mm^2} and less than 36 kgf/mm^2 {360 N/mm^2}]

λ	0	1	2	3	4	5	6	7	8	9	λ
20	1.06	1.06	1.07	1.07	1.08	1.08	1.09	1.09	1.10	1.11	20
30	1.11	1.12	1.13	1.14	1.14	1.15	1.15	1.16	1.17	1.18	30
40	1.18	1.19	1.20	1.21	1.22	1.23	1.24	1.25	1.26	1.27	40
50	1.28	1.29	1.31	1.32	1.33	1.34	1.35	1.37	1.38	1.40	50
60	1.41	1.43	1.44	1.46	1.47	1.49	1.51	1.52	1.54	1.55	60
70	1.58	1.60	1.62	1.64	1.66	1.68	1.70	1.72	1.74	1.76	70
80	1.79	1.81	1.83	1.86	1.88	1.91	1.93	1.96	1.98	2.01	80
90	2.05	2.10	2.14	2.19	2.24	2.29	2.33	2.38	2.43	2.48	90
100	2.53	2.58	2.64	2.69	2.74	2.79	2.85	2.90	2.95	3.01	100
110	3.06	3.12	3.18	3.23	3.29	3.35	3.41	3.47	3.53	3.59	110
120	3.65	3.71	3.77	3.83	3.89	3.96	4.02	4.09	4.15	4.22	120
130	4.28	4.35	4.41	4.48	4.55	4.62	4.69	4.75	4.82	4.89	130
140	4.96	5.04	5.11	5.18	5.25	5.33	5.40	5.47	5.55	5.62	140
150	5.70										150

Table 18-2 Buckling Coefficient, ω [applicable to cylindrical material with yielding point greater than 34 kgf/mm^2 {340 N/mm^2} and less than 36 kgf/mm^2 {360 N/mm^2}]

λ	0	1	2	3	4	5	6	7	8	9	λ
20	1.02	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.05	1.05	20
30	1.05	1.06	1.06	1.07	1.07	1.08	1.08	1.09	1.10	1.10	30
40	1.11	1.11	1.12	1.13	1.13	1.14	1.15	1.16	1.16	1.17	40
50	1.18	1.19	1.20	1.21	1.22	1.23	1.24	1.25	1.26	1.27	50
60	1.28	1.30	1.31	1.32	1.33	1.35	1.36	1.38	1.39	1.41	60
70	1.42	1.44	1.46	1.47	1.49	1.51	1.53	1.55	1.57	1.59	70
80	1.62	1.66	1.71	1.75	1.79	1.83	1.88	1.92	1.97	2.01	80

Note: Where the ratio of the diameter of the cylindrical material and the thickness is less than 6 and λ = 90 or more, the requirements specified in Table 18-1 shall be met.

Table 19-1 Buckling Coefficient, ω [applicable to steel with yielding point greater than 34 kgf/mm^2 {340 N/mm^2} and less than 36 kgf/mm^2 {360 N/mm^2}]

λ	0	1	2	3	4	5	6	7	8	9	λ
20	1.03	1.04	1.04	1.05	1.06	1.06	1.07	1.07	1.09	1.09	20
30	1.09	1.10	1.11	1.12	1.13	1.13	1.14	1.15	1.16	1.17	30
40	1.18	1.19	1.20	1.21	1.23	1.24	1.25	1.26	1.28	1.29	40
50	1.30	1.32	1.33	1.35	1.37	1.38	1.40	1.42	1.44	1.46	50
60	1.47	1.49	1.51	1.54	1.56	1.58	1.60	1.62	1.65	1.67	60
70	1.70	1.72	1.75	1.77	1.80	1.83	1.88	1.93	1.98	2.03	70
80	2.08	2.14	2.19	2.24	2.30	2.35	2.41	2.47	2.52	2.58	80
90	2.64	2.70	2.76	2.82	2.88	2.94	3.00	3.06	3.13	3.19	90
100	3.26	3.32	3.39	3.46	3.52	3.59	3.66	3.73	3.80	3.87	100
110	3.94	4.01	4.09	4.16	4.23	4.31	4.38	4.46	4.53	4.61	110
120	4.69	4.77	4.85	4.93	5.01	5.09	5.17	5.25	5.34	5.42	120
130	5.50	5.59	5.67	5.76	5.85	5.94	6.02	6.11	6.20	6.29	130
140	6.38	6.47	6.57	6.66	6.75	6.85	6.94	7.04	7.13	7.23	140
150	7.33										150

Table 19-2 Buckling Coefficient, ω [applicable to cylindrical material with yielding point greater than 44 kgf/mm^2 {440 N/mm^2} and less than 46 kgf/mm^2 {460 N/mm^2}]

λ	0	1	2	3	4	5	6	7	8	9	λ
20	1.00	1.00	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.03	20
30	1.03	1.04	1.05	1.05	1.06	1.06	1.07	1.08	1.08	1.09	30
40	1.10	1.11	1.12	1.12	1.13	1.14	1.15	1.16	1.17	1.18	40
50	1.20	1.21	1.22	1.23	1.25	1.26	1.27	1.29	1.30	1.32	50
60	1.34	1.35	1.37	1.39	1.41	1.43	1.45	1.47	1.51	1.55	60
70	1.60	1.64	1.69	1.74	1.78	1.83	1.88	1.93	1.98	2.03	70

Note: Where the ratio of the diameter of the cylindrical material and the thickness is less than 6 and λ = 80 or more, the requirements specified in Table 19-1 shall be met.

7. Design of members under tension: Tensile stress is calculated using the following equation with the effective area with bolt holes and rivet holes excluded:

$$\sigma_t = \frac{N}{A_n} \leq \sigma_{ta}$$

Where: N: Axial tensile force (kgf) {N}

A_n: Effective area (cm^2 or mm^2)

σ_t: Tensile stress (kgf/mm^2) {N/mm^2}

σ_{ta}: Allowable tensile stress as per 6

8. Design of members under compression: Compression stress is calculated using the following equation with the effective area with bolt holes and rivet holes included.

$$\sigma_c = \frac{\omega N}{A_n} \leq \sigma_{ca}$$

Where: N: Axial compression force (kgf) {N}

A_n: Effective area (cm^2 or mm^2)

σ_c: Tensile stress (kgf/cm^2) {N/mm^2}

σ_{ca}: Allowable compression stress as per 6

ω varies with the slenderness ratio (refer to 14.2 for λ) and material of compression members, as per the requirements of Table 16-1 ~ Table 19-2.

9. Design of box girder under bending and twisting: For the girders under bending or twisting, the bending and twisting shall be designed with the following equations respectively. However, for general cranes, since the ratio of (span)/(girder width) is less than 40, therefore, it is not necessary to consider the warping generated from bending.

9.1 Bending:

$$\sigma_t = \frac{M}{I} \cdot \frac{A}{A_n} \cdot c \leq \sigma_{ta}$$

$$\sigma_c = \frac{M}{I} \cdot e \leq \sigma_{ca}$$

$$\tau = \frac{F}{A_a'} \leq \tau_a$$

Where: σ_t: Stress at tension side flange (kgf/cm^2) {N/mm^2}

σ_c: Stress at compression side flange (kgf/cm^2) {N/mm^2}

τ: Shear stress (kgf/cm^2) {N/mm^2}

M: Bending moment (kgf-cm) {N-mm}

I: Moment of inertia (cm^4 or mm^4)

A: The total cross-sectional area of tension side flange (cm^2 or mm^2)

A_n: The effective cross-sectional area of tension side flange (cm^2 or mm^2)

e: The distance from neutral axis to tension side or compression side (cm or mm)

F: Shear force (kgf) {N}

A_n': The effective cross-sectional area of shear bearing webs (cm^2 or mm^2)

τ_a: The allowable shear stress as per 6

9.2 Twisting:

$$\tau_t = \frac{M_t}{2A \cdot t} \leq \tau_a$$

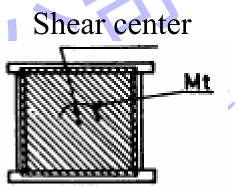
Where: τ_t: Torque induced shear stress (kgf/cm^2) {N/mm^2}

M_t: Torque acting at shear center (kgf-cm) {N-mm}

A: The area enclosed by the center lines of flanges and webs (cm^2 or mm^2)

τ: Thickness of flange or web (cm or mm)

Fig. 7 Box girder under twisting



10. Design of member for bending at axial direction: The design of member for bending at axial direction may follow the following simplified equations. However, deflection shall be taken into account to carry out more accurate buckling design if necessary.

$$\sigma_t = \frac{N}{A_n} + \frac{M}{I} \cdot \frac{A}{A_n} \leq \sigma_{ta}$$

$$\sigma_c = \frac{N}{A} \cdot \omega + 0.9 \cdot \frac{M}{I} \cdot e \leq \sigma_{ca}$$

Where: N: Axial force (kgf) {N}

M: Bending moment (kgf-cm) {N-mm}

I: Moment of inertia (cm^4 or mm^4)

A: The total cross-sectional area of member (cm^2 or mm^2)

A_n: The effective cross-sectional area of member (cm^2 or mm^2)

e: The distance from neutral axis to flange (cm or mm)

Also, if the section is an I-shape, warping shall be reviewed.

11. Design of welded joints:

11.1 The stresses acting at joints under tension, compression or shear: The stresses generated from butt welding or fillet welding shall follow the following equations:

$$\sigma = \frac{P}{\Sigma a \cdot l}$$

$$\tau = \frac{P}{\Sigma a \cdot l}$$

Where: σ: Tensile or compression stress occurred at welds (kgf/cm^2) {N/mm^2}

τ: Shear stress occurred at welds (kgf/cm^2) {N/mm^2}
P: The load acting at the welds (kgf) {N}
a: Throat size of the weld (refer to 16.2) (cm or mm)
l: Effective length of weld (refer to 16.3) (cm or mm)

11.2 Stress at joints under bending moment and shear simultaneously: For the continuous welds at web and flanges, such as the vertical or horizontal butt welds at webs and the fillet welds that attach I-beam to the wall, the joints on where such bending moment and shear can act simultaneously shall follow the following equation to determine the combined stress.

$$\sqrt{\sigma^2 + 2\tau^2} \leq \sigma_a$$

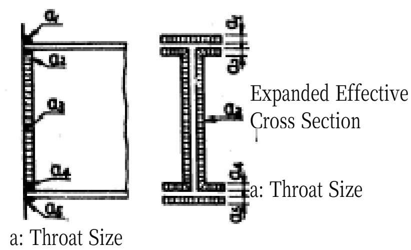
Where: σ: Bending stress (kgf/cm^2) {N/mm^2}, but $\sigma \leq \sigma_a$
τ: Shear stress (kgf/cm^2) {N/mm^2}, but $\tau \leq \tau_a$

(1) Bending moment induced stress:

$$\sigma = \frac{M}{I} \cdot y$$

Where: M: Bending moment acting at the weld (kgf-cm) {N-mm}
I: Moment of inertia about the neutral axis of weld throat; In the case of fillet weld, the throat is expanded to calculate the moment of inertia of the effective cross section for the joint surface as shown in Fig. 8
y: The distance between the point in question and the neutral axis (cm or mm)

Fig. 8 Expansion of Throat size



(2) Shear stress:

$$\tau = \frac{P \cdot Q}{I \cdot a}$$

Where: τ: Shear stress (kgf/cm^2) {N/mm^2}
P: Shear force acting at the weld (kgf) {N}
Q: Section modulus from the weld in question to the neutral axis of exterior cross section (cm^3 or mm^3)
I: The same as 11.2 (1)

a: Throat size (cm or mm)

When in simplified calculation: if the visible shear is taken only by the web, it shall follow the following equation:

$$\tau = \frac{P}{A_a}$$

Where: τ: Shear stress (kgf/cm^2) {N/mm^2}

P: Shear force (kgf) {N}

A_a: The total cross-sectional area; for fillet welds, it is the sum of the areas of weld throat at webs (cm^2 or mm^2)

12. Design of local buckling in plates: The local buckling strength of plates shall be designed based on the buckling at the block enclosed by the stiffener and the overall buckling with stiffener attached. In addition, the loads acting on the plate shall be multiplied with impact factor ψ and operation coefficient M.

12.1 When compression stress and shear stress act alone: When $\sigma_{1ki}, \sqrt{3}\tau_{k1}$ exceed the limit of material ratio, the allowable stress is reduced according to 12.2.

$$\sigma_l \leq \frac{\sigma_{lk1}}{S}$$

$$\tau \leq \frac{\tau_{k1}}{S}$$

Where: σ_l: The absolute value of the maximum compression stress (refer to Table 21-1 and Table 21-2) (kgf/cm^2) {N/mm^2}

τ: Shear stress (kgf/cm^2) {N/mm^2}

σ_{lk1}: Local ideal buckling stress, determined from the following equation:

$$\sigma_{lk1} = \sigma_e \cdot K$$

S: Factor of safety for local buckling, as per the requirements of Table 21.

σ_e: Basic buckling stress, determined from the following equation:

$$\sigma_e = \frac{\pi^2 \cdot E \cdot t^3}{12b^2(1-\mu^2)} = \left(1378 \cdot \frac{t}{b}\right)^3 \text{ (kgf/cm}^2\text{) \{N/mm}^2\text{\}}$$

Where: E: Modulus of elasticity (kgf/cm^3) {N/mm^3}

μ: Poisson’s ratio

t: Thickness of plate (cm or mm)

b: Width of block (cm or mm)

K: Local buckling coefficient; follow Table 21-1 for the block. For the cross sections with stiffener, follow Table 12-2. It shall be determined according to the loading conditions.

a: Length of block (cm or mm)

α: The ratio of length to width of block, $\alpha = \frac{a}{b}$

γ: The stiffness ratio of stiffener, $\gamma = \frac{F}{0.092 b \cdot t^3}$

J: Moment of inertia about the center line of plate for designing the local buckling of the entire cross section of the stiffener.

δ: Ratio of the area of the stiffener, $\delta = \frac{F}{b \cdot t}$

F: The total cross-sectional area of stiffener (cm^2 or mm^2)

Table 20 Factor of Safety for Local Buckling, S

Loading Condition	Factor of safety for local buckling for the entire cross section	Factor of safety for buckling for the block enclosed by the stiffener
A	1.71 + 0.180(ϕ-1)	1.5 + 0.075(ϕ-1)
B	1.50 + 0.125(ϕ-1)	1.35 + 0.05(ϕ-1)
C	1.35 + 0.075(ϕ-1)	1.25 + 0.025(ϕ-1)

12.2 When compression stress and shear stress act simultaneously: First determine the two local buckling stresses σ_{lk1} and τ_{k1}, and then determine the ideal combined stress σ_{vk1} with the following equation.

$$\sigma_{vk1} = \frac{\sqrt{\sigma_1^2 + 3\tau^2}}{\frac{1+\phi}{4} \cdot \frac{\sigma_1}{\sigma_{1k1}} + \sqrt{\left(\frac{3-\phi}{4} \cdot \frac{\sigma_1}{\sigma_{1k1}}\right)^3 + \left(\frac{\tau}{\tau_{k1}}\right)^3}} \ (\mathrm{kgf/cm^2})\ \{\mathrm{N/mm^2}\}$$

Where: f: The ratio between the maximum and minimum of the vertical stress acting on the plate as per the requirements of Table 20.

In special cases:

$\tau = 0$ and $\sigma_{vk1} = \sigma_{1k1}$

$\sigma = 0$ and $\sigma_{vk1} = \sqrt{3}\tau_{k1}$

Where the ideal combined stress σ_{vk1} exceeds the ratio limit of material, follow the requirements of Table Fig. to find the reduced combined stress to determine the allowable stress.

$$\sigma_v = \sqrt{\sigma_1^3 + 3\tau^2} \leq \frac{\sigma_{vk}}{S} \text{(kgf/cm}^2\text{) \{N/mm}^2\text{\}}$$

Where: S: Factor of safety for local buckling, as per the requirements of Table 20.

Fig. 9 Reduced Combined Stress

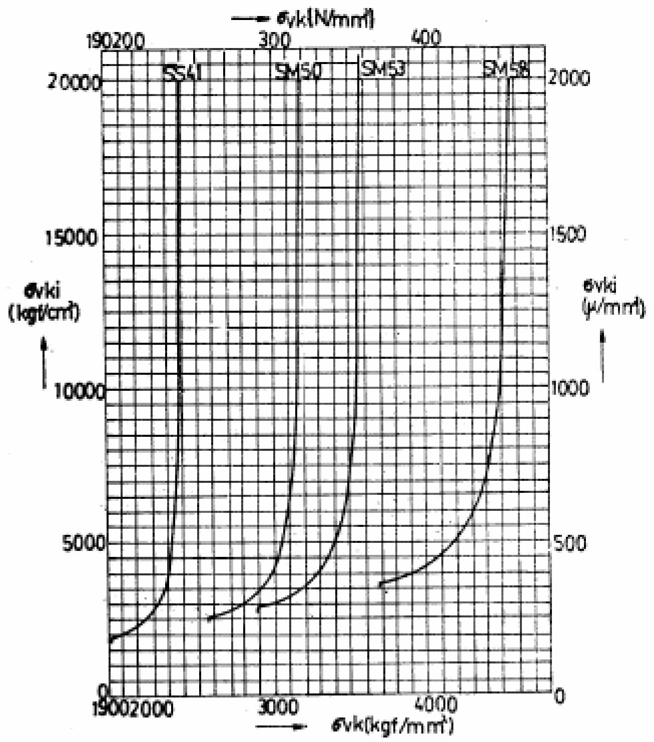
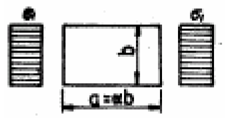
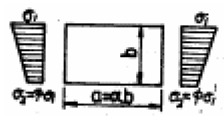
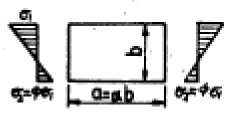


Table 21-1 Buckling Coefficient K for the Block

No.	Loading Conditions		Range of Application	Buckling Coefficient K
1	Uniformly distributed compression stress, ϕ = 1		α ≥ 1	K = 4
			α < 1	$K = \left(\alpha + \frac{1}{\alpha}\right)^2$
2	Linearly distributed compression stress, 0 ≤ ϕ < 1		α ≥ 1	$K = \frac{8.4}{\phi + 1.1}$
			α < 1	$K = \left(\alpha + \frac{1}{\alpha}\right)^2 \cdot \frac{2.1}{\phi + 1.1}$
3	Linearly distributed compression stress and tensile stress, while compression stress is			$K = (1+\phi) \cdot K' - \phi K'' + 10\phi(1+\phi)$ K': Buckling coefficient when ϕ=0 (as per No. 2) K": Buckling coefficient when

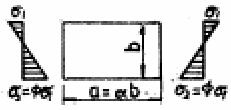
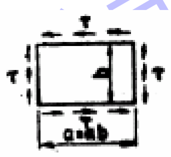
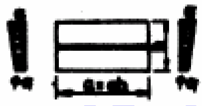
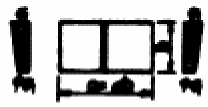
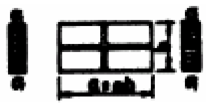
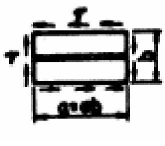
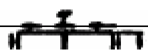
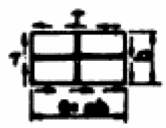
	larger			ϕ=-1 (as per No. 4)
4	Linearly distributed compression stress and tensile stress, while both are equal or tensile stress is larger, σ ≤ -1		α ≥ 2/3	K = 23.9
			α < 2/3	$K = 15.87 + \frac{1.87}{\alpha^2} + 8.6\alpha^2$
5	Uniformly distributed shear stress		α ≥ 1	$K = 5.34 + \frac{4.00}{\alpha^2}$
			α < 1	$K = 4.00 + \frac{5.34}{\alpha^2}$

Table 21-2 Buckling Coefficient K for the Entire Cross Section

No.	Loading conditions and arrangement of stiffener		Range of Application	Buckling Coefficient K
1	Uniformly distributed compression stress, 0 ≤ ϕ ≤ 1, a web placed horizontally at the center		$\alpha \le \sqrt[4]{1+2\gamma}$	$K = \frac{2}{0.95(\phi+1.1)} \cdot \frac{(1+\alpha^2)^2+2\gamma}{\alpha^2(1+2\delta)}$
			$\alpha > \sqrt[4]{1+2\gamma}$	$K = \frac{4}{0.95(\phi+1.1)} \cdot \frac{1+\sqrt{1+2\gamma}}{1+2\delta}$
2	Linearly distributed compression stress, 0 ≤ ϕ ≤ 1, a web placed vertically at the center		$0.4 \le \alpha \le 1.0$	$K = \frac{A-\sqrt{A^2-B}}{1.43\alpha^4(\phi+1.1)}$ $A = 1.5(1+\alpha^2)^2+0.167(9+\alpha^2)^2+3.3\alpha^4\gamma$ $B = (1+\alpha^2)^2(9+\alpha^2)^2+2\alpha^4\gamma[(1+\alpha^2)^2+(9+\alpha^2)^2]$
3	Uniformly distributed compression stress, a web placed horizontally and another placed vertically at the center		$0.9 \le \alpha \le 1.1$	$K = \frac{(1+\alpha^2)^2+2(\gamma_L+\gamma_Q\cdot\alpha^3)}{\alpha^2(1+2\delta_L)}$
4	Uniformly distributed shear stress, a web placed horizontally at the center		$0.5 \le \alpha \le 2.0$	
			$K = \frac{4.93(1+\alpha^2)}{\alpha^2\sqrt{\zeta}}$ $\zeta = \frac{10.24(1+\alpha^2)^2+3.16(1+9\alpha^2)^2+4.05\gamma}{(1+\alpha^2)^2(1+9\alpha^2)^2+2\gamma(1+\alpha^2)^2+2\gamma(1+9\alpha^2)^2} + \frac{10.24(1+\alpha^2)^2+0.41(9+\alpha^2)^2+13.11\gamma}{(1+\alpha^2)^2(9+\alpha^2)^2+2\gamma\alpha^4(9+\alpha^2)^2+162\gamma(1+\alpha^2)^2}$	
5	Uniformly distributed shear		$0.5 \le \alpha \le 2.0$	

	stress, a web placed vertically at the center		$K=\frac{4.93(1+\alpha^2)}{\alpha^2\sqrt{\zeta}}$ $\zeta=\frac{10.24(1+\alpha^2)^2+0.41(1+9\alpha^2)^2+13.11\gamma\alpha^2}{(1+\alpha^2)^2(1+9\alpha^2)^2+162\gamma\alpha^2(1+9\alpha^2)^2+2\gamma\alpha^2(1+\alpha^2)^2}$ $+\frac{10.24(1+\alpha^2)^2+3.16(9+\alpha^2)^2+4.05\gamma\alpha^2}{(1+\alpha^2)^2(9+\alpha^2)^2+2\gamma\alpha^2(9+\alpha^2)^2+2\gamma\alpha^2(1+\alpha^2)^2}$	
6	Uniformly distributed shear stress, a web placed horizontally and another placed vertically at the center		$0.5\leq\alpha\leq2.0$	$K=2.00\frac{1+\alpha^2}{\alpha^2}\sqrt{(1+\alpha^2)^2+2(\gamma_L+\alpha^2\gamma_Q)}$

Note:

1. The stiffness at the intersection of two stiffeners against bending shall not be reduced, or the two stiffeners must be jointed with the same stiffness.
2. The footnote Q stands for vertical stiffener and L stands for horizontal stiffener.

13. Stability against overturning and prevention for wind induced sliding:

13.1 Stability: The stability of a crane shall be confirmed with the following equation:

$$Stability=\frac{\Sigma RightingMoment}{\Sigma OverturningMoment}$$

The crane shall be checked against each load in accordance with the uses listed in Table 22 to prevent overturning.

When designing, all the loads which may have effect to the stability shall be placed at a most unfavorable location.

Use A: Applicable to general cranes

Use B: Applicable to cranes that are often relocated, such as tower cranes fro construction, and railroad cranes that travel on rail tracks.

Use C: Applicable to fixed or spinning-only cranes.

Table 22 Loading Conditions for Stability

Use	Condition	Vertical load	Loads from inertia force		Wind load	Remark
			Vertical	Horizontal		
A	1	1.3P	0.1P	0.1W	Wind load when operating	Retaining device released
	2	1.7P	0	0	0	Fastening device released
	3	0	0	0	Wind load when stopped	Fastening device activated

	4	-0.3P	0	0	0	Fastening device released
B	1	1.0P	0.1P	0.1W	Wind load when operating	No Fastening device
	2	1.4P	0	0	0	No Fastening device
	3	0	0	0	Wind load when stopped	No Fastening device
	4	-0.3P	0	0	0	No Fastening device
C	1	1.0P	0.1P	0.1W	Wind load when operating	Freeboard>300mm
	2	1.25P	0	0	0	Freeboard>300mm
	3	0	0	0	Wind load when stopped	Freeboard>300mm

Note:

1. Condition 1: There is wind load when operating and the effects of accelerating and decelerating in constant operation.
2. Condition 2: There is no wind load and the crane is subjected to dead load.
3. Condition 3: There is no load and the crane is subjected to wind load when stopped.
4. Condition 4: An upward load is considered.
5. P is the lifting load, and W is the weight of horizontal moving part (including lifting load).
6. The vertical load induced by inertia force is the load that is generated from stopping the wire from lowering.
7. The horizontal load induced by inertia force shall take into account the centrifugal force from spinning, the acceleration force from the longitudinal and transverse movement and horizontal shifting, and the swinging of load, as well as 0.1W of horizontal force acting on the moving part.
8. Use B is based on the assumption that there is no tilting or sagging in the tracks and shall be considered as the case may be.

13.2 Prevention for sliding induced by wind: A crane installed for exterior operations shall be equipped with an advancing electrical motor, corresponding to the wind load at operating state, which can propel the crane to where the anchor is located or any position where there is track clamps that can sufficiently resist the wind load. Anchors and track clamps shall conform to the following requirements:

(1) Anchor bolts for wind load (fastening device) — Wind load when stopped
Track clamps — 40% of Wind load when stopped

(2) Safety against sliding — 1.5 or higher

(3) Friction coefficient between tracks and track clamps

$\mu = 0.25$

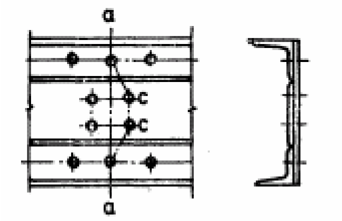
(4) Considering the propelling resistance of crane

(5) For those equipped with Anchor bolts (fastening device) and track clamps, any of the both alone shall be able to withstand the wind load specified in (1).

14. Detail design for members in axial load: Any member or weld shall not contain eccentric configuration or configuration which may causes stress concentration. Where inevitable, the design shall take the effect into account.

14.1 Effective cross-sectional area of tension members: To determine the effective cross-sectional area of a compression member, the appropriate rivet holes or bolt holes shall be removed from where those rivets or bolts locate. In Fig. 10, the cross-sectional area of a-c-c-a is less than that of a-a, so the cross-sectional area of this member shall be subtracted with 4 rivet or bolt holes. For angles and channels without eccentricity, the brackets and flanges shall be expanded and the design method above may apply.

Fig. 10 Effective Cross-Sectional Area



14.2 Slenderness ratio: The slenderness ratio of a member is calculated with the following equation.

$$\lambda = \frac{l_K}{K}$$

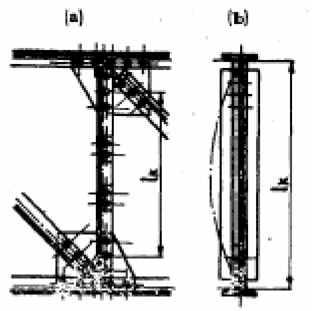
Where: l_K: Buckling length (cm or mm)
K: The minimum radius of gyration about the buckling axis (cm or mm)

Buckling length is calculated with the following equation.

(1) For buckling on the plane of member, it is where the member of which the distance of center of gravity of bolts (including rivets) at joint end is the buckling length l_K [refer to Fig. 11(a)] connects with other members while the compression members in the struts is connected with bolts of

1/4 of the number of bolts necessary, and no deflection occurs at the joint in the plane of member.

Fig. 11 Buckling Length



(2) For flexural buckling perpendicular to the plane of member, use the following equation.

(a) If a member is supported at both end without deflecting, l_K is the distance between nodes [refer to Fig. 11(b)].

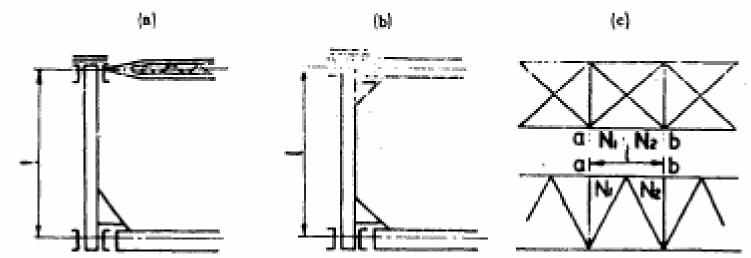
(b) If one end of a member is connected as a rigid frame using a lateral member with a deflection-resisting stiffness that prevents lateral deflection, $l_K = 0.8l$ [refer to Fig. 12(a)].

(c) If both ends of a members are connected to rigid frames with a deflection-resisting stiffness that prevents lateral deflection, $l_K = 0.7l$ [refer to Fig. 12(b)].

(d) In Fig. 12(c), if the nodes of two frames, a and b, do not deflect toward the right angle direction of the frame, the magnitudes of the forces in the members at half length of the frames, N_1 and N_2, are different and $N_1 > N_2$, then:

$$l_K = l \cdot \left(0.75 + 0.25\frac{N_2}{N_1}\right)$$

Fig. 12 The Buckling Length at the Outside of Frame



14.3 Slenderness limit: The slenderness of a member shall not exceed the values given in Table 23.

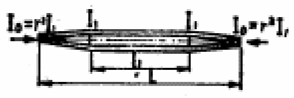
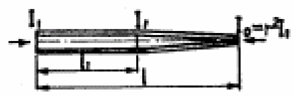
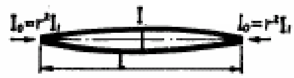
Table 23 Limit for Slenderness Ratio of a Member

Type of Member	Slenderness Ratio
Primary compression members	150
Secondary compression members	200

14.4 Compression members with changeable height: Compression members with constant cross section and changeable height are considered to have the moment of inertia equivalent to that is obtained by multiplying the greatest moment of inertia with the reduction coefficient C given in Table 24.

$I = C \times I_{max}$

Table 24 Reduction Coefficient C

	Shape of Member	Reduction Coefficient C
a		$\ell_1 \leq 0.5\ell$ $0.1 \leq \gamma \leq 1$ $C = (0.17 + 0.33\gamma + 0.5\sqrt{\gamma}) + \frac{\ell_1}{\ell}(0.62 + \sqrt{\gamma} - 1.62\gamma)$
b		$\ell_1 \leq 0.5\ell$ $0.1 \leq \gamma \leq 1$ $C = (0.08 + 0.92\gamma) + (\frac{\ell_1}{\ell})^{2}(0.32 + 4\sqrt{\gamma} - 4.32\gamma)$
c	 Parabola	$0.1 \leq \gamma \leq 1$ $C = 0.48 + 0.02\gamma + 0.5\sqrt{\gamma}$
d	 Parabola	$0.1 \leq \gamma \leq 1$ $C = 0.18 + 0.32\gamma + 0.5\sqrt{\gamma}$
Applicable to roller-supported members with $I_0 \geq 0.01I_{max}$ Where $l_1 \geq 0.8l$, C = 1 Where $0.8l > l1 > 0.5l$, C is determined with interpolation		

14.5 Compression structures: Compression structures are classified as laced structures, as shown in Fig. 13(a), and spliced structures, as shown in Fig. 13(b).

The equivalent slenderness ratio of a compression member is calculated with the following equation and is dealt with the same way as is a single compression structure.

$$\lambda_l = \sqrt{\lambda^2 + \frac{m}{2} \cdot \lambda_1^2}$$

Where: λ_l: The equivalent slenderness ratio of an assembled member

λ: The slenderness ratio to the center axis of the entire structure

m: The number of single members assembled with struts (laces or brackets) (Fig. 14-1 ~ Fig. 14-3)

λ_1: The slenderness ratio of a single member:

In spliced structures, $\lambda_1 = l_1/k_1$

In laced structures, $\lambda_1 = \pi\sqrt{\frac{A}{Z \cdot A_d} \cdot \frac{d^2}{l_1 \cdot e^2}}$

l_1: The buckling length of a single member (cm or mm)

k_1: The radius of gyration of a single member (cm or mm)

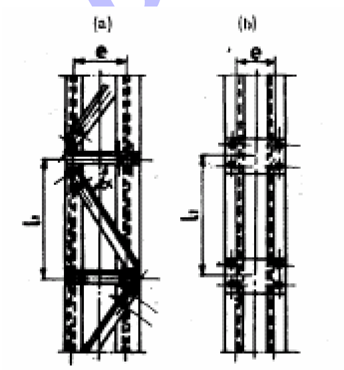
d: Length of lace (cm or mm)

A: The total cross-sectional area of structure (cm^2 or mm^2)

A_d: The total cross-sectional area of laced structure (cm^2 or mm^2)

Z: The number of lateral members located side by side in the parallel plane

Fig. 13 Assembled Compression Structure



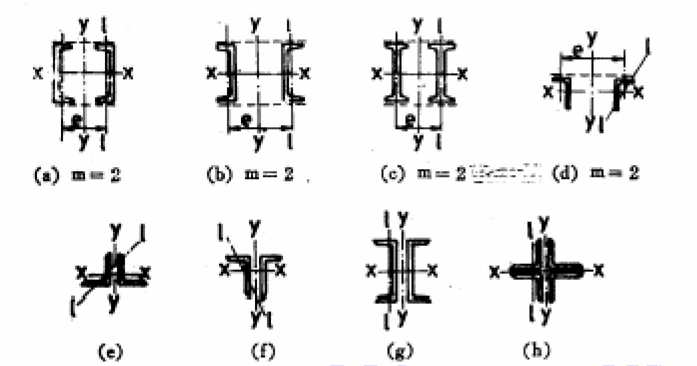
(1) In Fig. 14-1,

the buckling slenderness ratio vertical to x-x axis, λ_x, $\lambda_x = \frac{l_{kx}}{k_x}$

the equivalent buckling slenderness ratio vertical to y-y axis, λ_{y1}, is calculated as $\lambda_{y1} = \sqrt{\lambda_y^2 + \frac{m}{2} \cdot \lambda_1^2}$

Where: $\lambda_y = \frac{l_{ky}}{k_y}$ is the slenderness ratio of the entire structure to y axis.

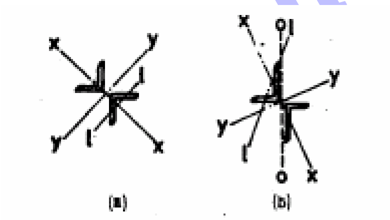
Fig. 14 The Selection of Slenderness Ratio



(2) In Fig. 14-2 is the buckling design for vertical to x-x axis. At this moment, the buckling length l_{kx} is taken to be the average of the buckling lengths of support bearing plane and perpendicular to that plane.

In Fig. 14-2(b), $k_x \cong \frac{k_o}{1.15}$, therefore, $\lambda_x = 1.15 l_{kx}/k_x$. But k_o is the radius of gyration of the whole cross section in relation to center axis parallel to the long side of a angle.

Fig. 14-2 Selection of Slenderness Ratio

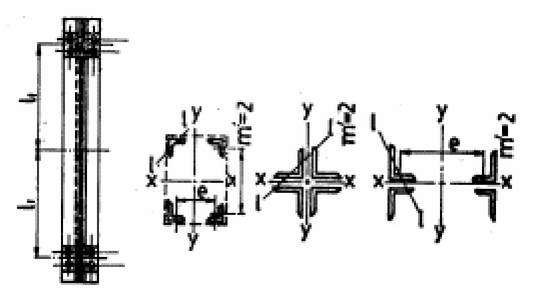


(3) In Fig. 14-3, the equivalent slenderness ratio is calculated using the following equation.

$$\lambda_{y1} = \sqrt{\lambda_y^2 + \frac{m}{2} \cdot \lambda_1^2}$$

$$\lambda_{x1} = \sqrt{\lambda_x^2 + \frac{m'}{2} \cdot \lambda_1^2}$$

Fig. 14-2 Selection of Slenderness Ratio



14.6 Shear force in compression structures: All the brackets, cover plates and theirs joints, in relation with the action of equivalent shear force shown in the equation below, shall not exceed the allowable stress.

$$F_i = \frac{A \cdot \sigma_{ca}}{80}$$

Where: Fi: Equivalent shear force (kgf) {N}

A: The total cross-sectional area of the compression structure (cm^2 or mm^2)

σ_{ca}: Allowable compression stress (kgf/cm^2) {N/mm^2}

(1) In spliced structures, where the distance between the center lines of single members, e, exceeds $20k_i$, the equivalent shear force is taken to be value given by the following equation. However, this is not necessary for laced structures.

$$F_i = \frac{A \cdot \sigma_{ca}}{80} \left[1 + \frac{5(e/k_1 - 20)}{100} \right] = \frac{A \cdot \sigma_{ca}}{80} \cdot \frac{e/k_1}{20}$$

Where: k_1: The minimum radius of gyration of a single member

(2) For laced structures made of two members [refer to Fig. 13(a)], the force in lace, D, generated from F_1 may be the value from the equation below.

$$D = \frac{F_1}{Z \cdot \sin\alpha}$$

Where: a: The angle between the main member and the lace [refer to Fig. 13(a)]

(3) For rigid frames made of two members [refer to Fig. 13(a)], the axial shear force F in the battens may be the value from the equation below.

$$F = \frac{F_1 \cdot l_1}{e}$$

15. Detail design for girders under bending

15.1 Fastening rivets or bolts in girders: The fastening rivets or bolts in the assembled members of girders are calculated with the equation below.

$$P = \frac{H_a \cdot I}{F \cdot S}$$

Where: P: Pitch of rivets or bolts (cm or mm)

H_a: Allowable load of rivet or bolt (kgf) {N}

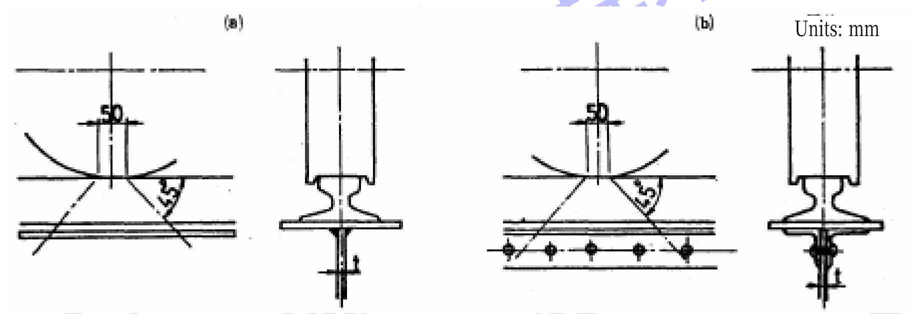
I: The moment of inertia of the girder about the neutral axis (cm^4 or mm^4)

F: Shear force that the girder is bearing (kgf) {N}

S: The area moment of the cross section jointed by rivets and bolts about the neutral axis of the whole cross section (cm^3 or mm^3)

15.2 Rivets, bolts or welds bearing directly the wheel loads: For rivets, bolts or welds bearing directly the wheel loads, follow the requirements of Fig. 15. For rails located directly above the web and not requiring accurate design, the wheel loads may be considered in compliance with Fig. 15 and are uniformly distributed within 50mm directly under the wheels and spread over 45 degrees.

Fig. 15 The Distribution of Wheel Loads



15.3 Girder web joints under bending: The plate girder web joints under bending moment shall be designed with shear force and bending moment. The maximum combined force acting on joint bolts (including rivets) may be calculated using the equation below. At this moment, the allowable strength of bolts may be reduced based on the distance from the flanges of plate girder to the neutral axis and the ratio of y_n in the equation.

$$R = \sqrt{\left(\frac{F}{n}\right)^2 + \left(\frac{M_w}{\Sigma y^2} \cdot y_n\right)^2}$$

But $M_w = M \cdot \frac{I_w}{I}$

Where: R: The combined force acting on a bolt about y_n (kgf) {N}

n: The number of joint bolts at a joint line

F: Maximum shear at joint (kgf) {N}

M_w: Bending moment that the web is taking (kgf-m) {N-m}

M: Bending moment that the girder is taking at the joint (kgf-m) {N-m}

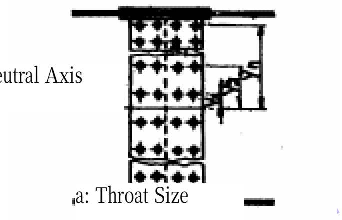
I_w: Moment of inertia of the web about the neutral axis of the entire cross section (cm^4 or mm^4)

I: Moment of inertia about the neutral axis of the entire cross section (cm^4 or mm^4)

Σy^2: The sum of squares of the distances from the bolts at one side of joint line to neutral axis (cm^2 or mm^2)

y_n: The distance from neutral axis (refer to Fig. 16) to the farthest bolts (cm or mm)

Fig. 16 Web Joint



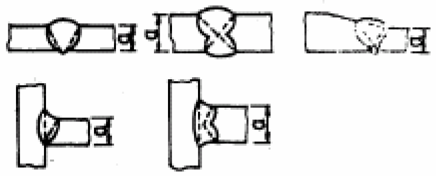
16. Detail design for welded structures:

16.1 The welding of primary members: In principle, the welding of primary members shall be done in shop.

16.2 Effective thickness of welded joints: The effective thickness of welded joints that transfer stresses shall be the depth of weld throat and the selection method follows the requirements below.

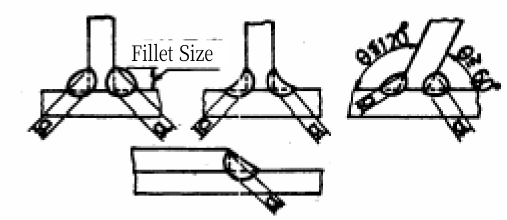
(1) The throat size of groove welds is the thickness of plate in the jointing member, as shown in Fig. 17, and is the thinner one if the thicknesses of plates are different.

Fig. 17 Thickness of Plate in Groove Welds



(2) The throat size of a fillet weld, as shown in Fig. 18, is the height of isosceles triangle with the fillet size of short leg as the side.

Fig. 18 Throat Size of a Fillet Weld



16.3 Effective length of welded joints: The effective length of welded joints is the weld length with complete throat size.

(1) If the line of fillet weld is not perpendicular to the stress, it is the perpendicular projection length of weld line [refer to Fig. 19(a)].

(2) For fillet weld with all-around welds, the parts around the corner are not considered as part of effective length [refer to Fig. 19(b)].

Fig. 19 Effective Length of Welds