Advantage and application of Steel Buildings

1. Introduction
2. Production of Steel
3. Steel Products for building structure
4. Characteristic of Structural Steel
5. Special Steel Products for Building

The Japan Iron and Steel Federation

1. Introduction

Iron Cycle Supports Human Life

1.1 Iron is Abundant Resources
1.2 Iron is Essential for Creatures
1.3 Iron Supports Civilization
1.4 Iron is Strong and Tough
1.5 Iron Circulate through Society

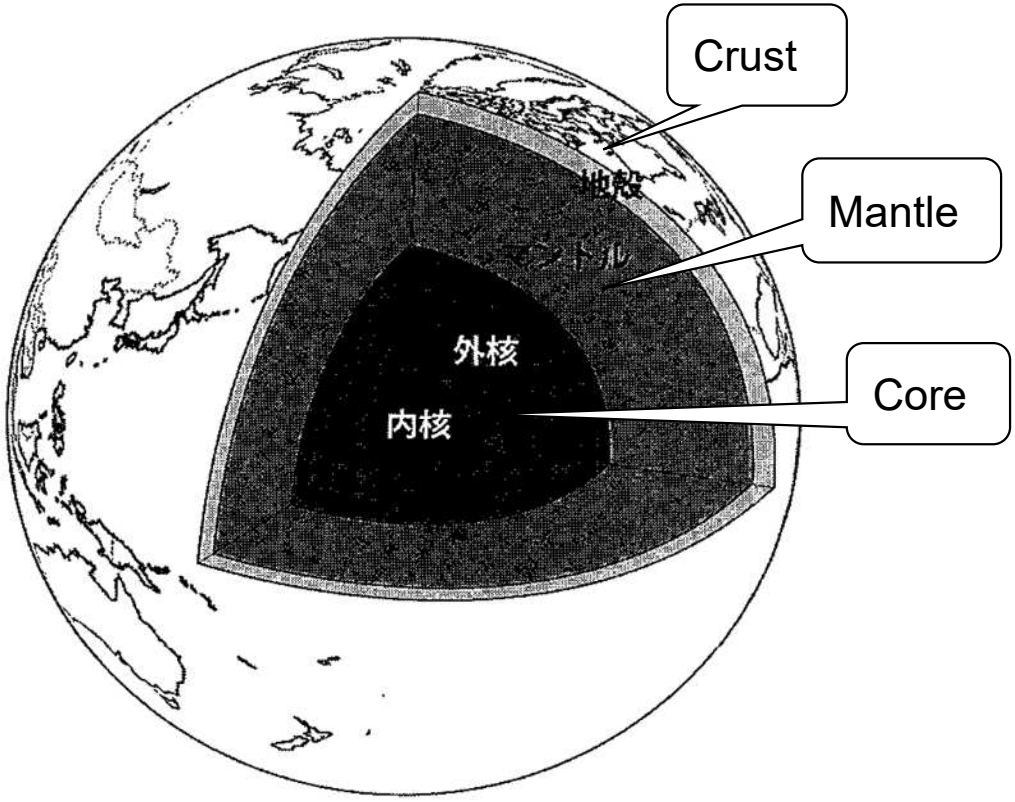
1.1 Iron is Abundant Resources

1/3 of the earth mass is iron.

Iron ore is abundant resource all over the earth.

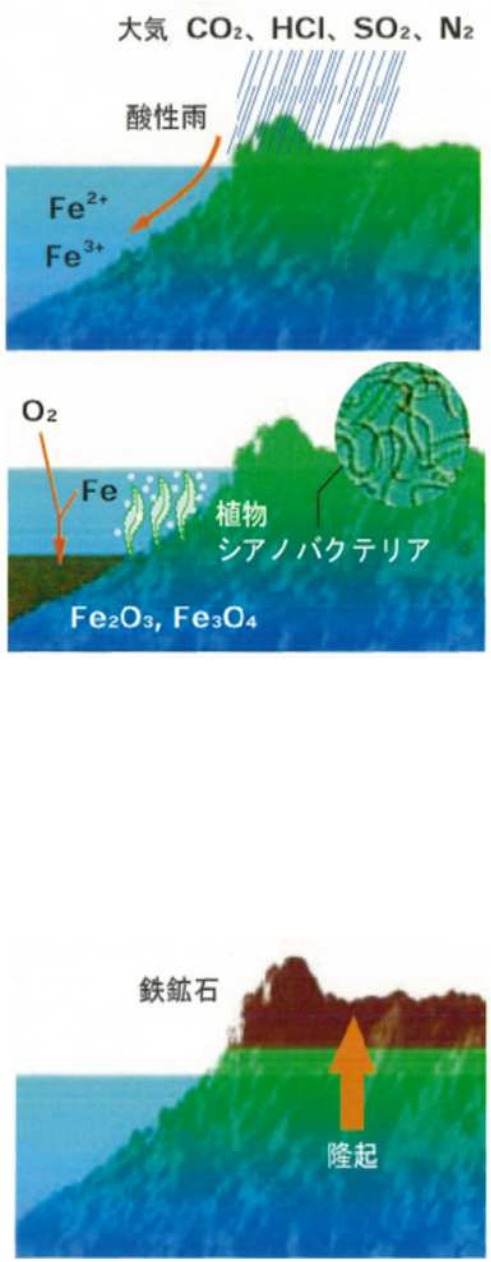
iron ore

4.5 billion years ago
Birth of primitive earth



Inside the Earth

1.1 Iron is Abundant Resources



4.5 billion years ago

Birth of primitive earth

Most iron sank to earth center, but still 5% of the crust is iron.

3.8billion years ago

Birth of ocean

Iron dissolved into water.

2.0 billion years ago

Vast breeding of Cyanobacteria

Huge release of oxygen

↓

Oxidation of iron ion

↓

Settling as iron hydroxide

↓

Sedimentation as iron oxide with quartz sand alternately

↓

Stripe iron ore layer

1.5 billion years ago

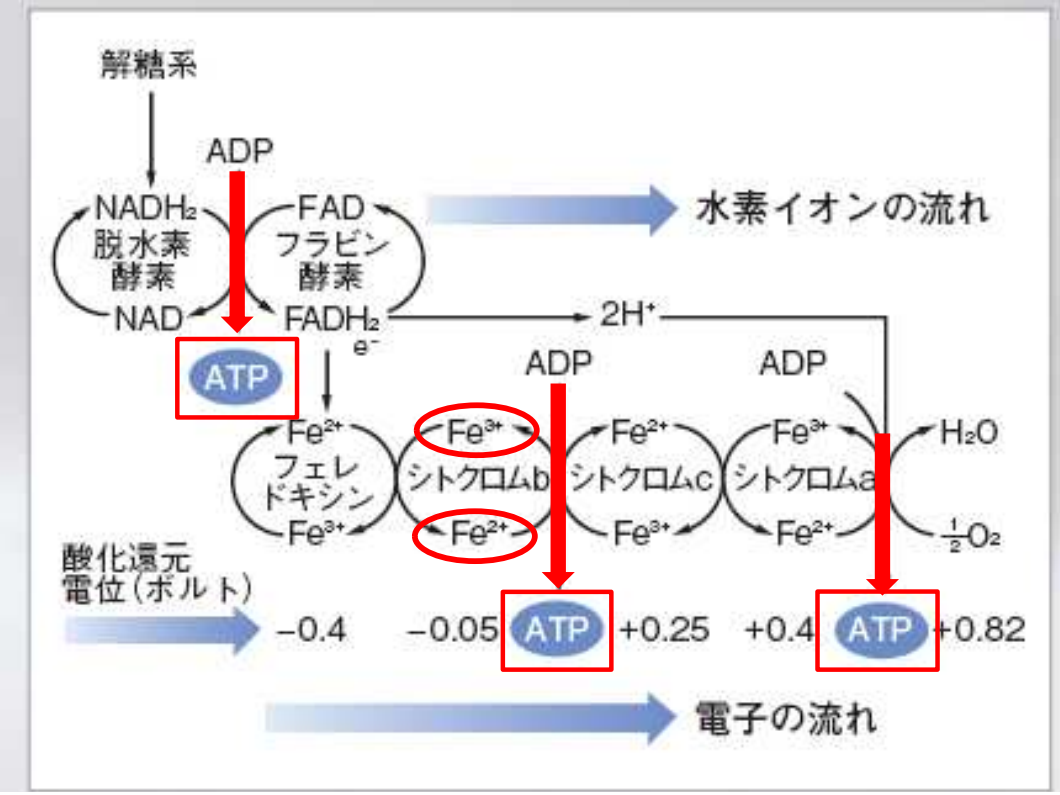
Rise of ocean floor

- Distributed to old layers all over the world
- Estimated reserves are more than 100 trillion tons

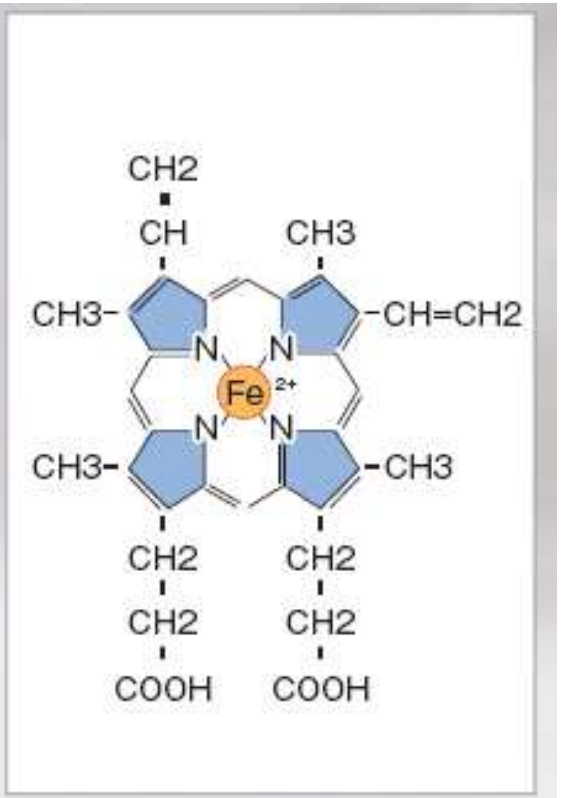
1.2 Iron is Essential for Creatures

Iron rotates for metabolism of all creatures

$$Fe^{3+} + e^- \Leftrightarrow Fe^{2+}$$



①Electron transfer system in aerobic respiration



②Hemoglobin

- Difference of electrostatic potential of Fe^{2+} and Fe^{3+} is small.
- Creatures utilize iron ion for transferring electron in aerobic respiration system and photosynthesis system.
- Creature extract energy burning oxygen safely with iron cycle.

1.3 Iron Supports Civilization

Development of iron making process with coal saved forest and realized sustainable civilization.

"Iron Bridge" made by iron making process with coke (1779)

1500BC : Invention of iron making method

Rise of civilization by iron

↓

Huge amount of charcoal were required

↓

Forest resources were exhausted

↓

Decline of civilization

18th century : Invention of iron making by coke (England)

1709 Blast furnace with coke
1742 Steam engine for bellows

↓

Free from limit of resources

Driving force for industrial revolution

1.4 Iron is Strong and Tough

Superior structural feature of STEEL
supports the safety of modern society

STEEL is iron which is adjusted to contain carbon less than 2%

- High elastic modulus and strength → Best for large structure
- Abundant plastic deformation capacity → Superior anti-seismic capacity
- Higher strength by heat treatment → Various construction method

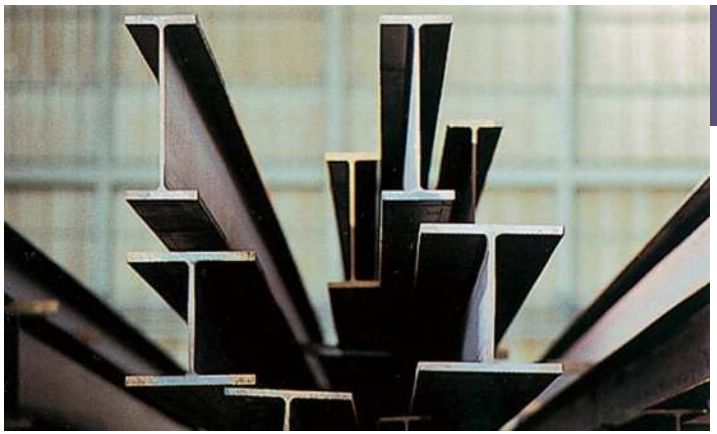
1.5 Iron Circulates through Society

① Steel regenerates over and over

- Almost all the waste steel is recycled.
- Steel can be recycled many times.
- Steel recycling industry is stable.

② Steel can be recycled easily

- Steel does not deteriorate.
- Easy to separate from others by magnet.
- Easy to adjust chemical composition.



③ Recycled steel keeps quality

- Horizontal recycling. Steel becomes steel.
- Using steel is sustainable

2. Production of Steel

2.1 Iron-making Process
2.2 Steel-making Process

2.1 Iron-Making Process

★3 major raw materials for iron

Iron ore : 1.6t
Limestone : 0.2t
Coal : 0.4t

} Iron : 1.0t

Iron (pig iron) is produced by reducing iron ore (iron oxide); 1,500ºC

Iron ore

Limestone

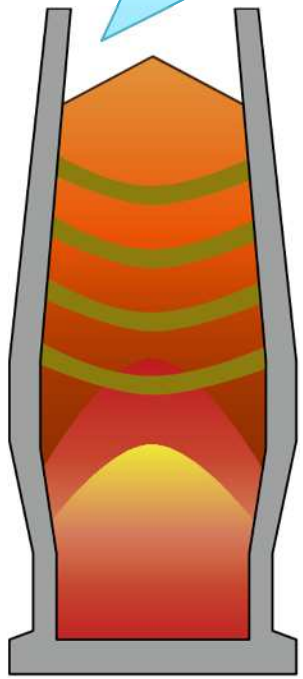
Coal

Sinter Plant

Sinter

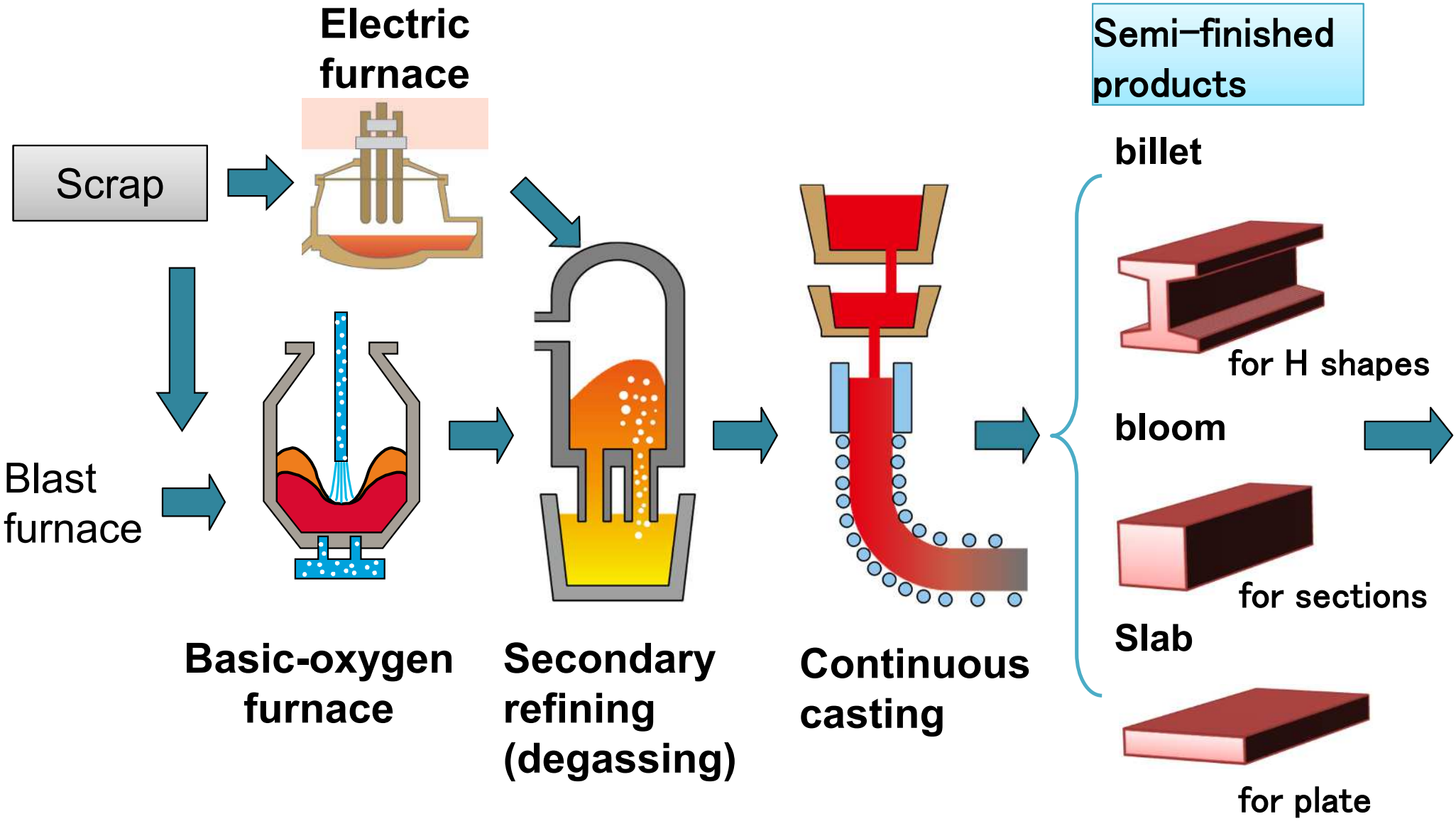
Coke Oven

Coke



Blast Furnace

2.2 Steel-Making Process



3. Steel Products for building structure

3.1 Steel Framing
3.2 Types of Steel Products
3.3 Shapes
3.4 Plates
3.5 Round Sections
3.6 Rectangular Hollow Structural Sections

3.1 Steel Framing -characteristic-

①Construction resistant to earthquakes and disasters

- Excellent in quake resistance, and can be used for disaster prevention bases or storage stations

②Rich design

- Thin columns and beam, easy to create curves

③Stable quality & short construction period

- It is possible to ensure quality and shorten construction period by factory production

④Creation of flexible space

- It is possible to produce a pillar-less large space, and also possible to respond to a need for change of use purpose or layout in the future.

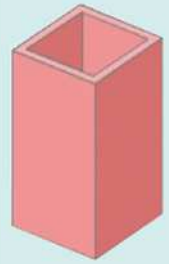
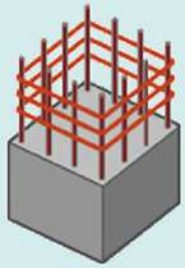
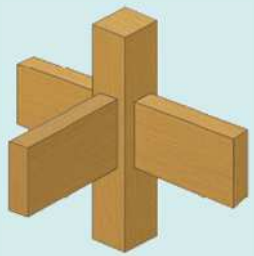
⑤Eco-friendly materials

- It is possible to conserve resources by means of recycling



[Cited from] materials of Japan Iron and Steel Federation

3.1 Steel Framing -characteristic-

No.	①	②	③	④
Construction type	S construction	CFT construction	RC construction	W construction
Material	Steel	Concrete-filled steel tube	Reinforced concrete	Wood
Characteristics	▪ Large span (flexibility of space, layout change) ▪ Short construction period	▪ Increase in strength and deformation capacity due to effects of mutual constraint	▪ Large stiffness ▪ Fire resistance ▪ Heavy, long construction period	▪ Easy to process ▪ Fire resistance measures needed
Outline				

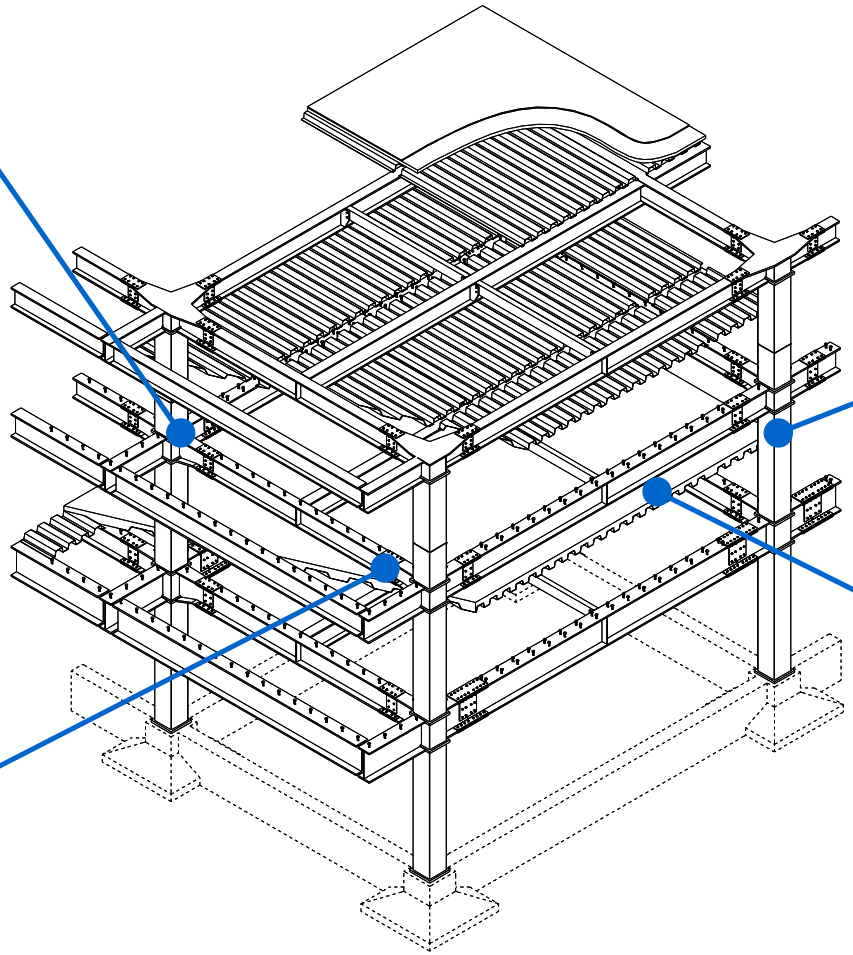
3.1 Steel Framing -steel products-

Round section

High strength bolt

Rectangular hollow structural section

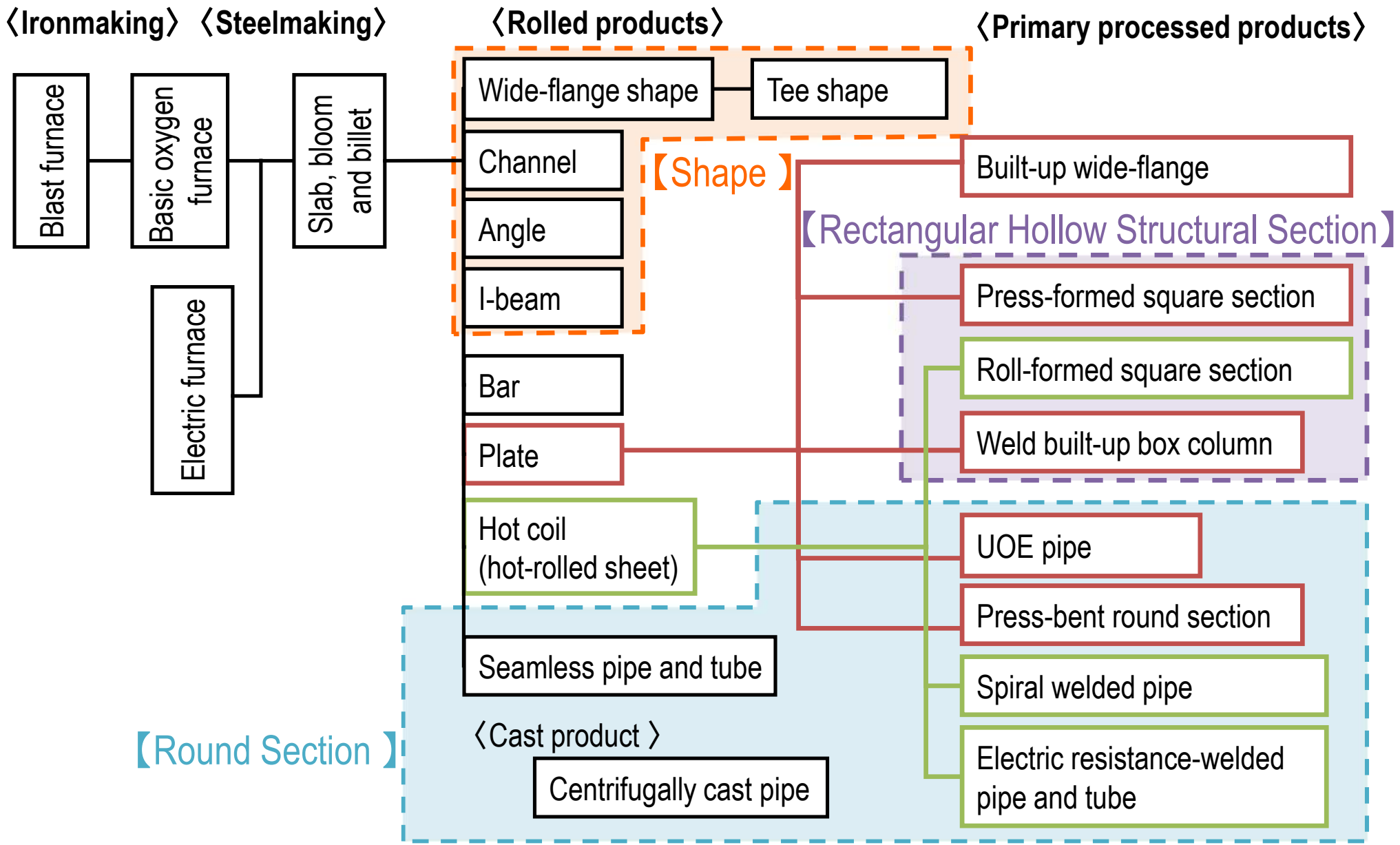
Welding



H-section steel

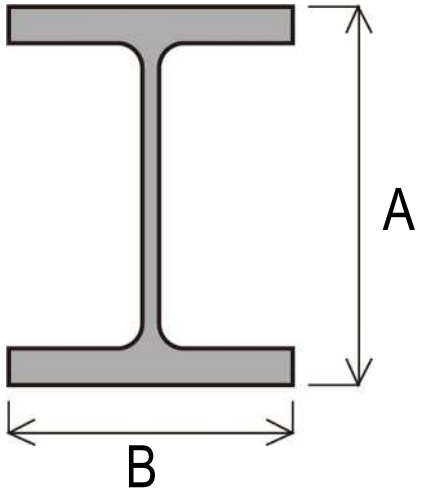
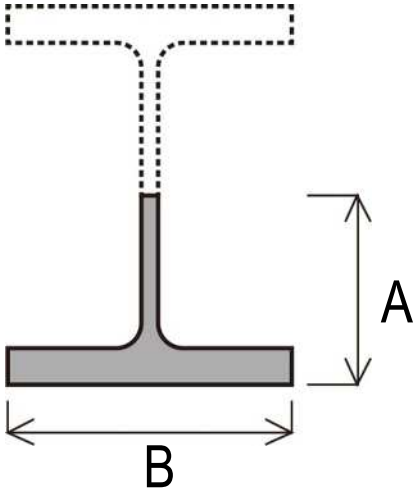
Plate

3.2 Types of Steel Products



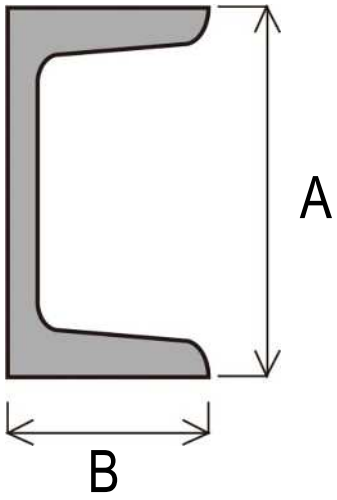
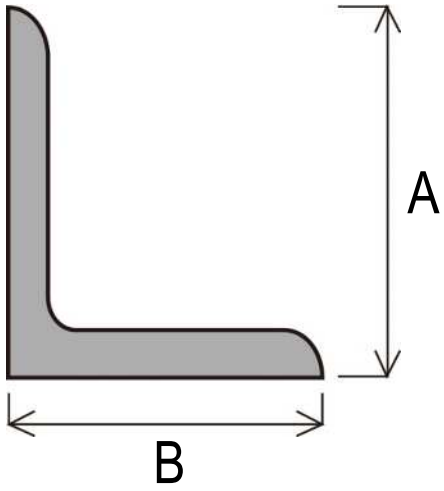
3.3 Shapes

(1) Wide Flange and H Beams, Structural Tees

	Wide-flange and H beams	Structural Tee shapes
Section		
Size (mm)	Wide width : 100 × 100～400 × 400 Medium width : 150 × 100～900 × 300 Narrow width : 150 × 75～600 × 200 Fixed outer dimension : 400 × 200～1000 × 400	Shape manufactured by equally dividing wide-flange beam
Application	Column, beam, brace, stud, small beam	Brace, truss member, assembly member

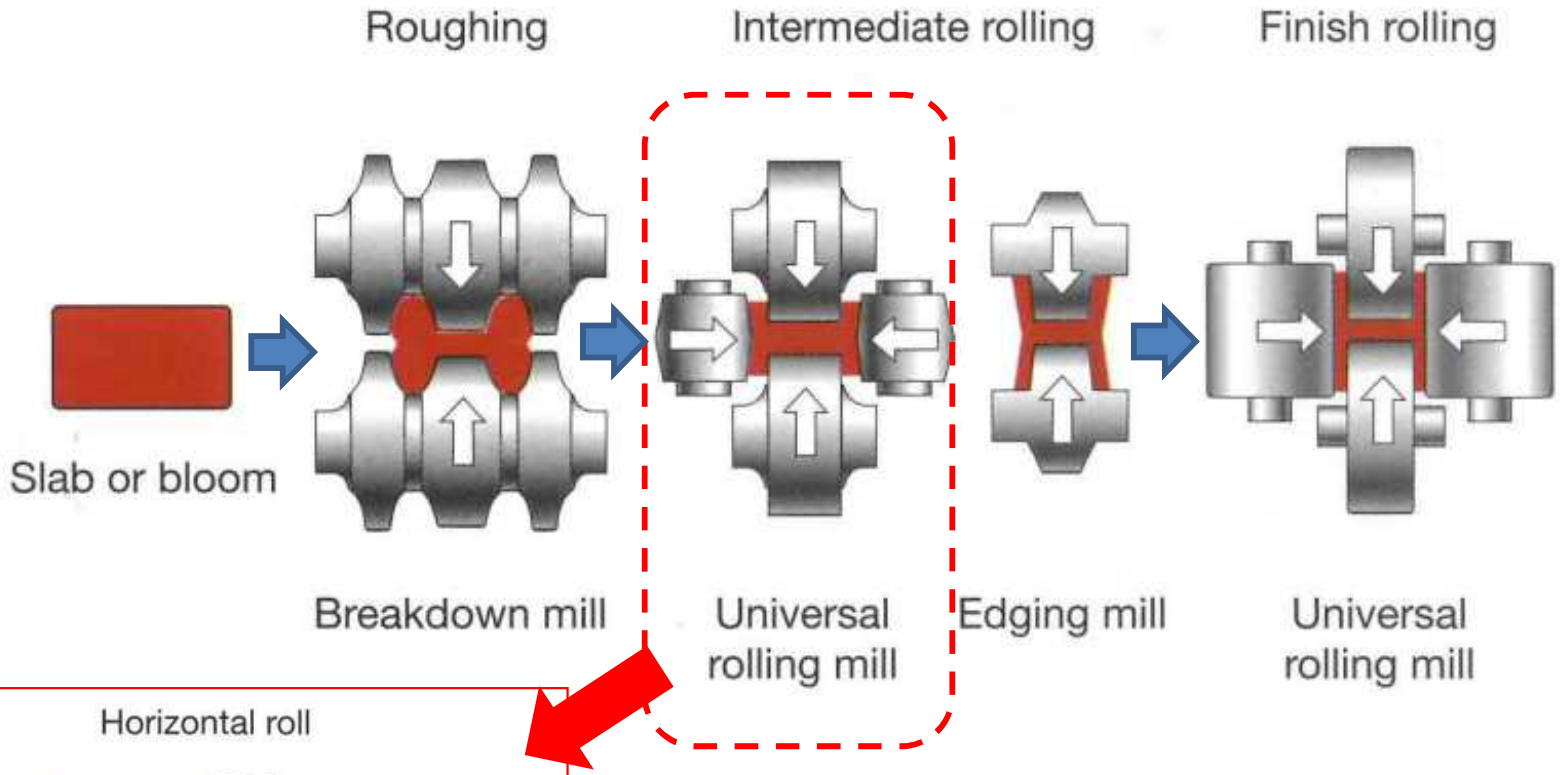
3.3 Shapes

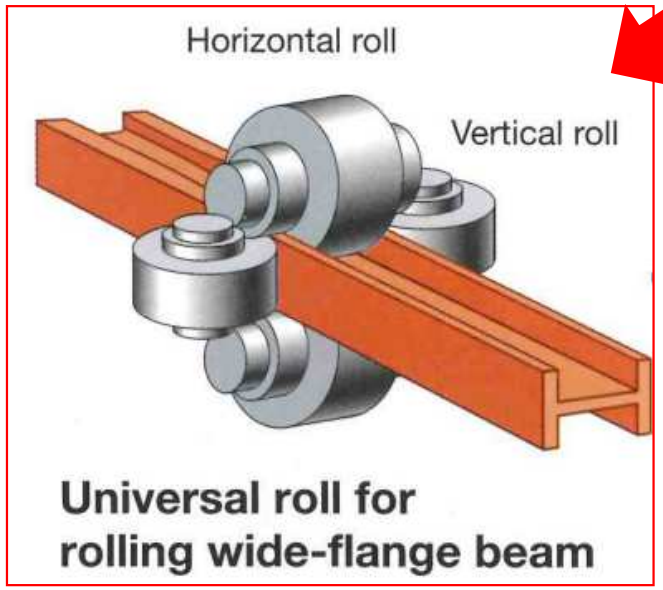
(2) Channels and Angles

	Channels	Angles
Section		
Size (mm)	75 × 40～380 × 100	Equal leg : 20 × 20～350 × 350 Unequal leg : 75 × 50～150 × 100 Unequal leg and unequal thickness : 200 × 90～600 × 150
Application	Furring strip, joist, purlin, small beam, truss member	Brace, truss member, assembly member

3.3 Shapes

(3) Manufacturing Process of Wide Flange and H Beam



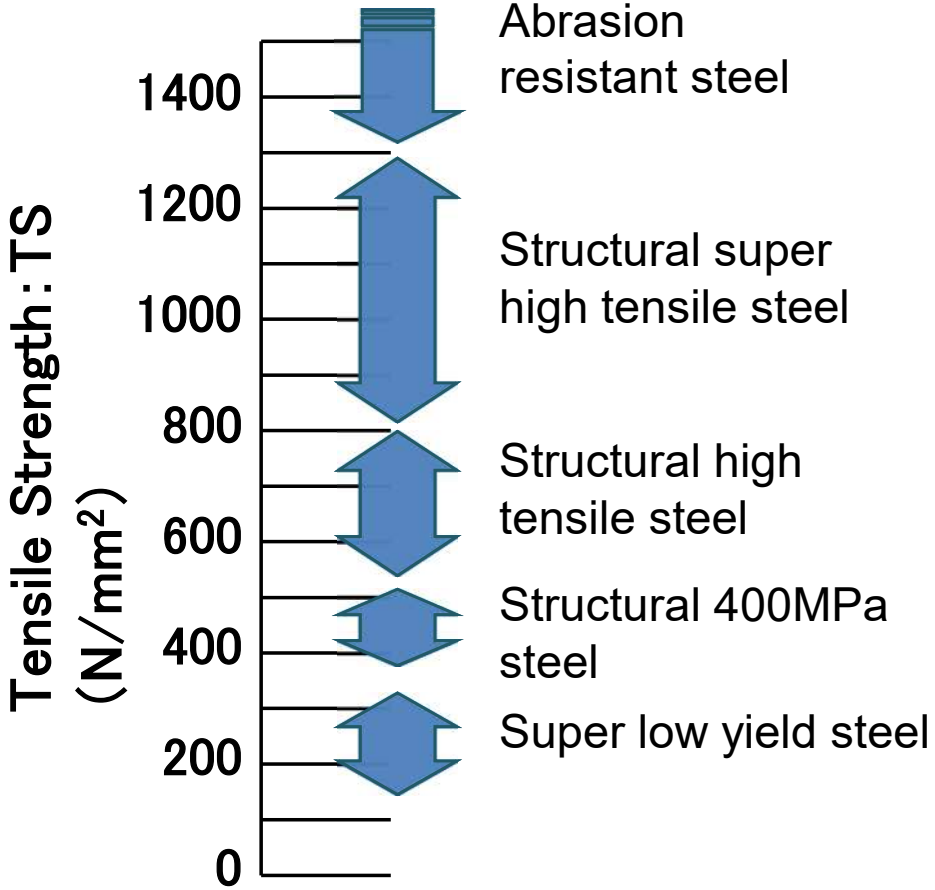


using same horizontal roll and edging roll for different thickness

↓

outer dimension varies

3.4 Plates



Steel plates

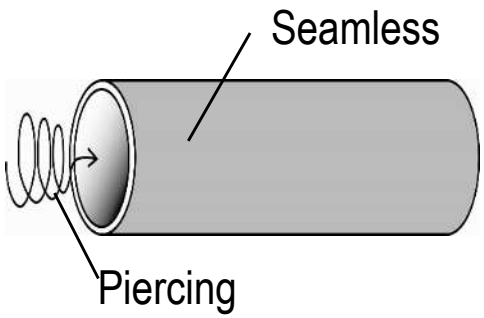
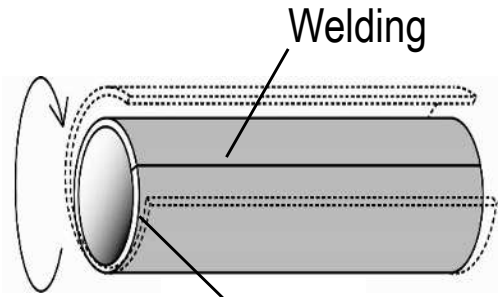
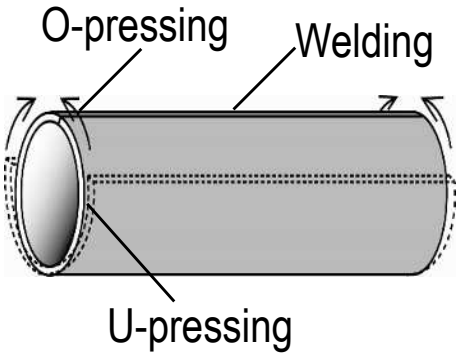
- 6mm or more in thickness; 100 mm or less in thickness practically applied for building structures, excluding special uses.
- 1~5 meters in width, 3~25 meters in length

Major applications of steel plates

Base plates, splice plates, gusset plate, welded built-up columns, built-up H-shapes and press-bent steel
(applied for assembled structural members with heavy plate thicknesses and large sections, for which rolled products are difficult to apply)

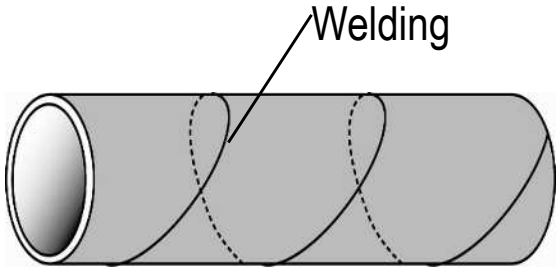
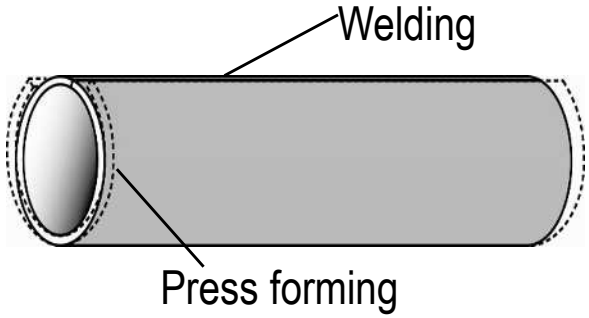
3.5 Round Sections

(1) Types of Round Sections

	Seamless	Welded	
	①Seamless pipe and tube	②Electric resistance-welded pipe and tube	③UOE pipe and tube
Production method			
Outside diameter	20～400 mm	60～600 mm	400～1600 mm
Wall thickness	2～60 mm	1～20 mm	6～45 mm
Application	Line pipe, oil-well tubular goods	General structure, pipe pile, gas and water piping	Gas and oil transport, building structure

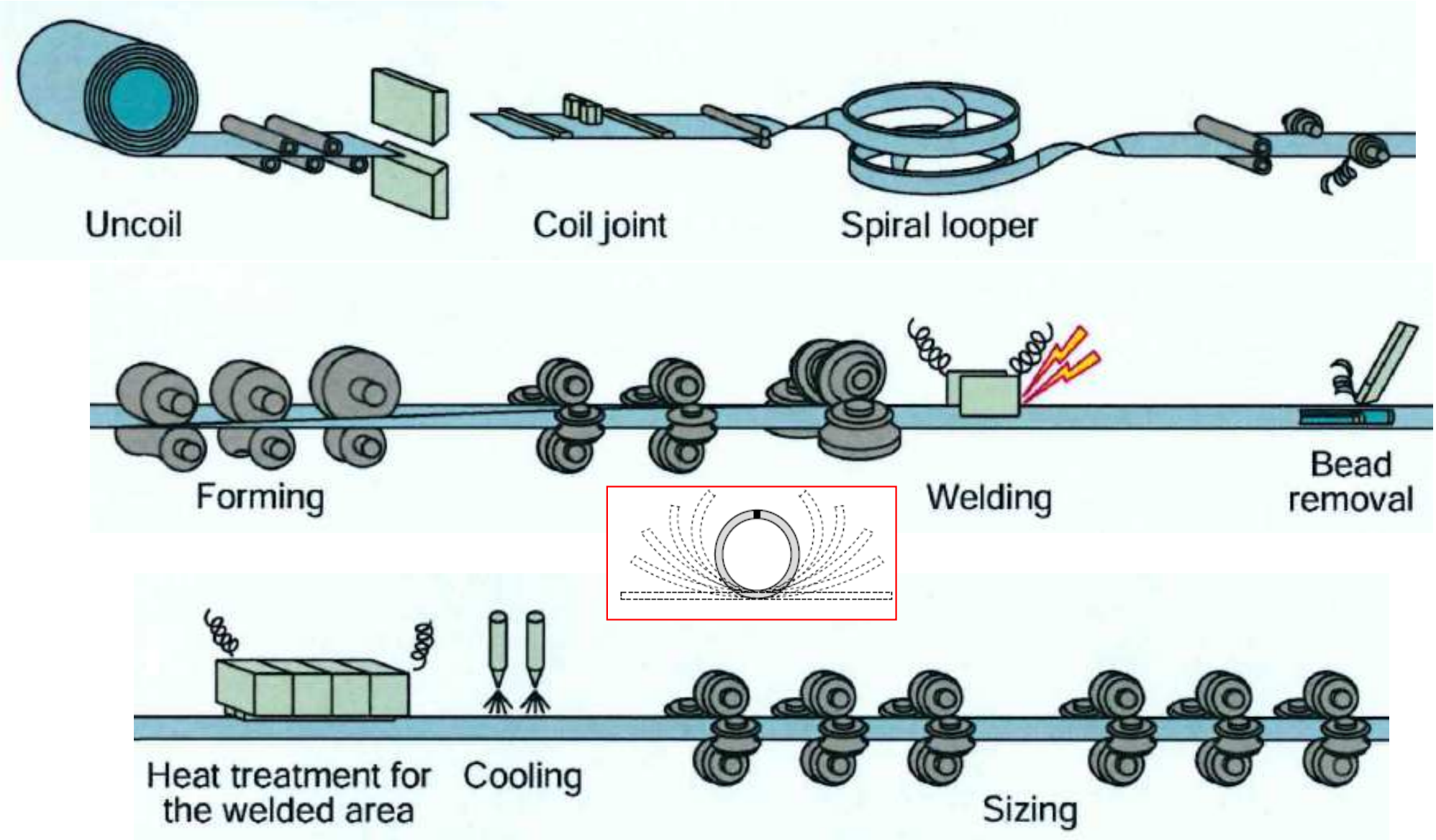
3.5 Round Sections

(1) Types of Round Sections

	Welded	
	④Spiral welded pipe and tube	⑤Press-bent pipe and tube
Production method		
Outside diameter	400～2500 mm	400～5000 mm
Wall thickness	6～25 mm	6～100 mm
Application	Mainly for pile	Product with heavy wall thickness and large outside diameter unavailable with other production methods

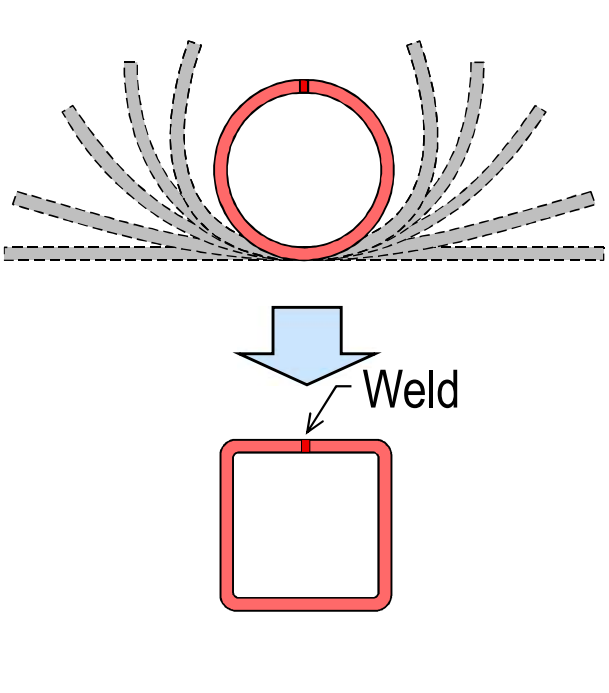
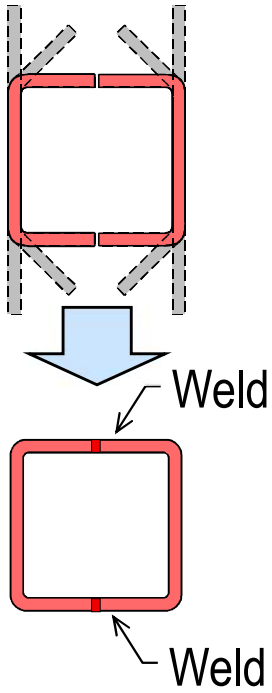
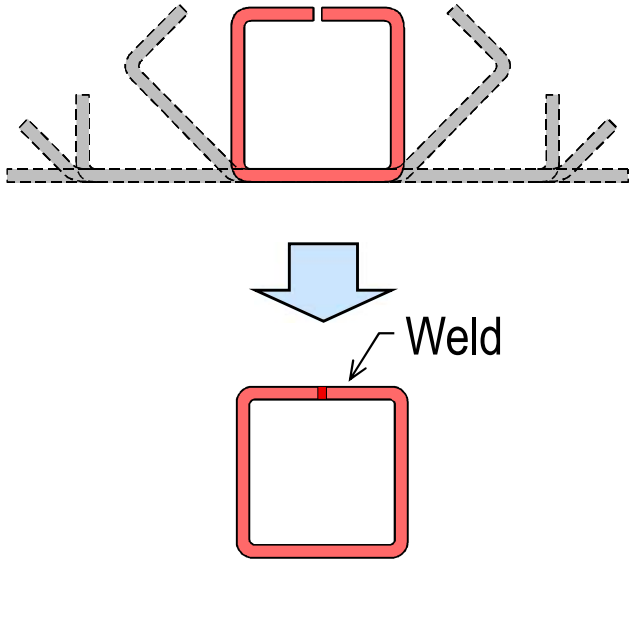
3.5 Round Sections

(2) Manufacturing Process of ERW Pipes



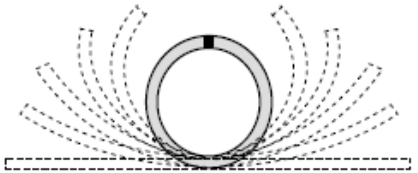
3.6 Rectangular Hollow Structural Sections

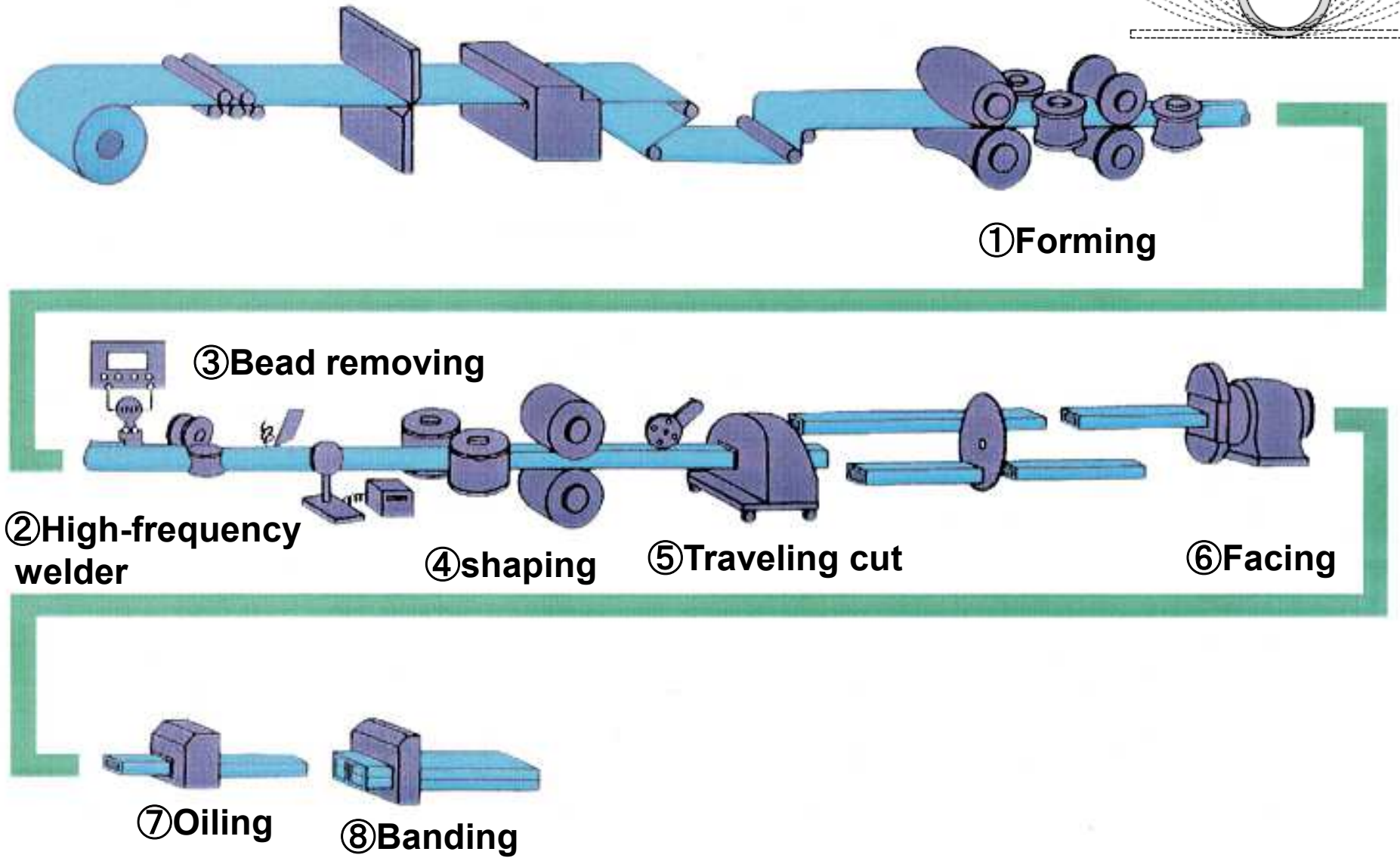
(1) Types of Rectangular Hollow Structural Sections

	Cold roll-formed square pipes	Cold press-formed square pipes	
Section	 Roll forming + Electric resistance welding	 Press forming + Arc welding (2 seams)	 Press forming+ Arc welding (1 seam)
Size (mm)	□—200 × 6～□—550 × 25	□—300 × 9～ □—1000 × 40	

3.6 Rectangular Hollow Structural Sections

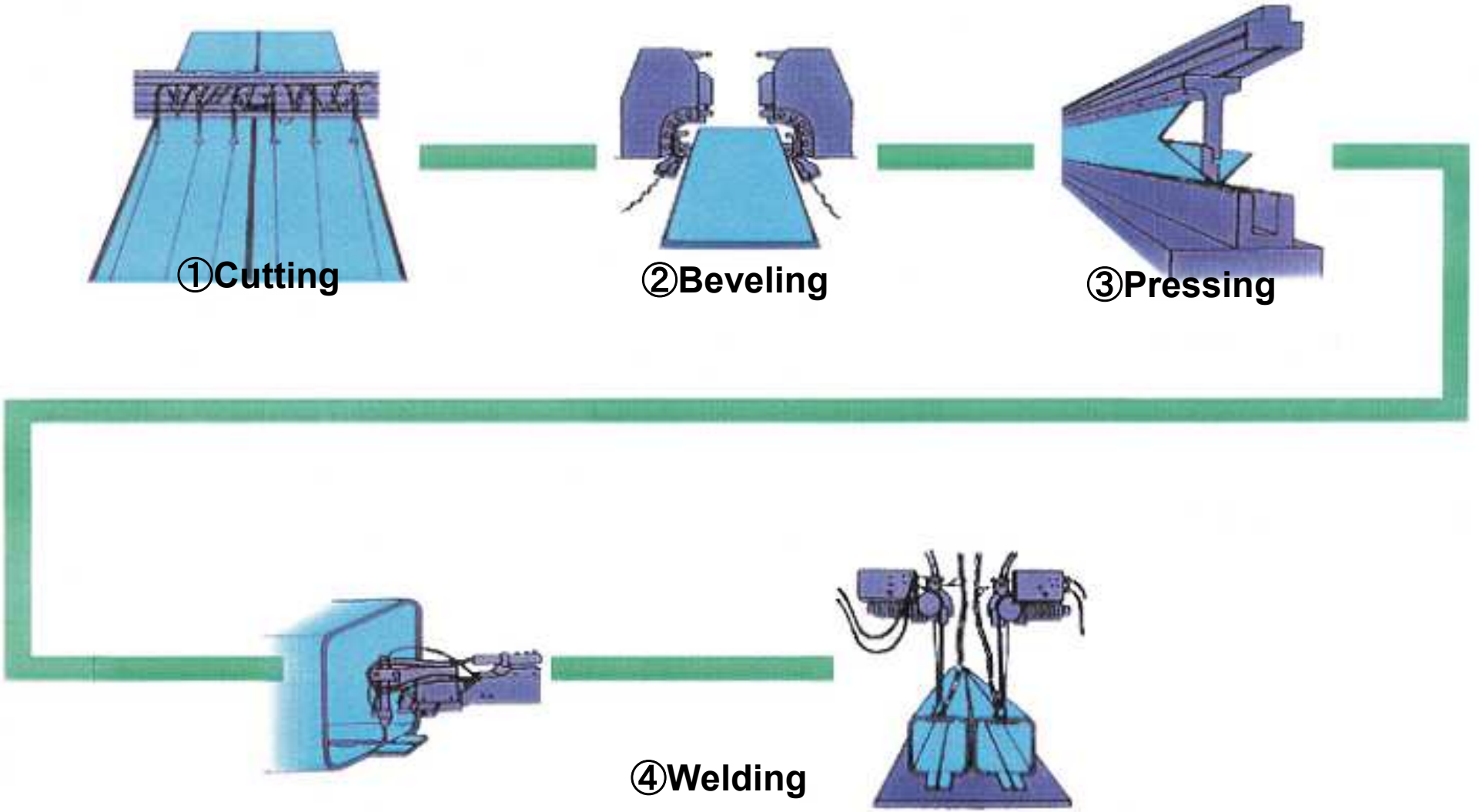
(2) Manufacturing Process of Rectangular Hollow Structural Sections





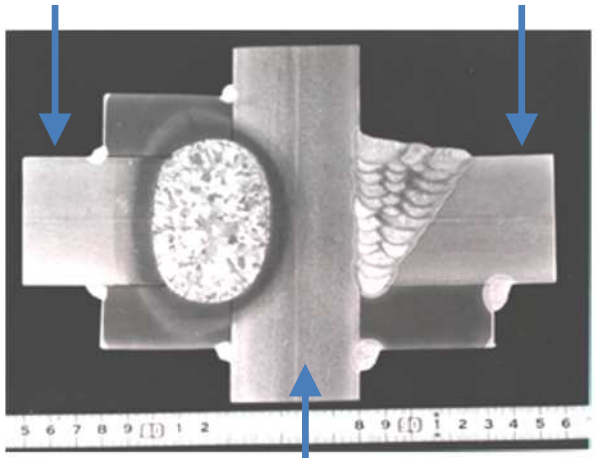
3.6 Rectangular Hollow Structural Sections

(3) Manufacturing Process of Press-formed Square Sections

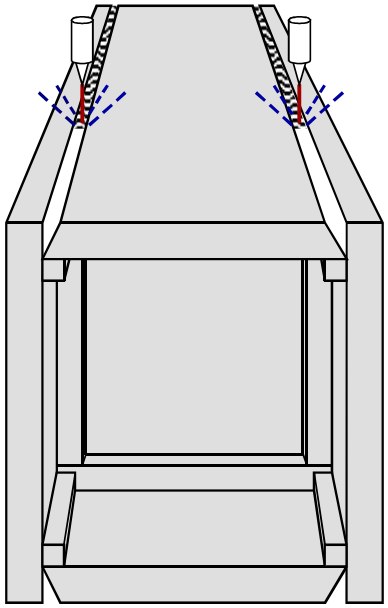


3.6 Rectangular Hollow Structural Sections

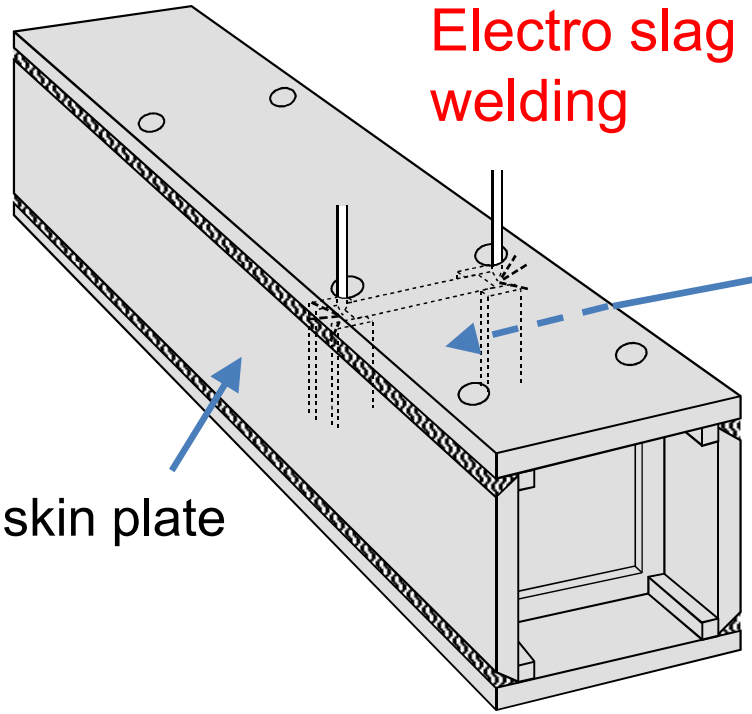
(3) Manufacturing Process of Welded Box Columns



Submerge arc welding



Electro slag welding

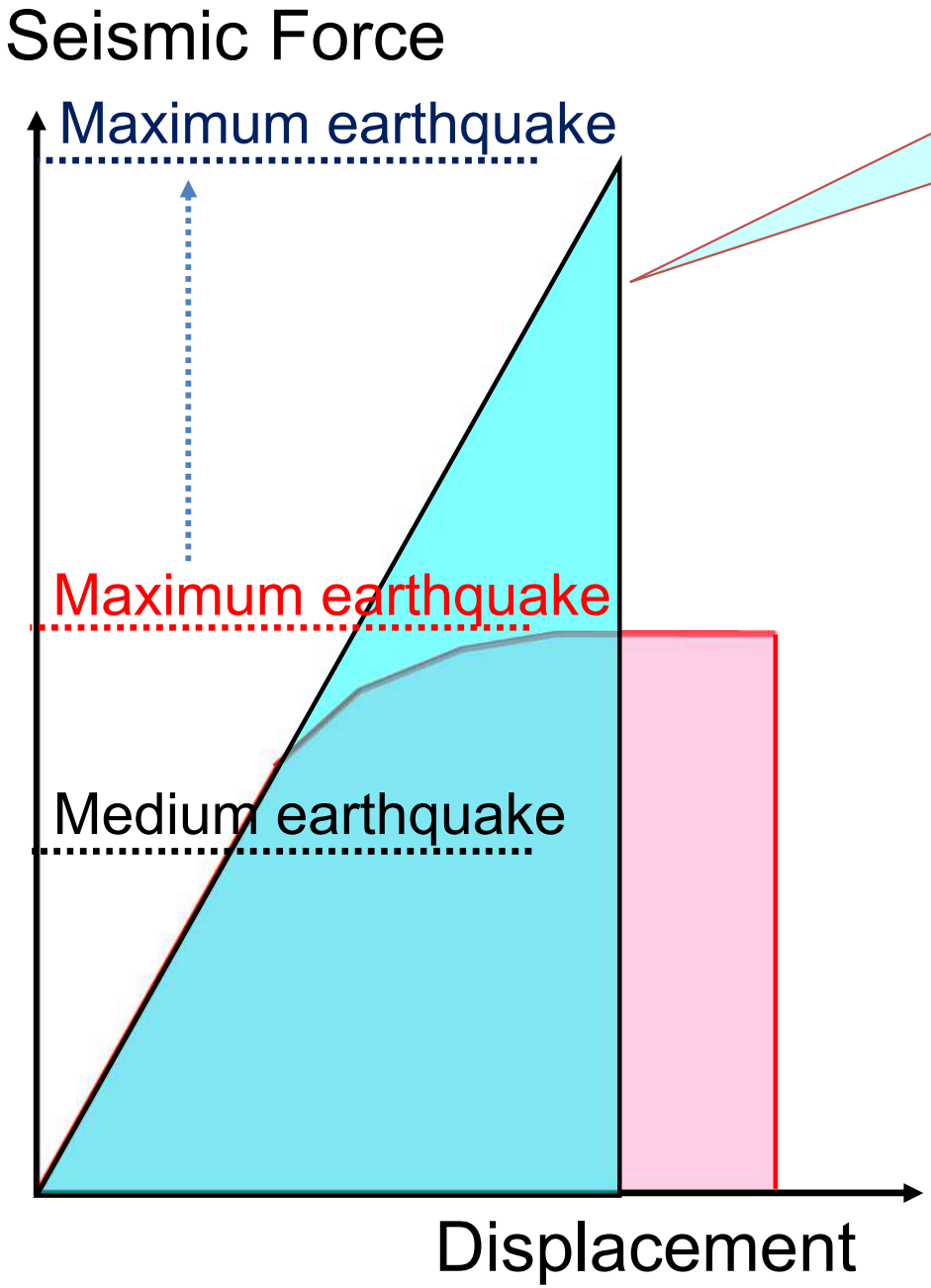


4. Characteristic of Structural Steel

4.1 Steel for Seismic Design
4.2 SN Steel Grade / JIS G 3136
4.3 Mechanical Properties
4.4 Chemical Composition

4.1 Steel for Seismic Design

(1) Basic Idea of Seismic Design for Building



Very high strength is required

if keeping the structure elastic

What is Anti-Seismic Performance of Buildings?

Energy Absorption Capacity

※Energy＝Force × Displacement

For maximum earthquake, plastic deformation capacity of structural elements is important, on top of strength

4.1 Steel for Seismic Design

(2) Relationship between Seismic Design and Steel Performance

Seismic design

- (A) Frame collapse type
- (B) Plastic deformation capacity of column and beam members
- (C) Ultimate strength of joint
  - High-strength bolt joining
  - Weld joining
- (D) Brittle fracture of weld joint

Performance of steel products

【Mechanical properties】
(1) Deviation of yield point, ΔYP
(2) Yield ratio, YR
(3) Elongation
(4) Impact property

【Chemical composition】
(1) C, Si, Mn, P, S
(2) C_{eq}, P_{CM}

4.2 SN Steel Grade / JIS G 3136

(1) Feature of SN Steel Grade

Conventional Steel Grade
- JIS SS400, SM490 etc.
- ASTM A36, A572 / EN S355 etc.
- Intended for elastic design

SN Steel Grade
- Established in 1994 in JIS G 3136
- Intended for plastic design
- Most suitable for seismic design

1. Excellent plastic deformation capacity
Specification of upper limit of yield point and yield ratio

2. Excellent weldability
Specification of Charpy absorption energy, Ceq and PCM

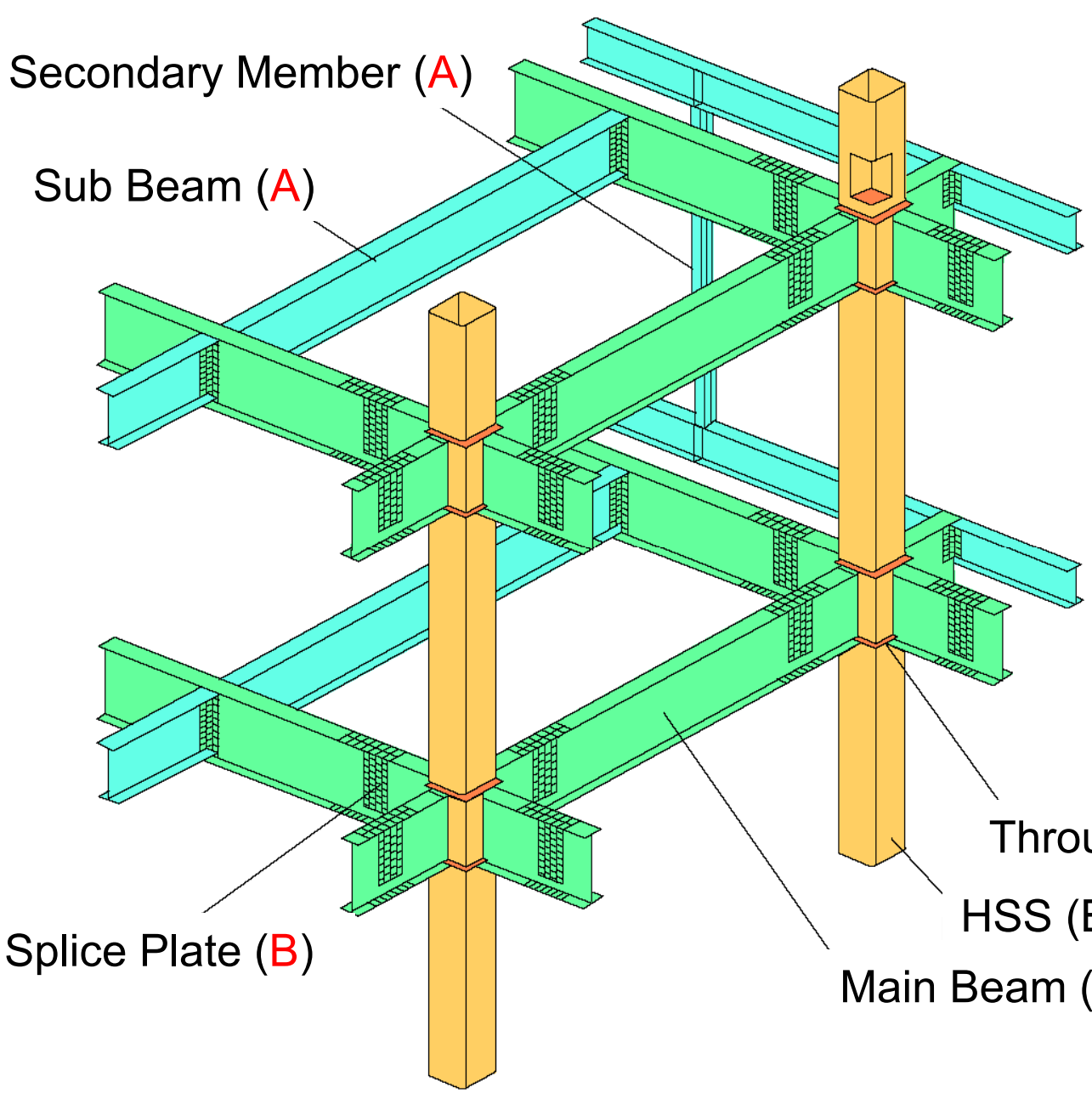
3. Securement of thickness-direction property
Strict limit of P and S, Through thickness strength (Grade C only)

4. Securement of nominal sectional dimension
Strict specification of minus thickness tolerance

5. Variation of grades to meet kinds of element
Line-up of three steel grades (Grades A, B and C)

4.2 SN Steel Grade / JIS G 3136

(2) Type of SN Steel Grade and their Uses



Type A
Severe geometry tolerance

Type B
Type A + ductility, weldability, and fracture toughness

Type C
Type B + through thickness strength and lower P, S

4.2 SN Steel Grade / JIS G 3136

(3) Comparison with Other Steel Grades

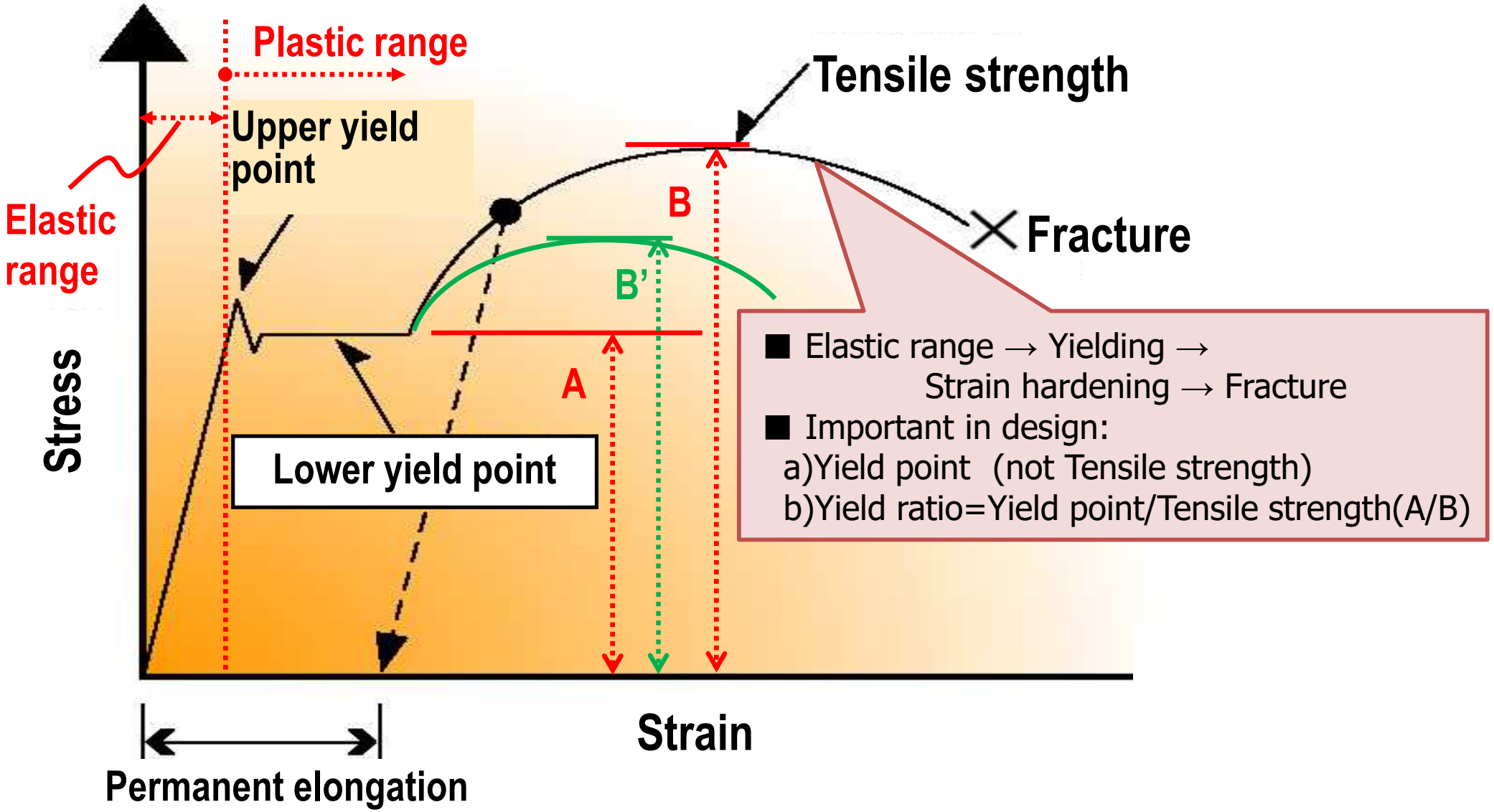
comparison at 16mm < nominal thickness ≦40mm

Std.	Grade	Yield strength (MPa)		Tensile strength (MPa)		Yield ratio (%)	Charpy absorption energy (J)	Ceq (%)	S (%)
		Min.	Max.	Min.	Max.	Max.	Min. (0℃)	Max.	Max.
JIS	SS400	235	-	400	510	-	-	-	0.0050
	SM490A	315	-	490	610	-	-	-	0.0035
	SN400A	**235**	-	**400**	**510**	-	-	-	**0.0050**
	SN400B	**235**	355	**400**	**510**	80	27	**0.36**[*1]	**0.0015**
	SN400C	**235**	355	**400**	**510**	80	27	**0.36**[*1]	**0.0008**
	SN490B	**325**	**445**	**490**	**610**	**80**	**27**	**0.44**[*1]	**0.0015**
	SN490C	**325**	**445**	**490**	**610**	**80**	**27**	**0.44**[*1]	**0.0008**
ASTM	A572 Gr.50	345	-	450	-	-	-	-	0.0050
	A992	345	450	450	-	85	-	-	0.0045
EN	S355J0	345	-	-	-	-	27	0.45[*2]	0.0030

*1 : Ceq=C+Mn/6+Si/24+Ni/40+Cr/5+Mo/4+V/14　　*2 : Ceq=C+Mn/6+(Cr+Mo+V)/5+(Cu+Ni)/15

4.3 Mechanical Properties

(1) Stress-Strain Relationship of Structural Steel

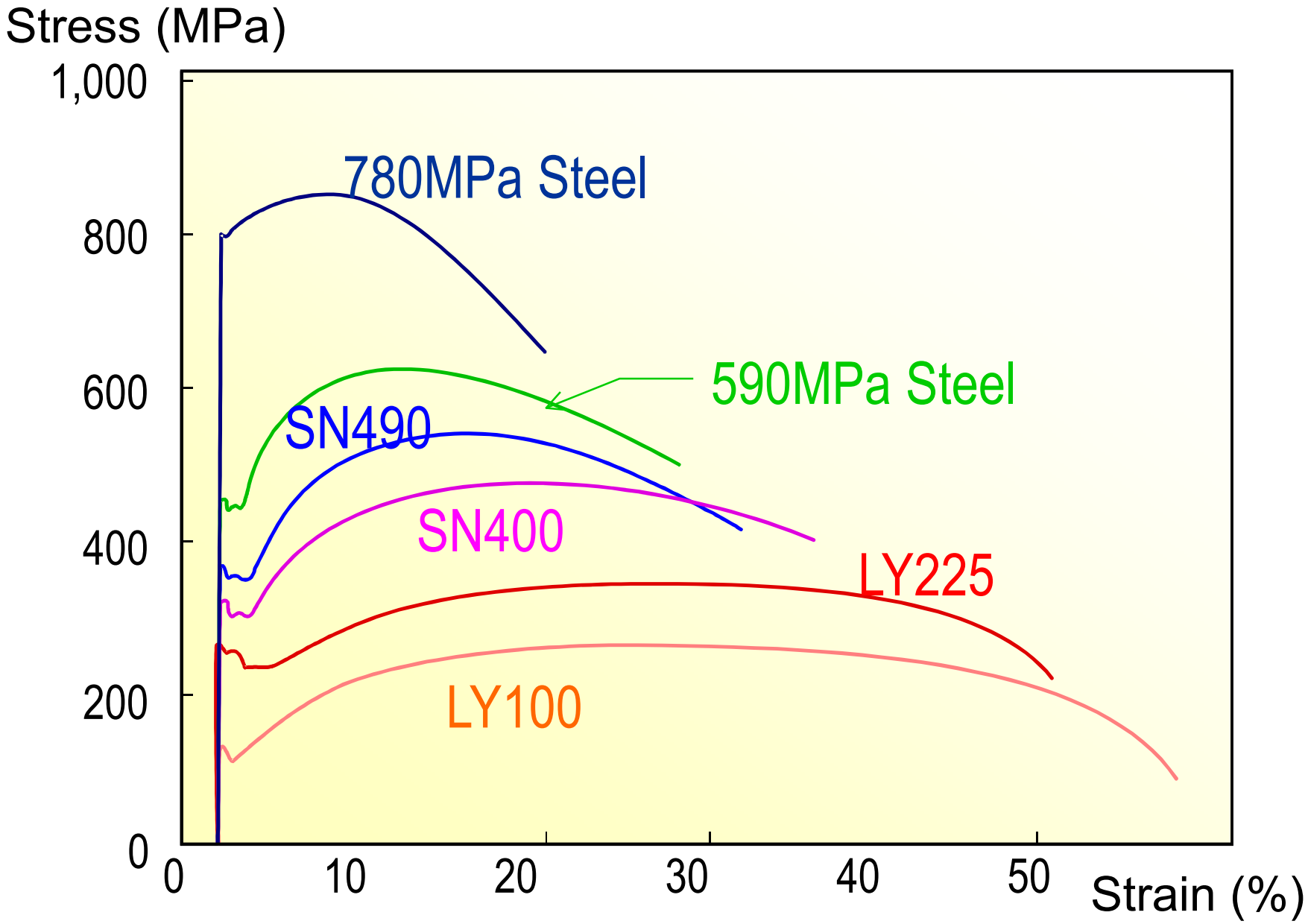


■ Elastic range → Yielding →
Strain hardening → Fracture

■ Important in design:
a)Yield point (not Tensile strength)
b)Yield ratio=Yield point/Tensile strength(A/B)

4.3 Mechanical Properties

(1) Stress-Strain Relationship of Structural Steel



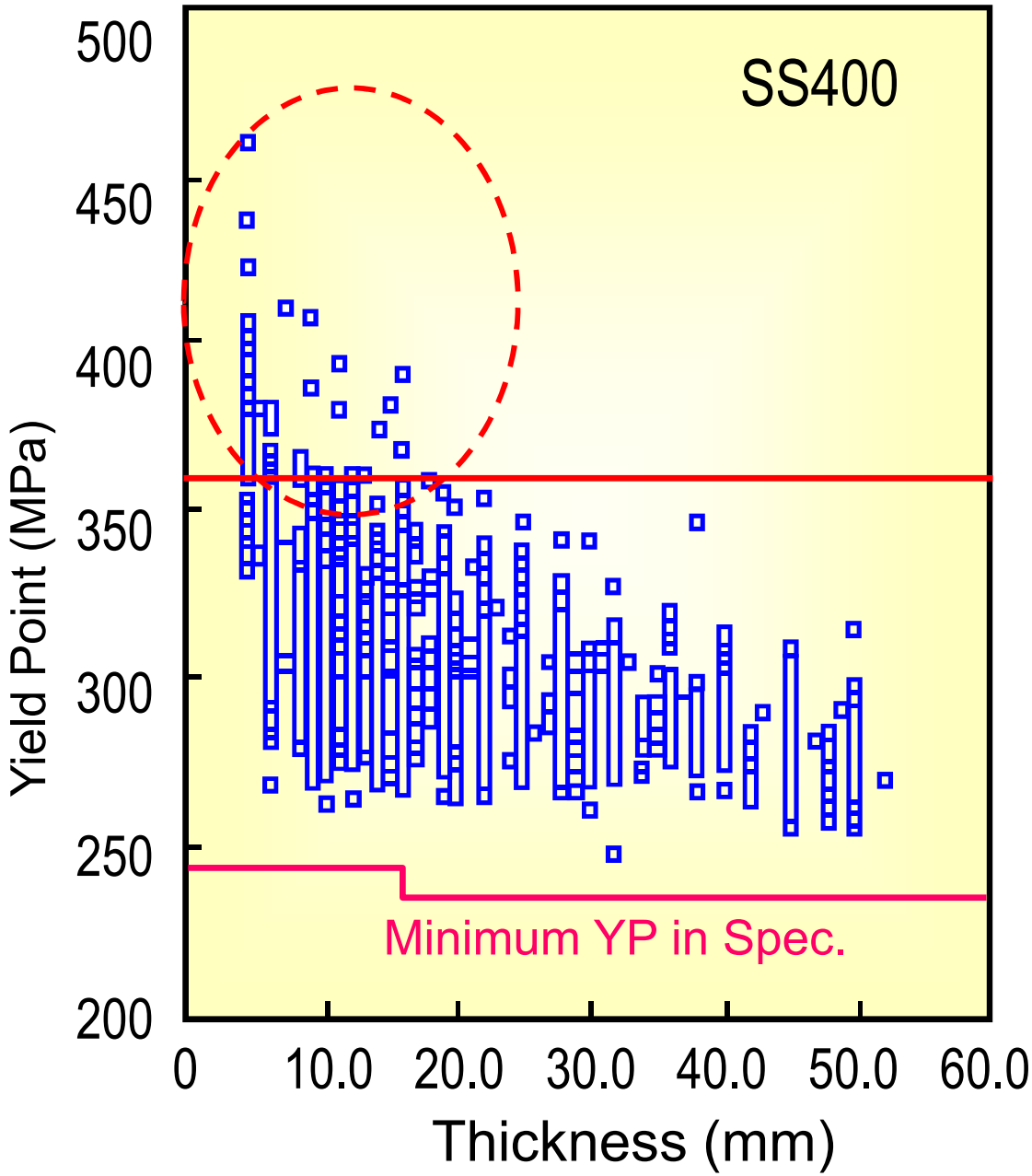
4.3 Mechanical Properties

(2) Deviation of Yield Point

Deviation of actual yield point of conventional steel is very large.

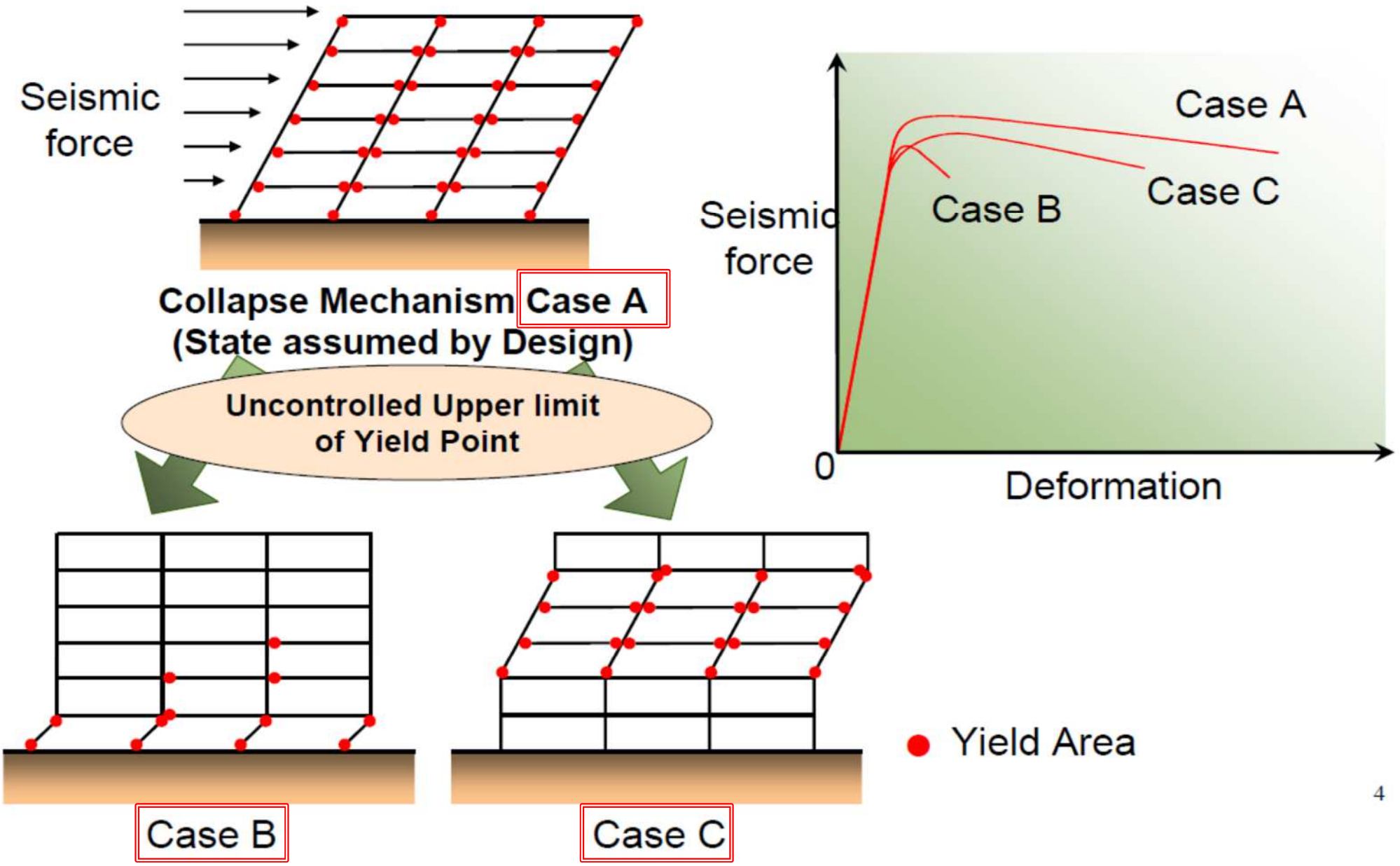
Actual structure may show different performance than what designed by specified minimum YP

Using steel of smaller deviation is important for seismic design



4.3 Mechanical Properties

(2) Deviation of Yield Point

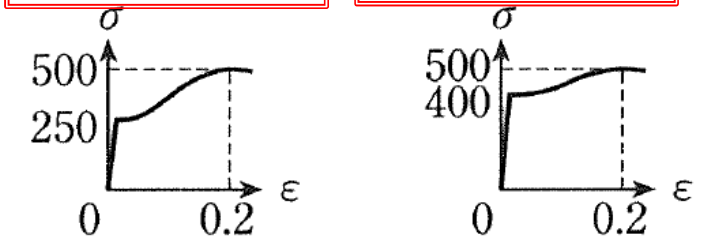


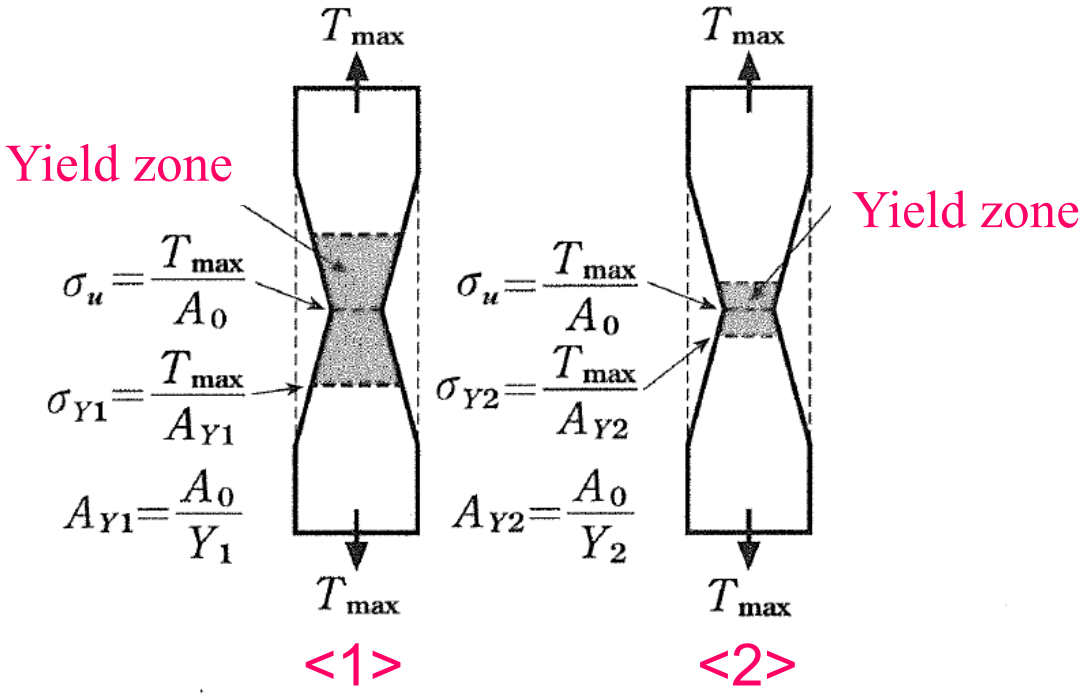
4.3 Mechanical Properties

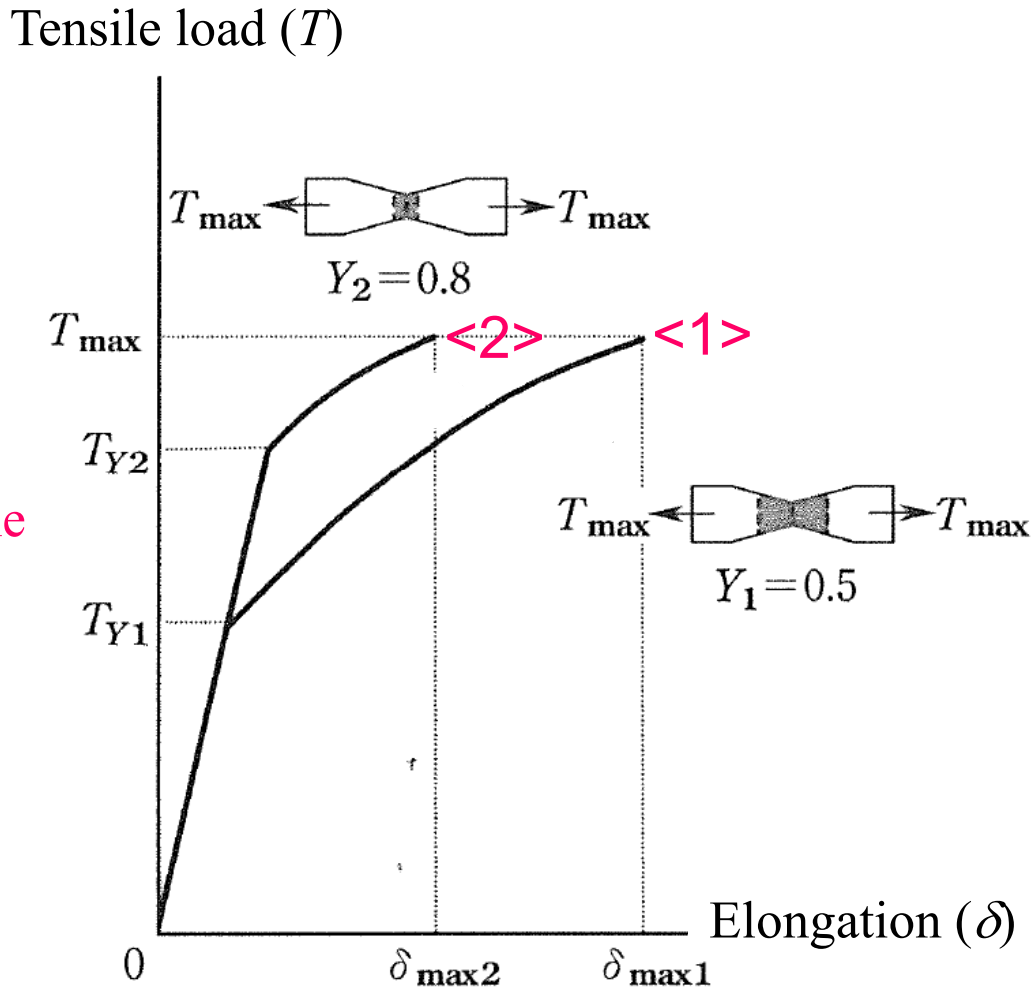
(3) Yield Ratio

Spreading of yield zone under a stress gradient is strongly related to YR(=YP/TS)

$Y_1 = \frac{250}{500} = 0.5$ $\quad$ $Y_2 = \frac{400}{500} = 0.8$



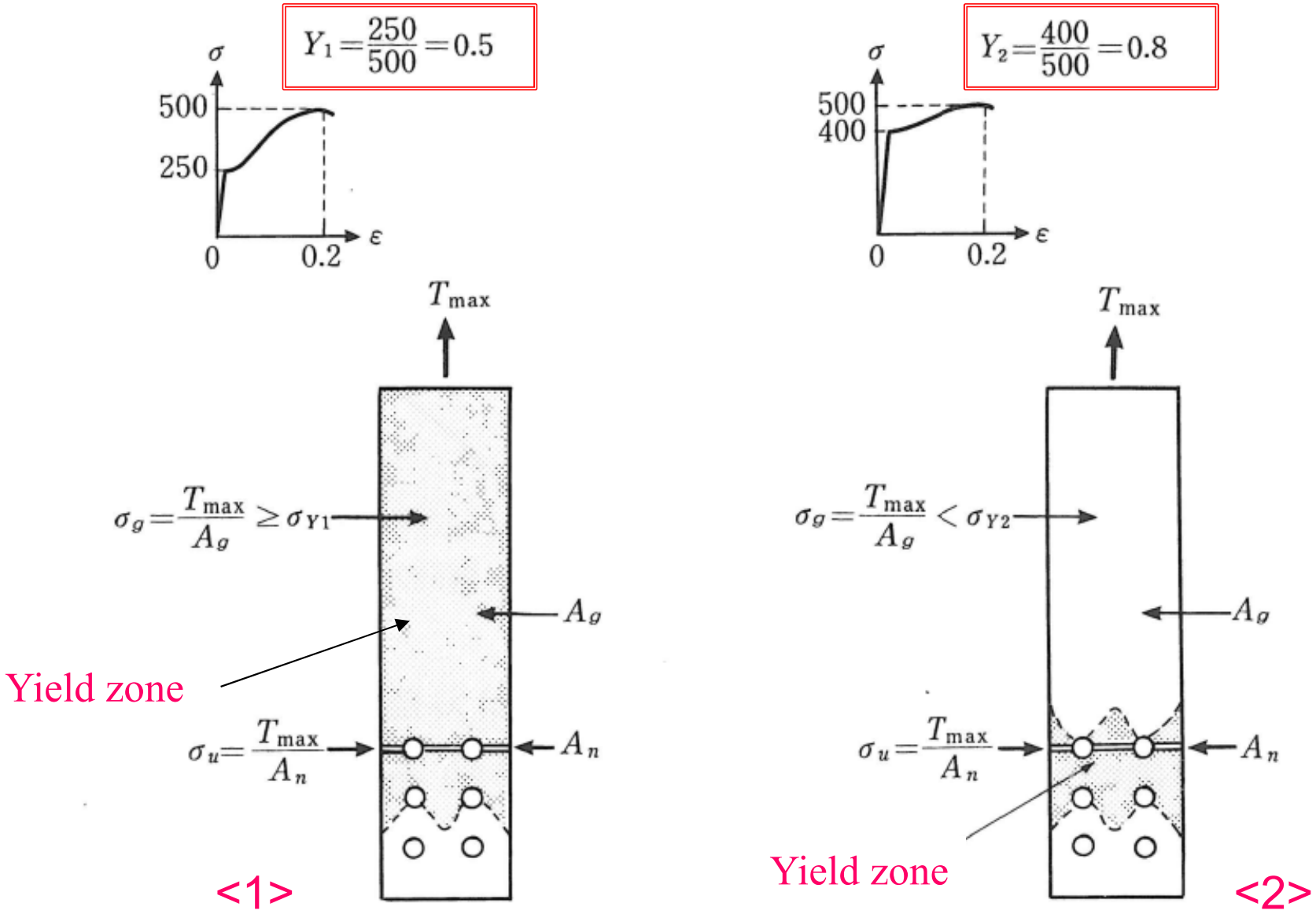




4.3 Mechanical Properties

(3) Yield Ratio

Yield zone does not extend if YR is high beyond bolt holes



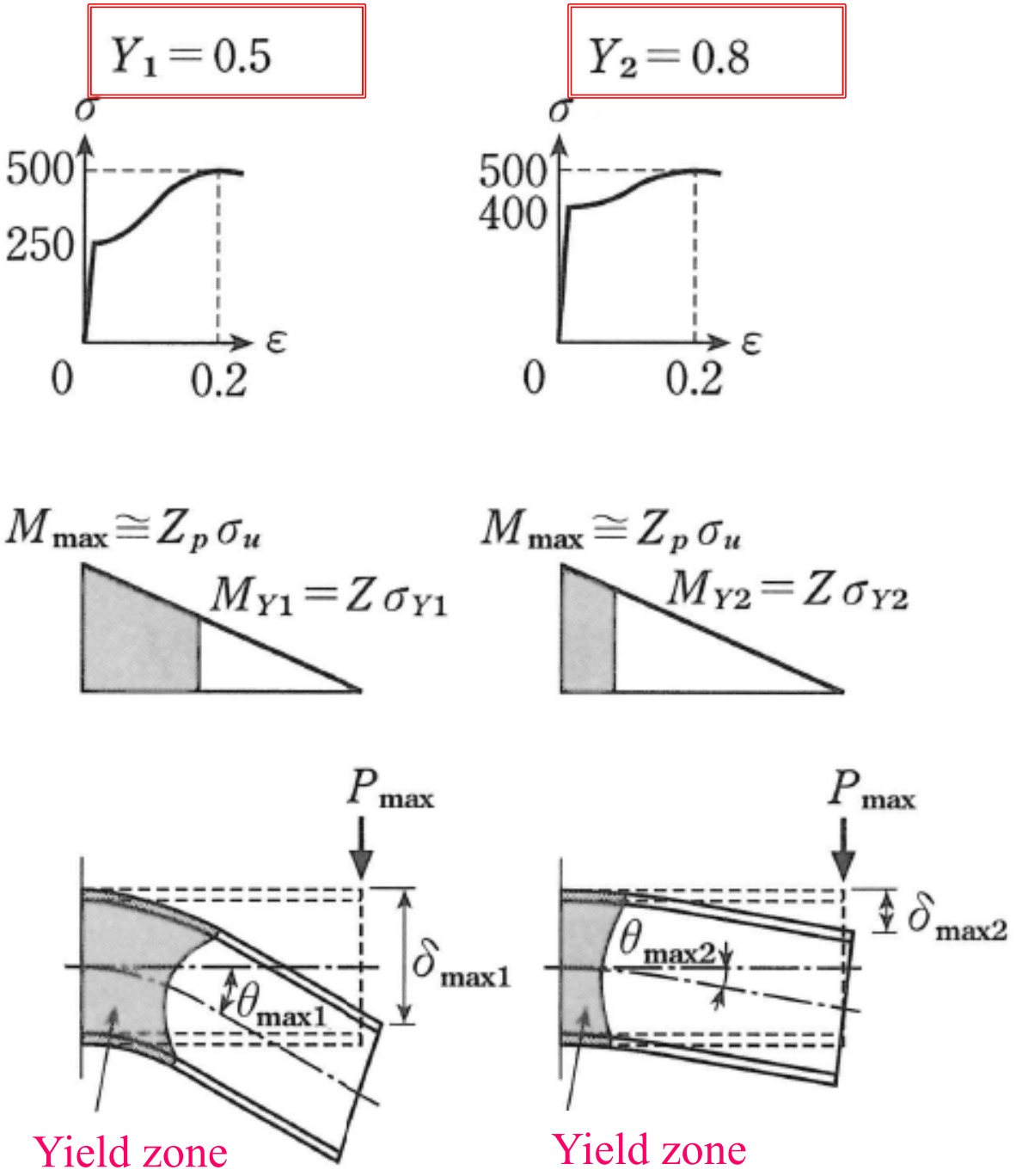
4.3 Mechanical Properties

(3) Yield Ratio

Yield spreading at beam ends is also related to YR

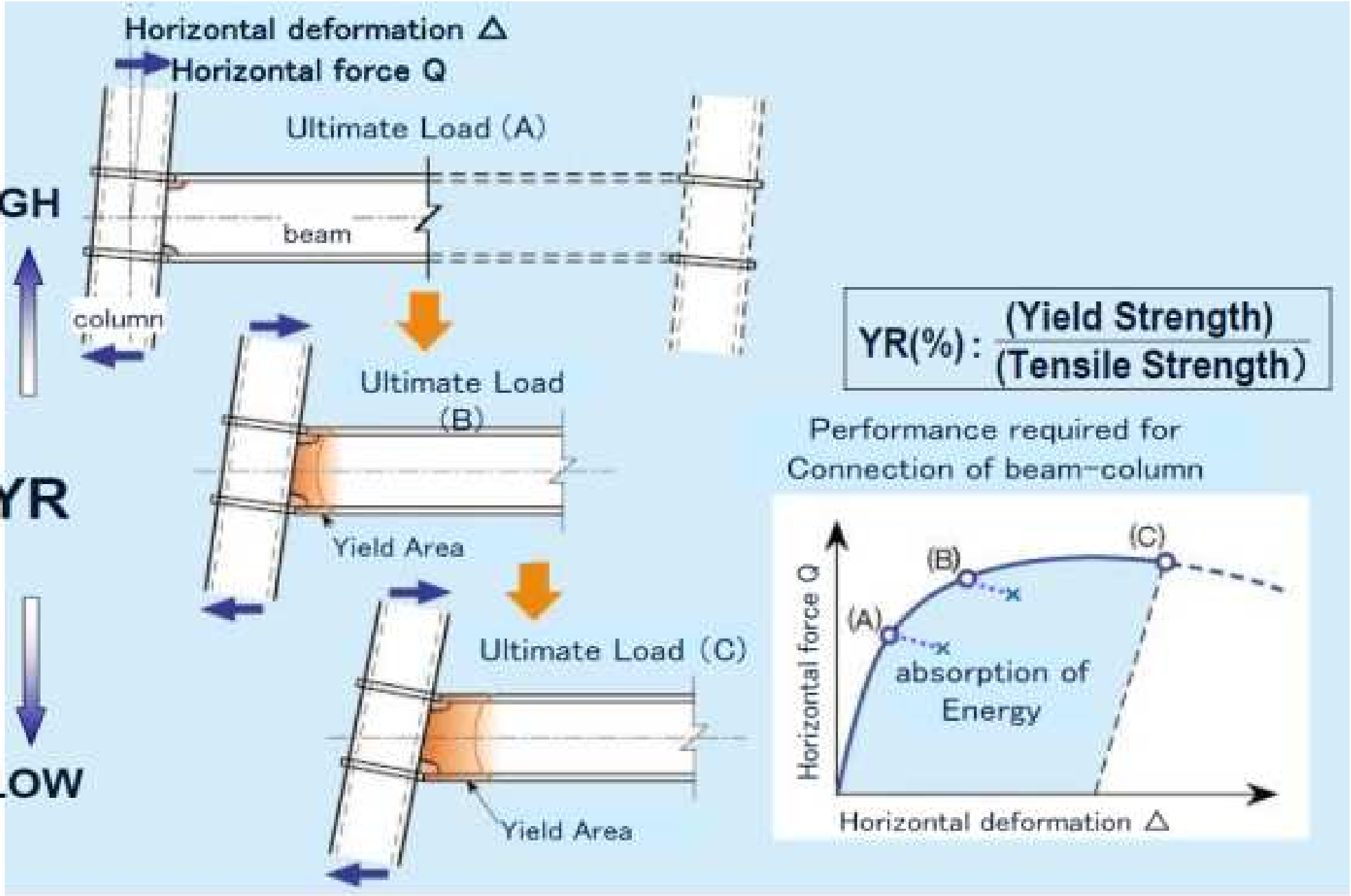
to ensure plastic deformation capacity of members

setting upper limit for yield ratio is crucial



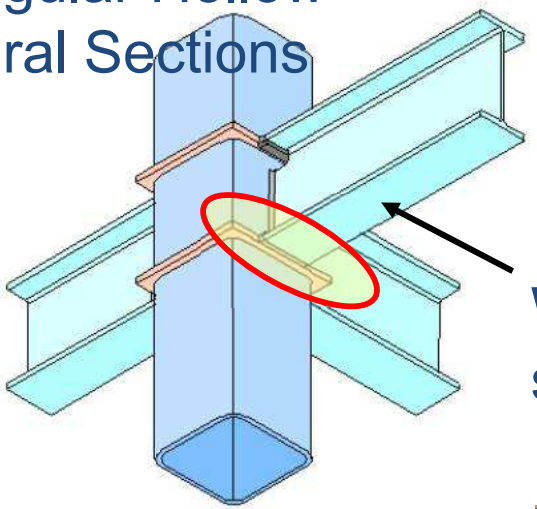
4.3 Mechanical Properties

(3) Yield Ratio



(4) Impact Property

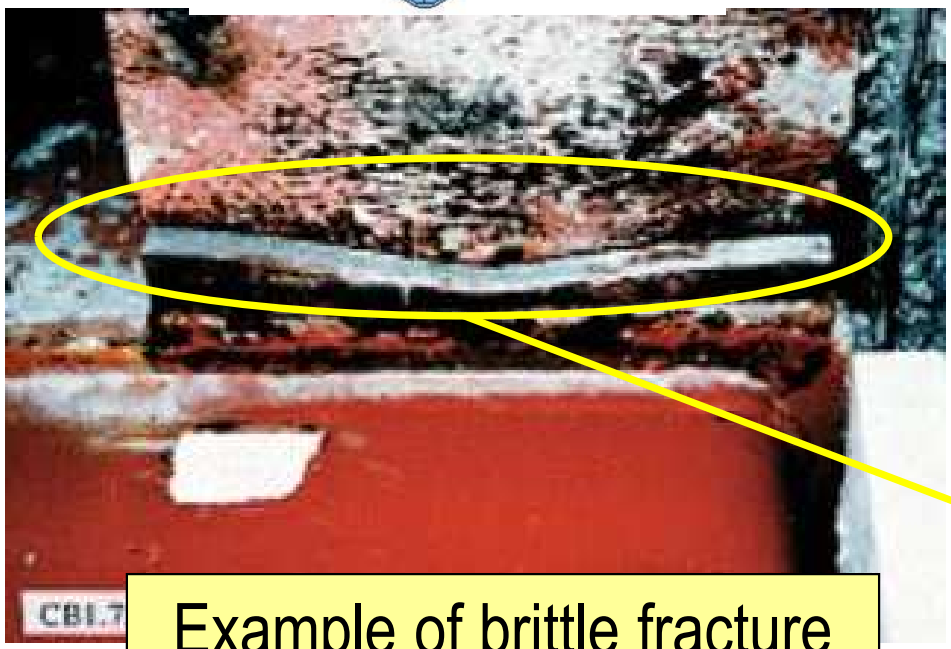
Rectangular Hollow Structural Sections



Wide-flange shape Beam

Prevention of occurrence and development of brittle fracture

Securement of Charpy absorption energy



Example of brittle fracture at the lower flange of beam

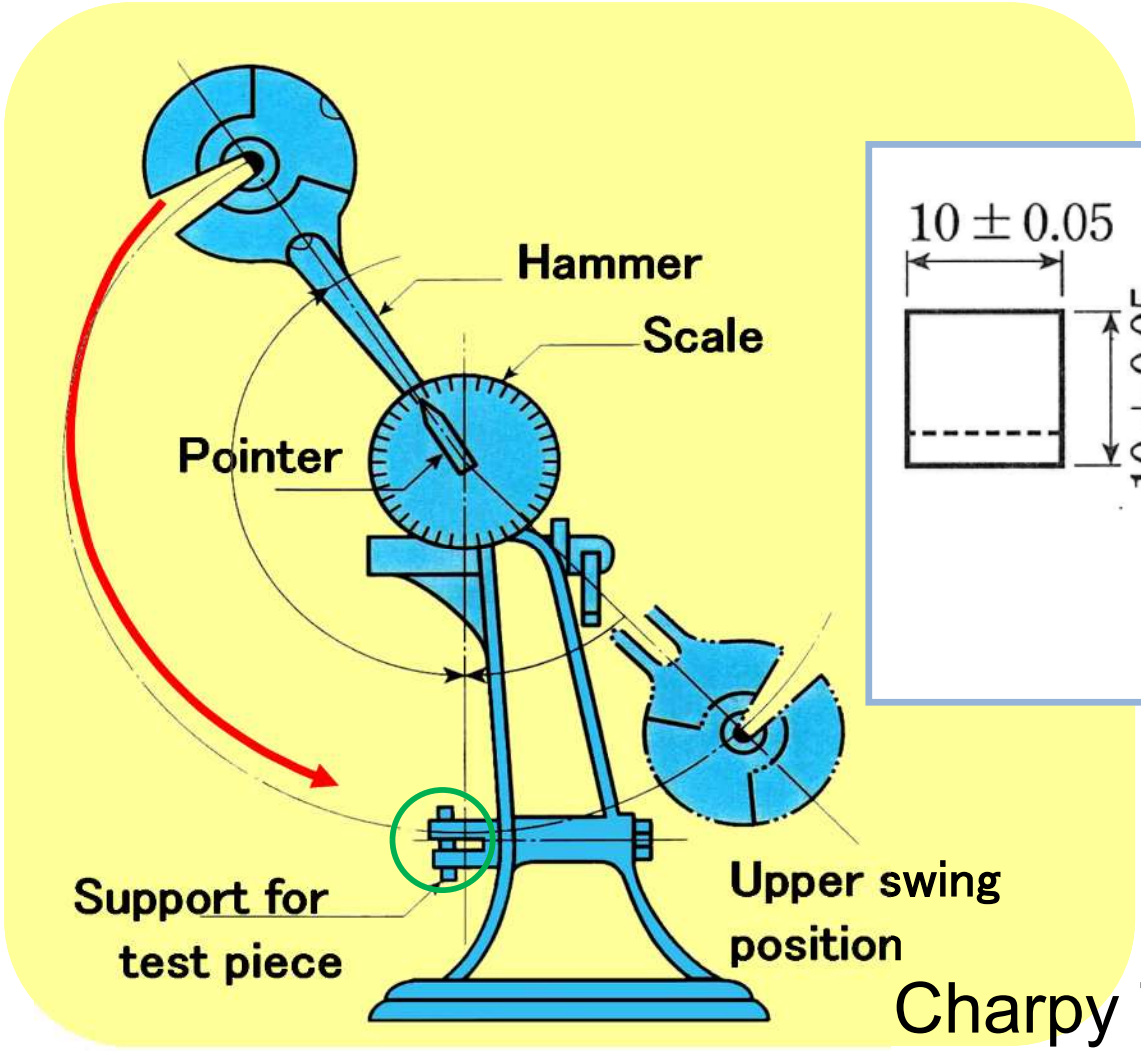
Fracture surface

4.3 Mechanical Properties

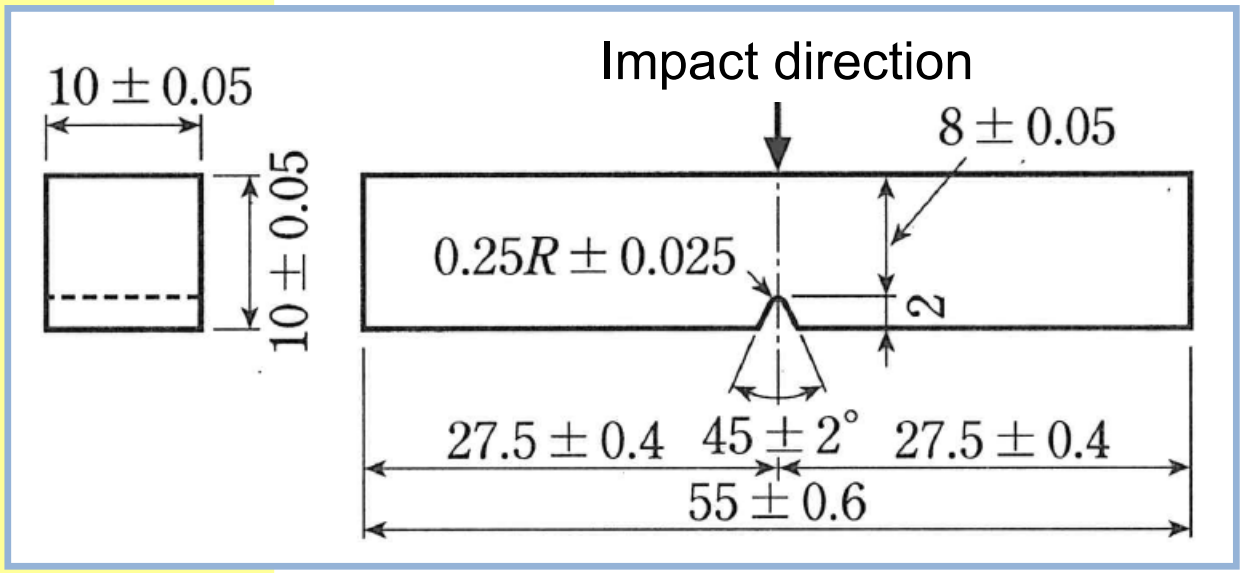
(4) Impact Property

Impact Test for Charpy Absorption Energy

Energy required for splitting a test piece with a V notch



Charpy Test Machine

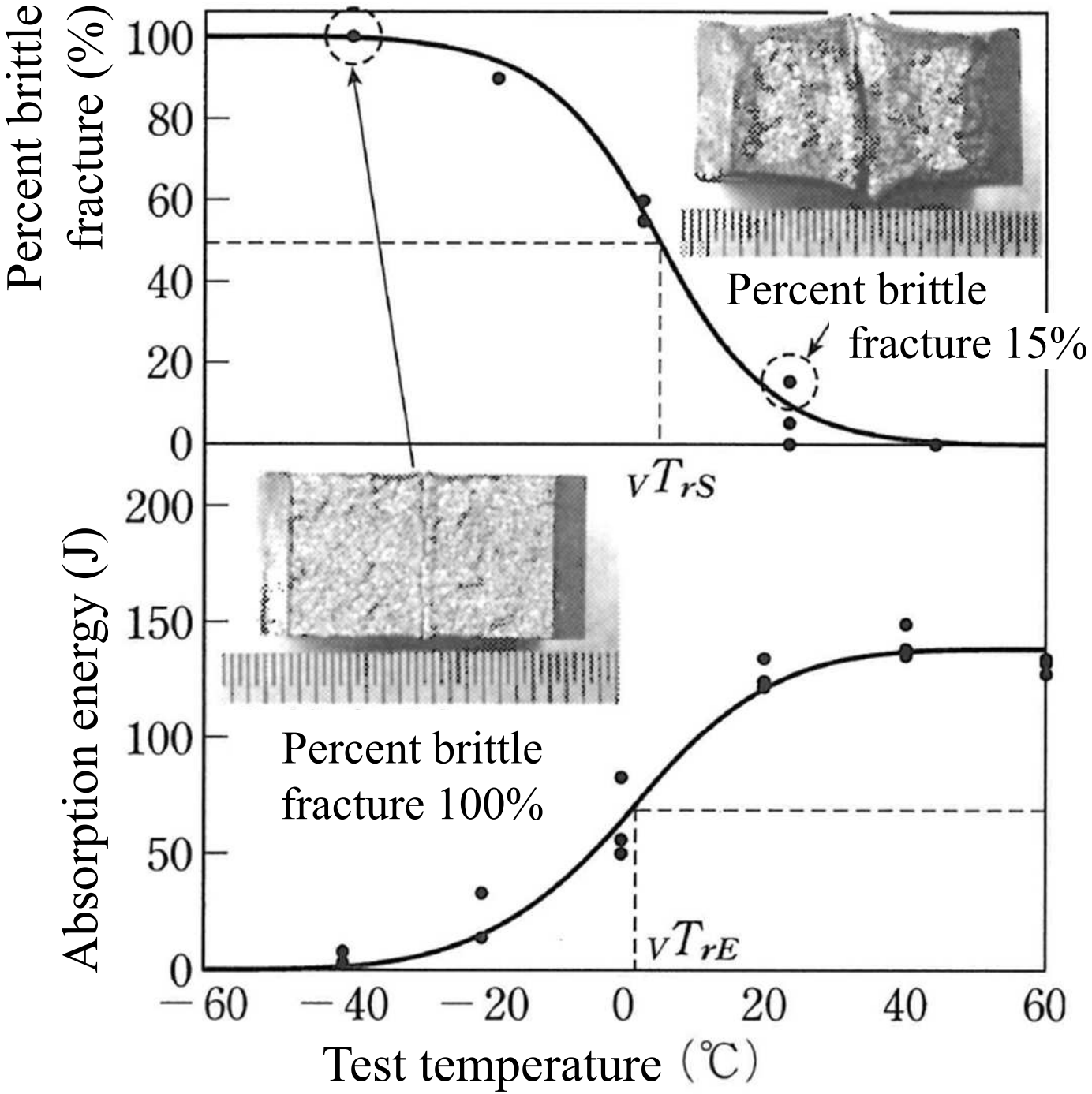


Test Piece

4.3 Mechanical Properties

(4) Impact Property

Test temperature affects absorption energy and percent brittle fracture



4.4 Chemical Composition

(1) Features of Five Major Elements

	Advantage	Disadvantage
Carbon (C)	Strength of steel is increased.	Ductility (elongation, etc.) and impact property are impaired; Weldability is deteriorated and thus the inclusion amount is limited.
Silicon (Si)	Strength of steel is increased. It acts on deoxidization.	A large amount of addition (0.5% or more) lowers the impact property and ductility.
Manganese (Mn)	Strength of steel is increased. Ductility and impact property are improved. It acts on deoxidization.	A large amount of addition (1.6% or more) lowers the impact property and ductility.

4.4 Chemical Composition

(1) Feature of Five Major Element

Element	Advantage	Disadvantage
Phosphorus (P)	A large amount of addition (0.07% or more) enhances weather resistance.	Weldability, cold workability and impact property are deteriorated.
Sulfur (S)	Machinability is improved.	S combines with Mn contained in steel to form MnS-type nonmetallic inclusions; MnS elongates in rolling, thus deteriorating impact property and thickness-direction reduction of area. S forms a cause for lamellar-tear cracking.

4.4 Chemical Composition

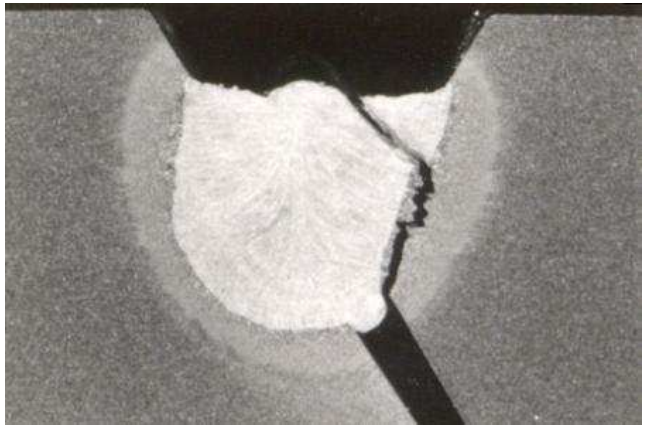
(2) Carbon Equivalent

◇High carbon (C) content

Cracking is likely to occur during welding in steel-frame assembly.

※Increase of the maximum hardness of heat-affected zone

⇒ Occurrence of low-temperature cracking



◇Effect of elements other than carbon

- Carbon equivalent (Ceq)
- Weld cracking sensibility composition (P_{CM})

※Ceq: Converted to carbon content in conformity with the level of the effect of elements other than carbon on weldability

$$Ceq = C + \frac{Si}{24} + \frac{Mn}{6} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{V}{14} \ (\%)$$

5. Special Steel Products for Building

5.1 H Shapes with Fixed Outer Dimensions

5.2 Heavy H Shapes

5.3 High Strength Steel

-TMCP Steel - -SA440/H-SA700-

5.4 Rectangular Hollow Structural Sections

5.5 Connections (bolt etc.)

5.1 H Shapes with Fixed Outer Dimensions

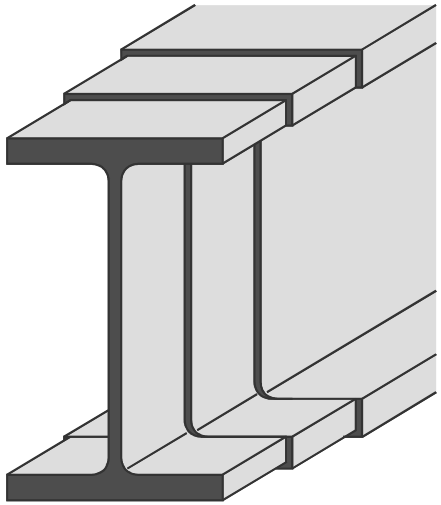
(1) Features

① **Constant beam depth and flange width in a same size series**

⇒ simplification of design and fabrication work

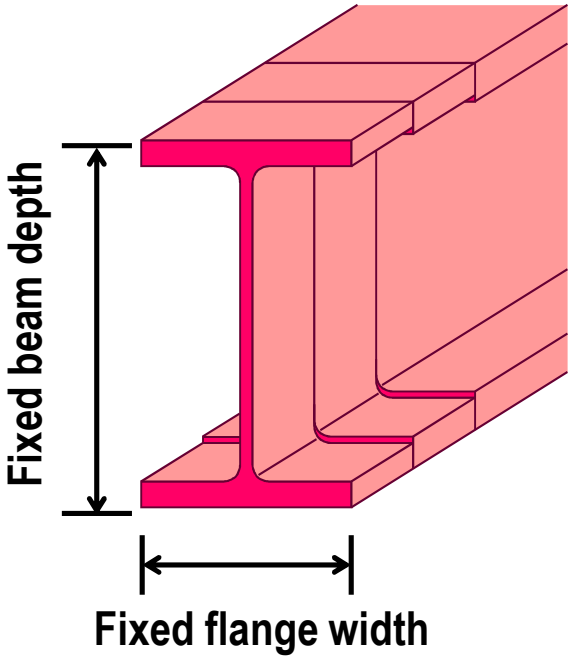
② **Wide variety of sizes**

⇒ optimal structural design and construction cost saving



Synchronous change of beam depth and width

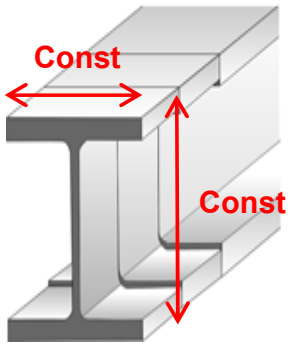
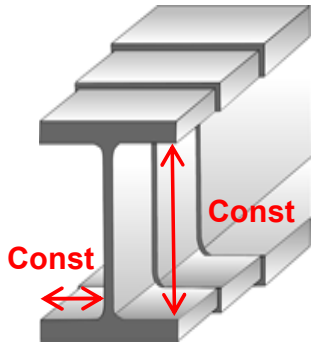
Conventional H-beam (fixed inner dimensions)



H-beam with fixed outer dimensions

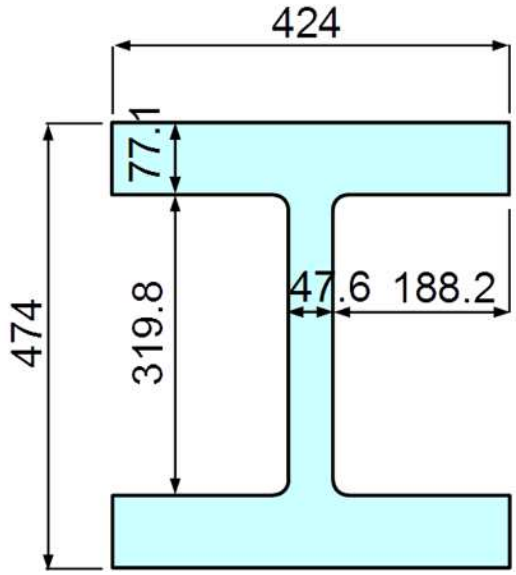
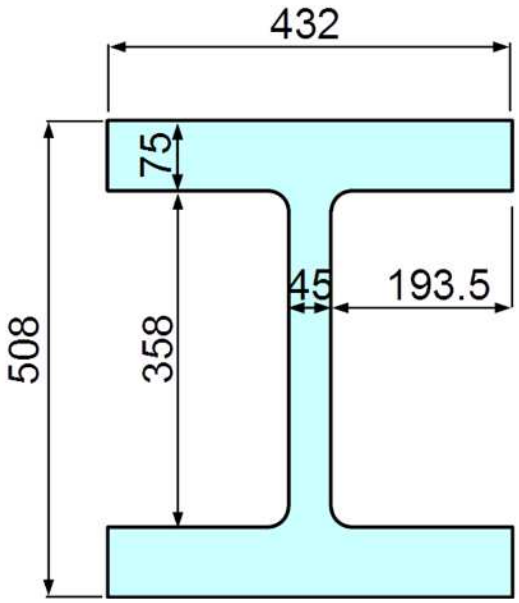
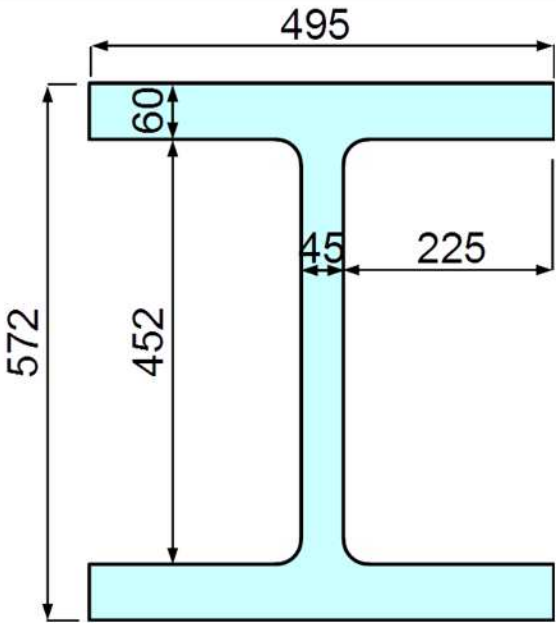
5.1 H Shapes with Constant Outer Dimensions

(2) Comparison with European Wide Flange Beams

		H shapes with COD	HE
Feature		Constant outer depth 	Constant inner depth 
Size range	Depth	400mm ~ 1000mm	91mm ~ 1118mm
	Width	200mm ~ 400mm	100mm ~ 314mm
	Flange thickness (tf)	12mm ~ 40mm	5.5mm ~ 64mm
	Web thickness (tw)	9mm ~ 19mm	4.2mm ~ 36mm
	Thickness ratio (tf / tw)	1.14 ~ 2.25	1.29 ~ 1.90

5.2 Heavy H Shapes

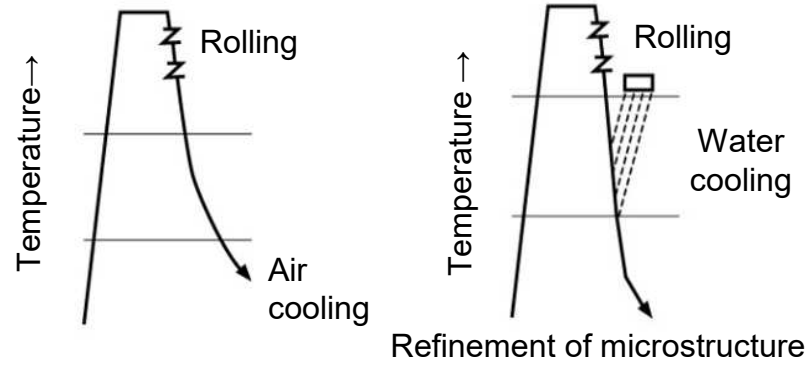
① 400 and 500 series have wide size variation
② 400 and 500 series have wider inner depth than W14x16

Series	ASTM	400	500
Size	W14x16x426	H508x432x45x75	H572x495x45x60
Mass	634 kg/m	638 kg/m	631 kg/m
A	806.5 cm^2	811.3 cm^2	803.2 cm^2
I_x	275,000 cm^4	325,000 cm^4	429,000 cm^4
r_y	11.0 cm	11.1 cm	12.3 cm
			

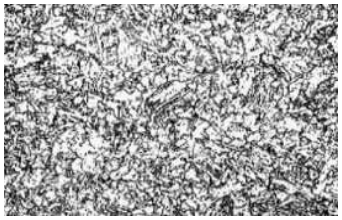
5.3 High Strength Steel -TMCP Steel-

TMCP Steel achieve higher strength & toughness
through water cooling process, not by adding the alloys.
⇒result in low Ceq,
which improves weldability & reliability of welded joint.

①Difference in manufacturing method

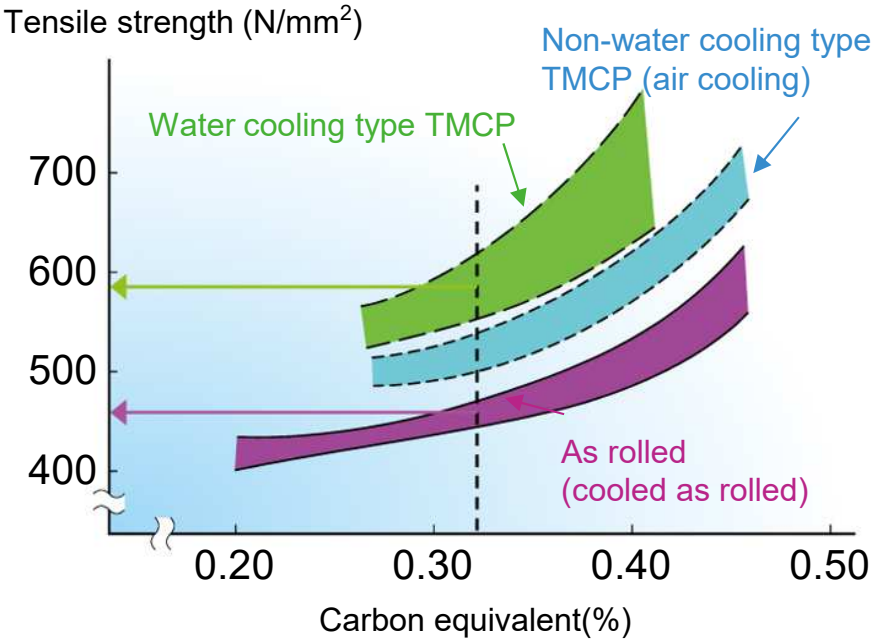


Conventional manufacturing method (as rolled)



TMCP

②Relationship between carbon equivalent and tensile strength of steel sheet

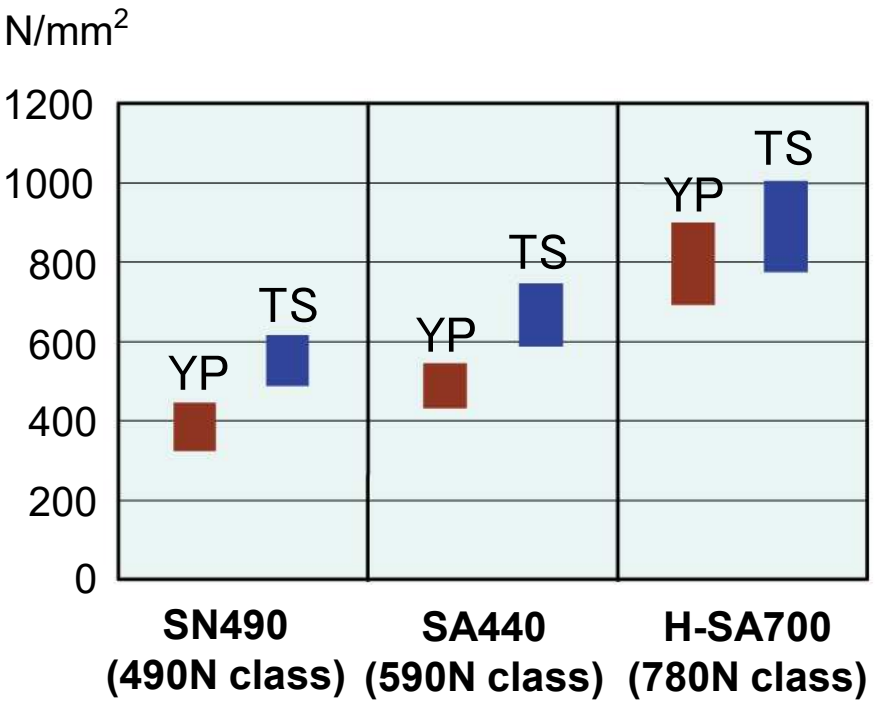


[Cited from] materials of Japan Iron and Steel Federation

5.3 High Strength Steel -SA440/H-SA700-

Higher design strength enable the smaller section size, which leads to the less welding volume

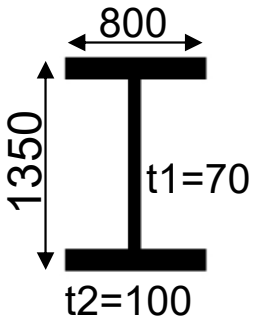
①Yield point, tensile strength of each steel material



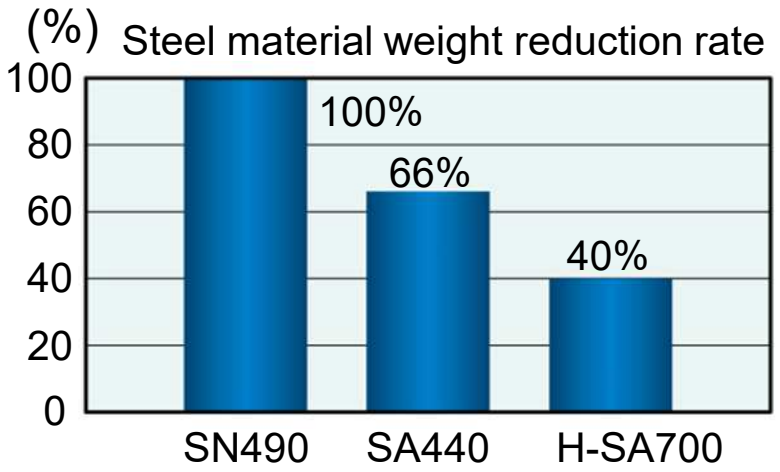
- **YP: yield point, TS: tensile strength**
- **Upper limit for yield point is provided so as to reduce variation of steel material strength.**

②Effect of reducing steel material weight by making it highly strong (example)

Original design: BH-1350×800×70×100(SN490)



	SN490	SA440	H-SA700
F value (N/mm²)	295	440	700
t1 (mm)	70	45	28
t2 (mm)	100	65	38



- It is possible to reduce plate thickness by making it stronger, thereby reducing steel material weight.

[Cited from] materials of Japan Iron and Steel Federation

5.3 High Strength Steel –material standard-

Higher grade Steels

No	Designation	Thickness (mm)	Yield Strength (N/mm^2)	Tensile Strength (N/mm^2)	Yield Ratio (%)	Elongation (%)	Charpy (J)
1	(TMCP) A1066-Gr60	(t≦100)	415≦	520≦	-	18≦	48≦ (-23℃)
2	(TMCP) EN10025-4 S460M	(40＜t≦63) (63＜t≦80) (80＜t≦100)	430≦ 410≦ 400≦	530～710 510～690 500～680	-	17≦	40≦ (-20℃)
3	(TMCP) TMCP355B*	(t≦100)	355～470	520～640	≦80	21≦	27≦ (0℃)
4	(TMCP) TMCP385B*	(t≦100)	385～505	550～670	≦80	20≦	70≦ (0℃)
5	(TMCP) TMCP440B*	19～100	440～540	590～740	≦80	20≦	70≦ (0℃)
6	SA440C	19～100	440～540	590～740	≦80	20≦	47≦ (0℃)
7	630class*	(t≦80)	630～750	780～930	≦85	17≦	47≦ (0℃)
8	H-SA700B	6～50	700～900	780～1000	≦98	16≦	47≦ (-20℃)

*These products are available by the proprietary brand names of the Japanese manufacturers

5.4 Rectangular Hollow Structural Sections

(1) Features and Size Variations

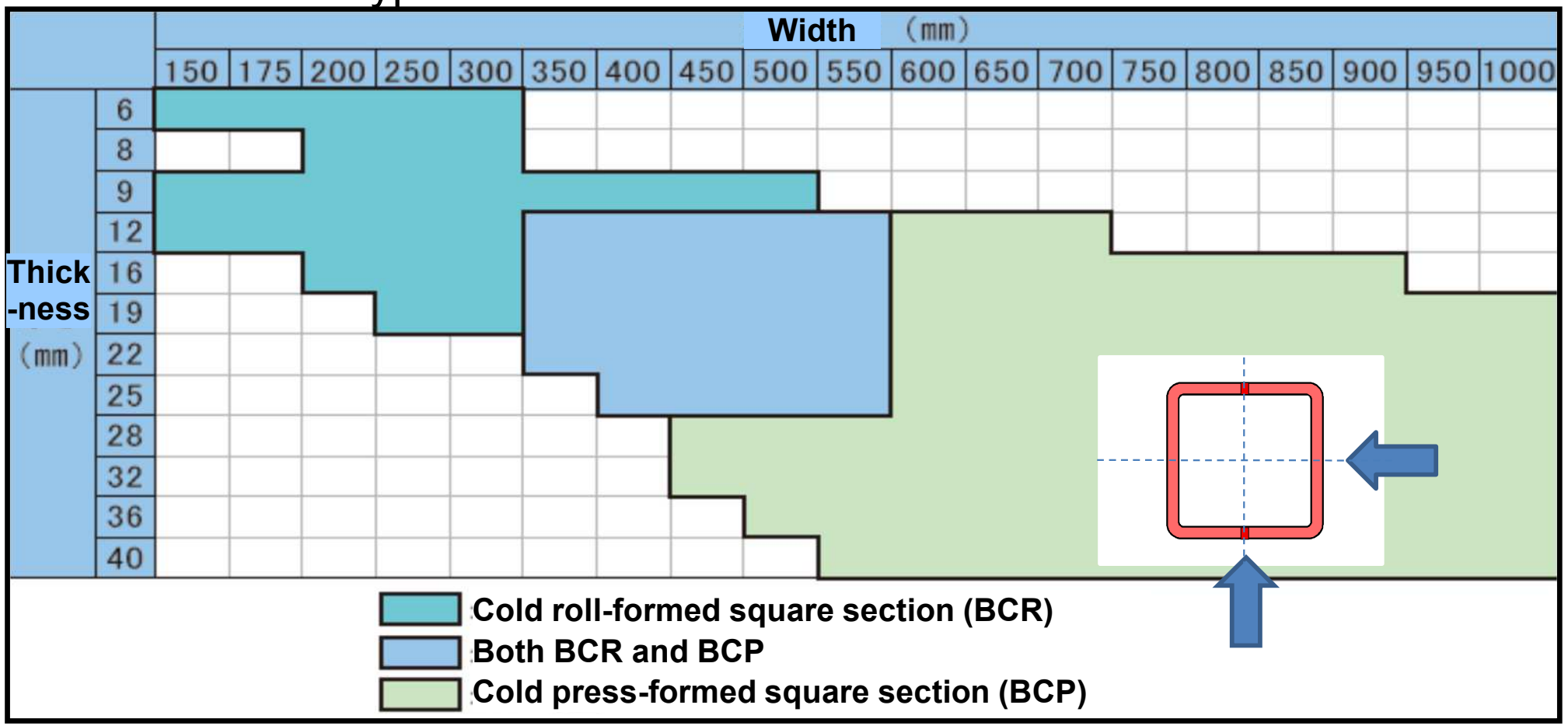
① **Same section properties for both directions**

⇒ **Most appropriate for moment frame structures without braces**

② **Volume of panel in beam-to-column connection is large**

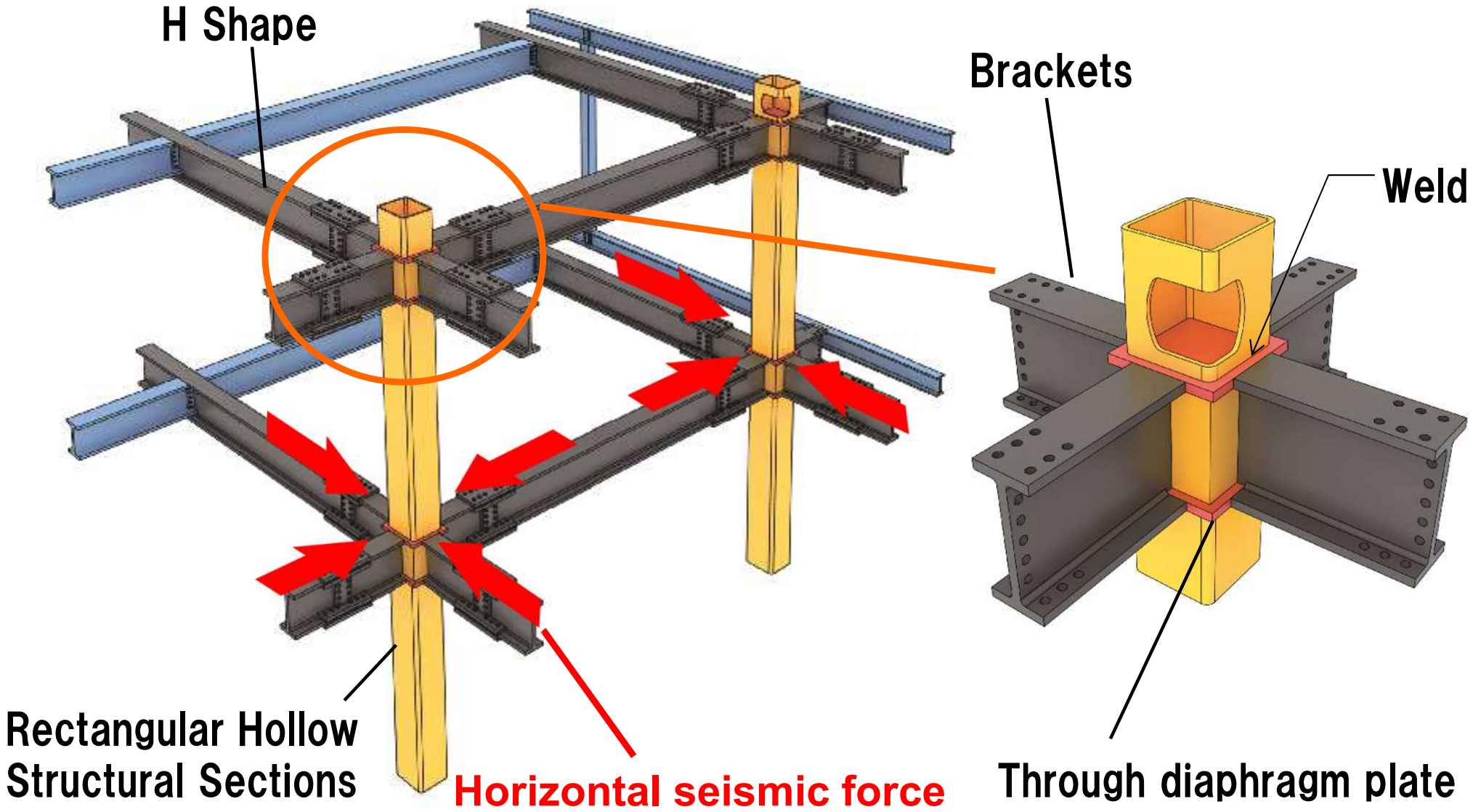
⇒ **No need for strengthening panel zones like H shape columns**

Typical Product size of cold-formed hollow section



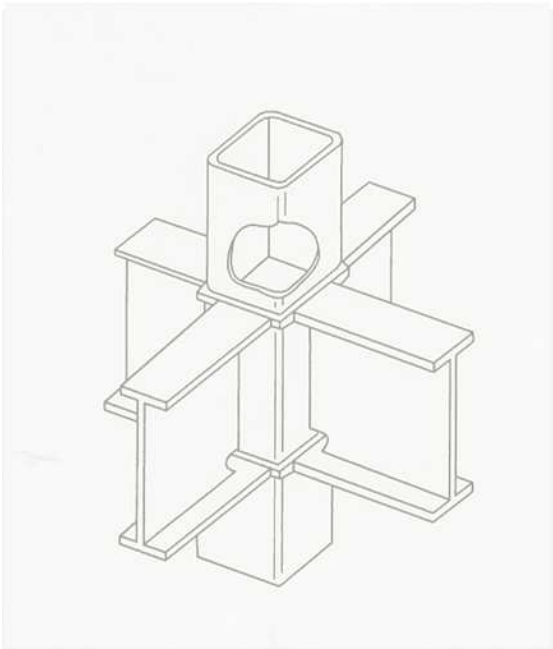
5.4 Rectangular Hollow Structural Sections

(2) Typical Moment Frame with Rectangular Hollow Structural Sections

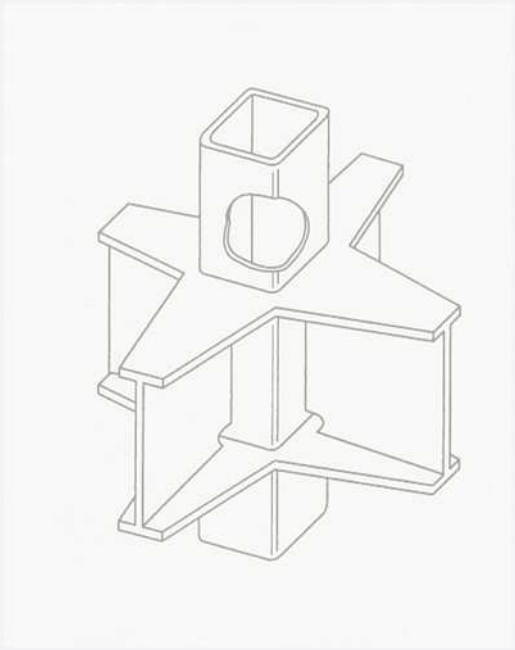


5.4 Rectangular Hollow Structural Sections

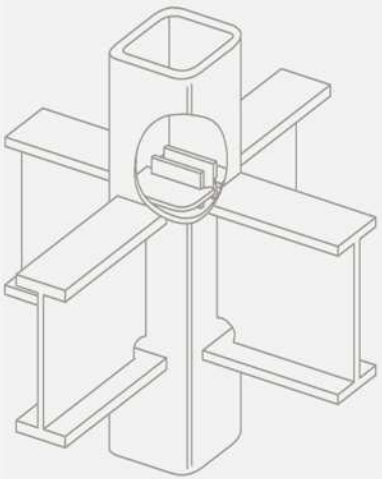
(3) Type of Column-Beam Connections



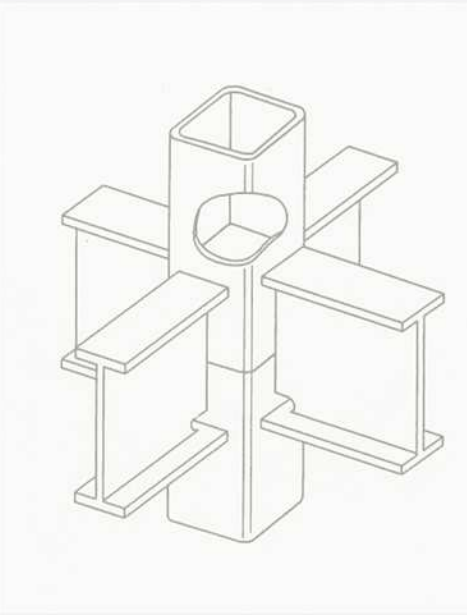
①Through diaphragm



②Outer diaphragm



③Inner diaphragm
(Built-in diaphragm type)



④Inner diaphragm
(Insertion diaphragm type)

5.4 Rectangular Hollow Structural Sections

(4) CO_2 Robotic Welding for Through Diaphragm

Robotic Welding of Column Shaft (CO_2 Automatic Welding)

Precautions in robotic welding method

① Confirmation of dimensional and assembly accuracy for columns and other members

②Assembly welding of column to diaphragm using backing metal (The use of robotic welding must bear in mind that it cannot respond appropriately to a sudden change in shape in grooves and the like and small gaps and clearances as a result of a narrow groove.)

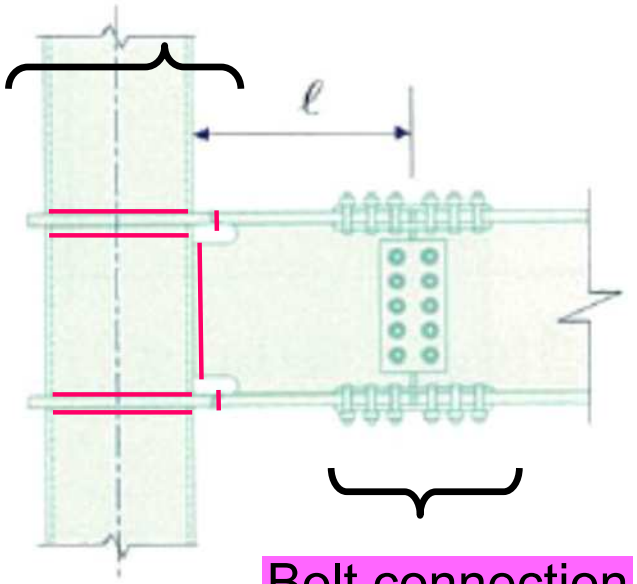
③Robotic welding

(The actual groove profile of weld joint under restricted conditions in terms of welding heat input and interpass temperature, and welding conditions in tune with root gaps and radius at corner)

④Certification as welding robot operator and the Japan Robot Association's type certification for welding robots for building structures

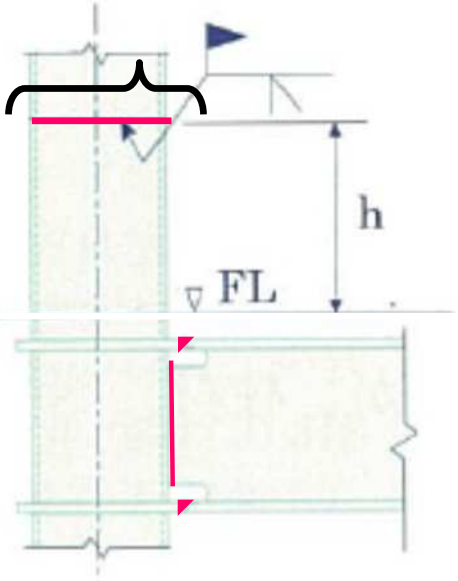
Types of Connections in Steel Framing

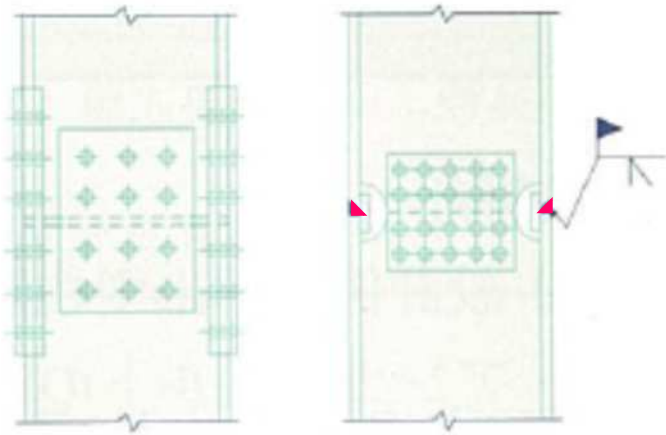
Shop welding



Bolt connection (on-site)

Site welding





Bolt Connection (on-site)

Bolt & Weld Connection (on-site)

Beam Column connection

Column butt joint

5.5 Bolted Connection

Types of Bolt connection

	Friction type (non-slip type)		Bearing Type	
Standard Designation	**JIS B 1186 (ASTM A490 etc.)**		JIS B1051 etc.	
Bolt Diameter	**16 ~ 30mm***		12 ~ 30mm*	
Strength Grade	**F8T**	**F10T**	4.6	・・・
Yield Strength (N/mm^2)	**min.640**	**min.900**	min.240	・・・
Tensile Strength (N/mm^2)	**800-1000**	**1000–1200**	min.400	・・・

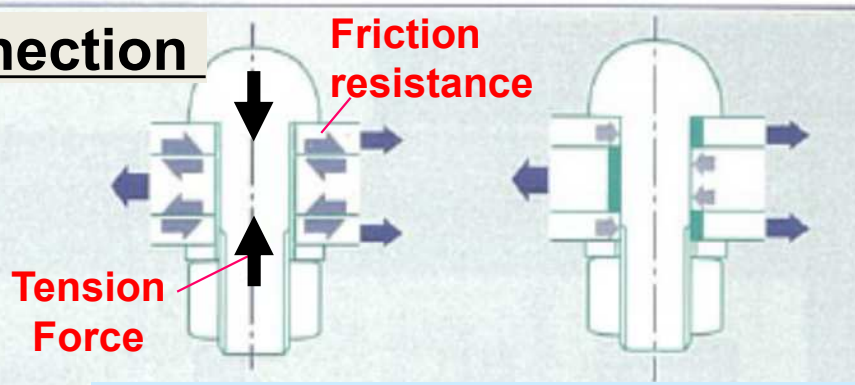
*Common size

Resistant strength of Friction type connection

$Rs = m \times \mu \times No$

where

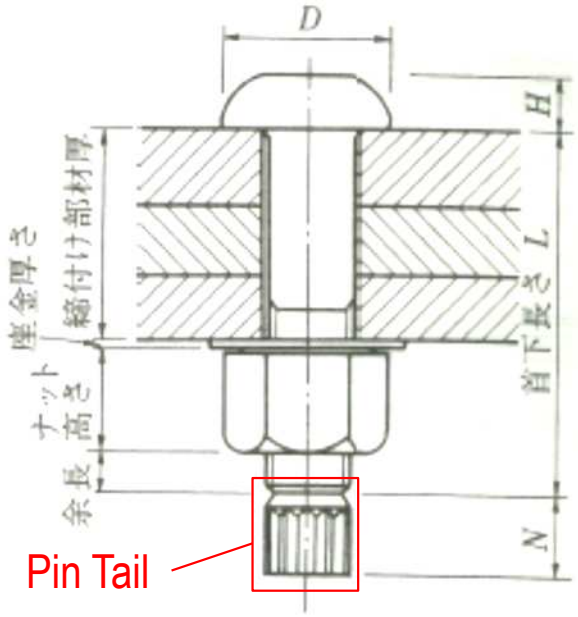
- m : num. of friction surface
- μ : friction coefficient
- No : introduced tension force



5.5 Bolted Connection

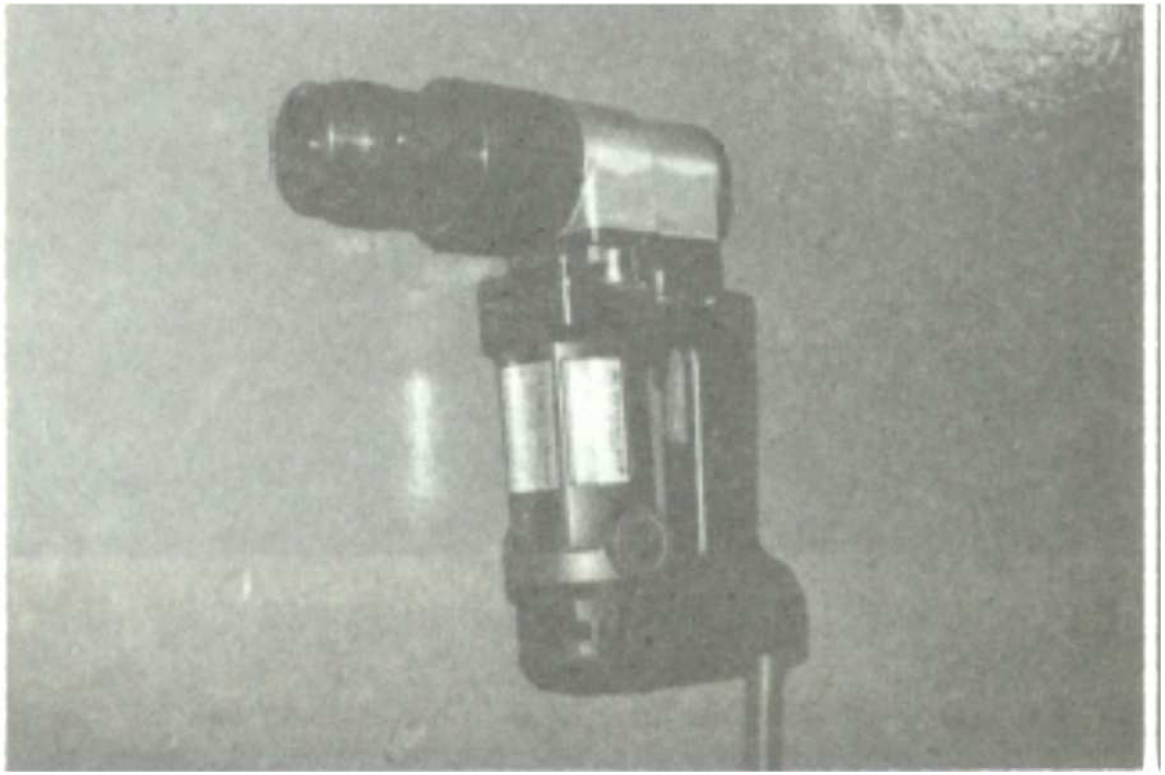
Special Friction Type Bolt "Torque Shear Bolt"

Profile & Sizes of Torque-shear Bolt



サイズ	D	H	N	L
M16	27	10	15	締付け部材厚 +25
M20	34	13	18	〃 +30
M22	38.5	14	19	〃 +35
M24	43	15	20	〃 +40
M27	49	17	22	〃 +45

Special Tools "Shear Wrench" designed for Torque-shear Bolt



Thank you for your attention