FY2023
ENII01
27 Feb (Tue) PM

<Lecture>

Introduction

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AOTS

The Association for Overseas Technical Cooperation and Sustainable Partnerships

Schedule

※Includes Q&A

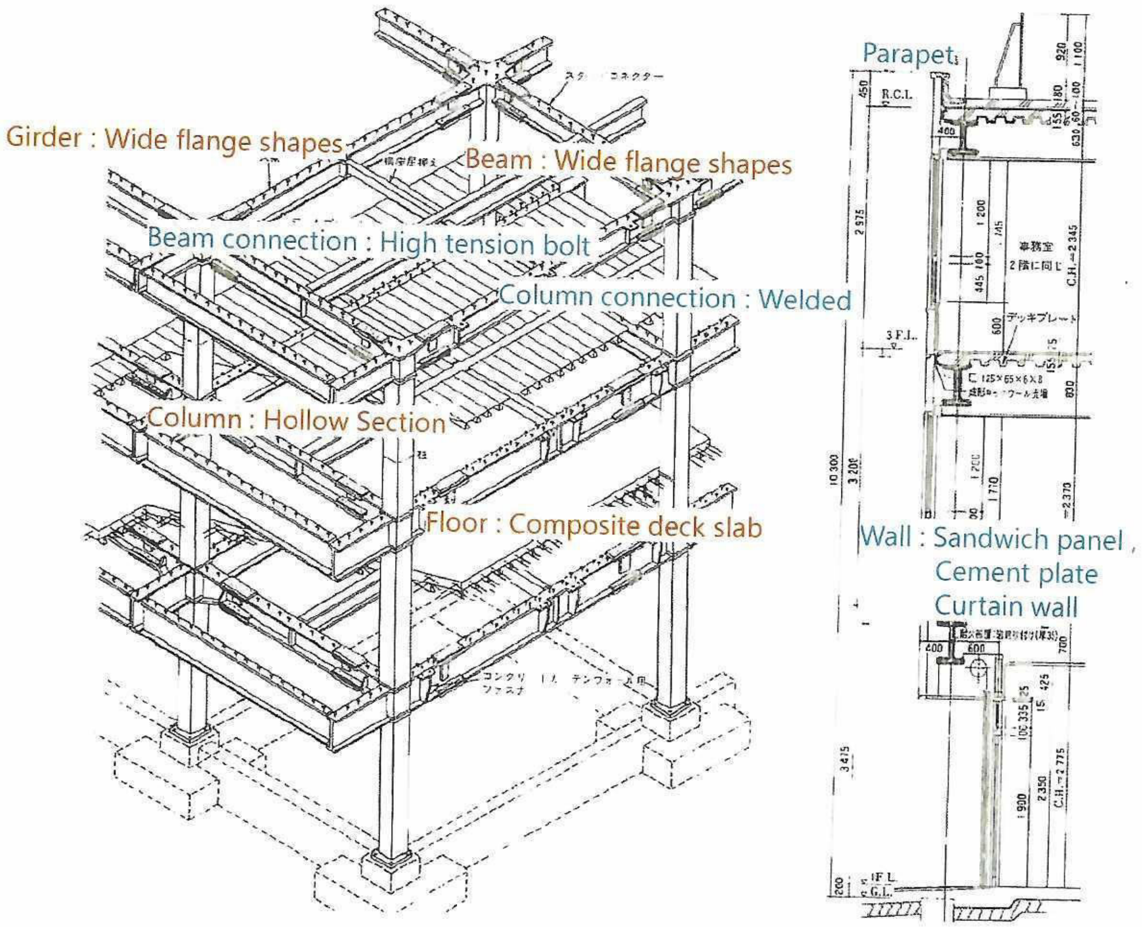
1.Introduction (Building materials applicable to steel structures)	13:30-13:45
2.Column structure (Cold-formed Square Steel Tubes)	13:45-15:00
Break	15:00-15:15
3.Floor structure	15:15-16:30

Confidentiality

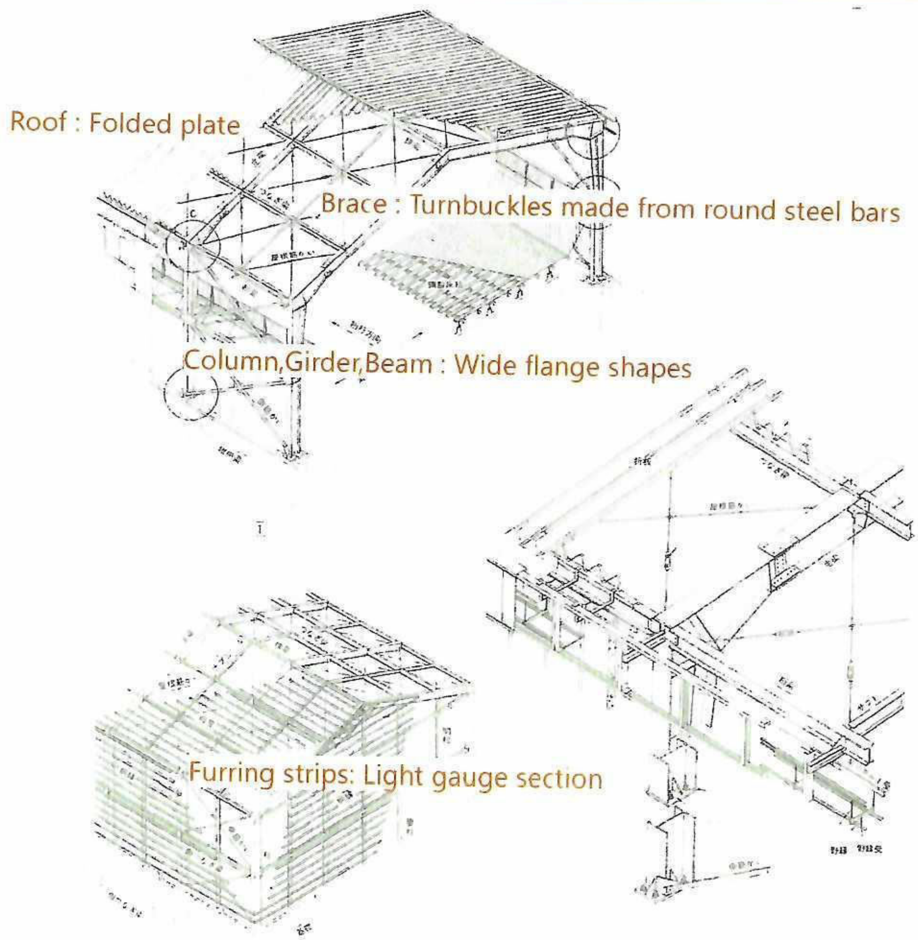
Introduction

Building materials applicable to steel structures

Example:Building of Steel Structures in Japan

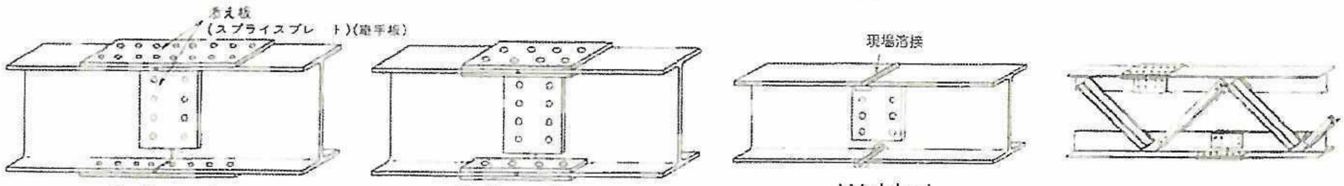


Example:Factory of Steel Structures in Japan



Example:Connections of Steel Structures in Japan

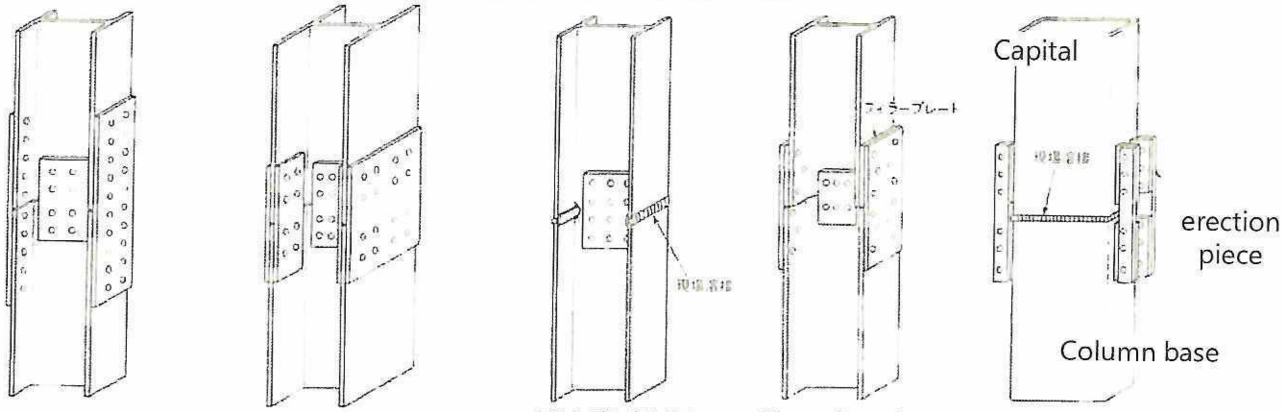
Connection of beams,girder



Splice plate (one surface) | Splice plate (twe surface) | Welded | Welded(truss)

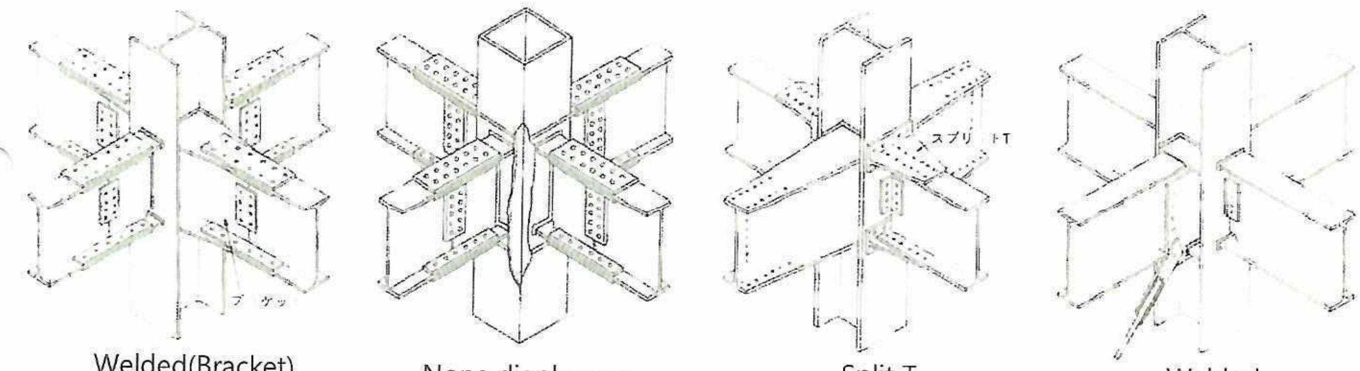
(ロ) 梁継手

Connection of columns

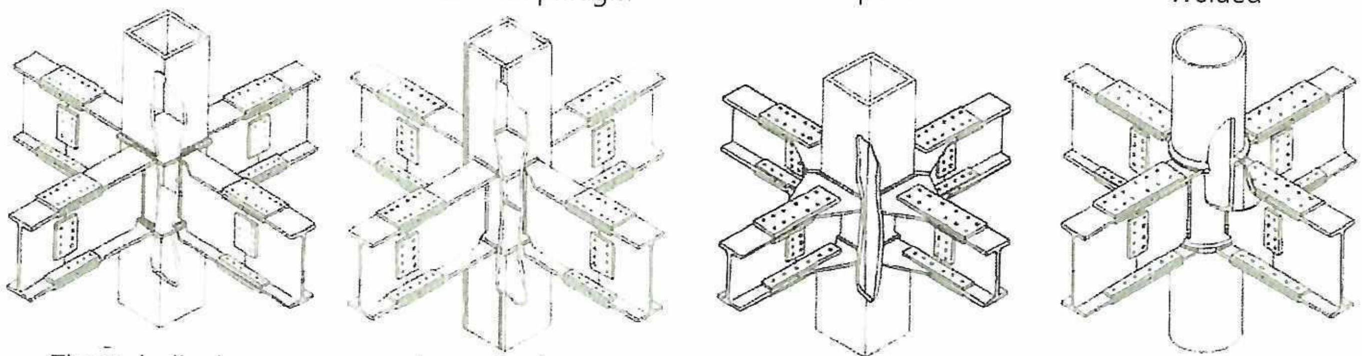


Splice plate (one surface) | Splice plate (twe surface) | c. フランジの溶接接合 Welded (wide flange shapes) | Changing size (filler plate) | Welded (hollow section)

Example : column-girder connection of Steel Structures in Japan

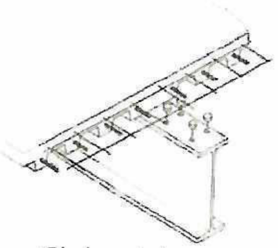


Welded(Bracket) | None diaphragm | Split T | Welded

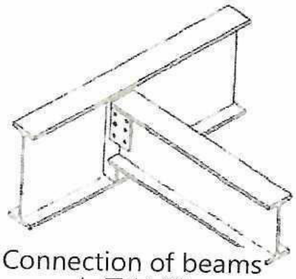


Through diaphragm | Inner diaphragm | Outer diaphragm | h. スチフナーリング

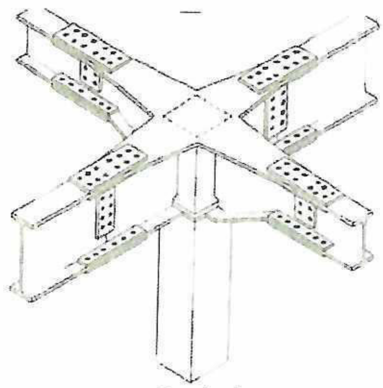
Example:Connections of Steel Structures in Japan



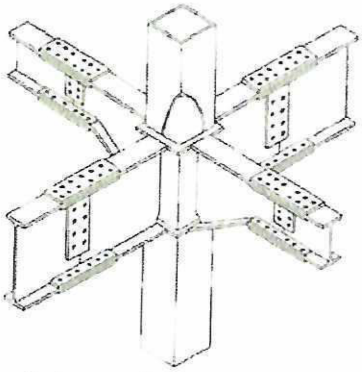
Girder-slab connection



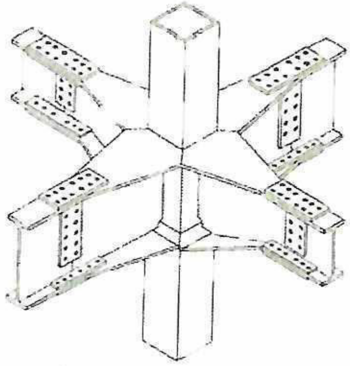
Connection of beams
(一面せん断)



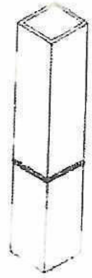
Capital



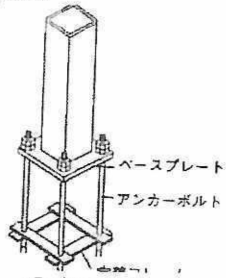
Column-girder connection
Through diaphragm



Column-girder connection
Outer diaphragm



Connection of
column to column



Column base

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Design and Construction of Cold-formed Square Steel Tubes (Building Structures)

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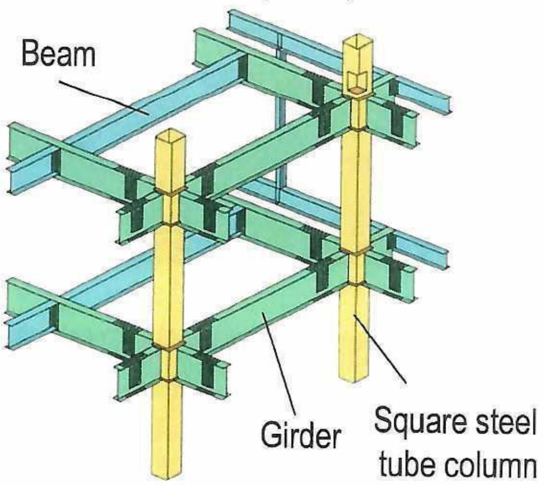
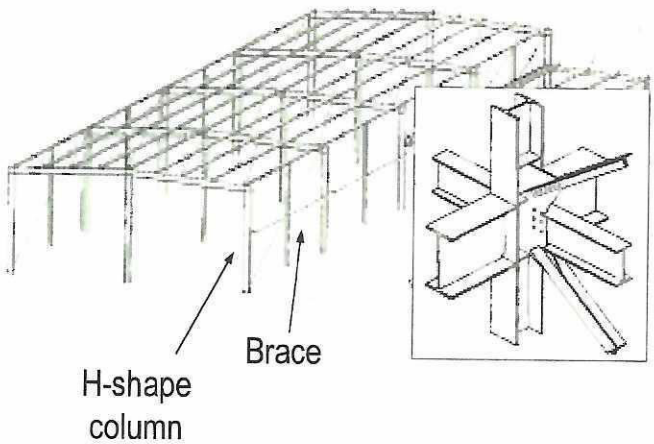
Design and Construction of Cold-formed Square Steel Tubes (Building Structures)

Typical Structural Type of Steel Structures

■Features of steel structure: Reduction of on-site construction term and securement of quality due to factory manufacture





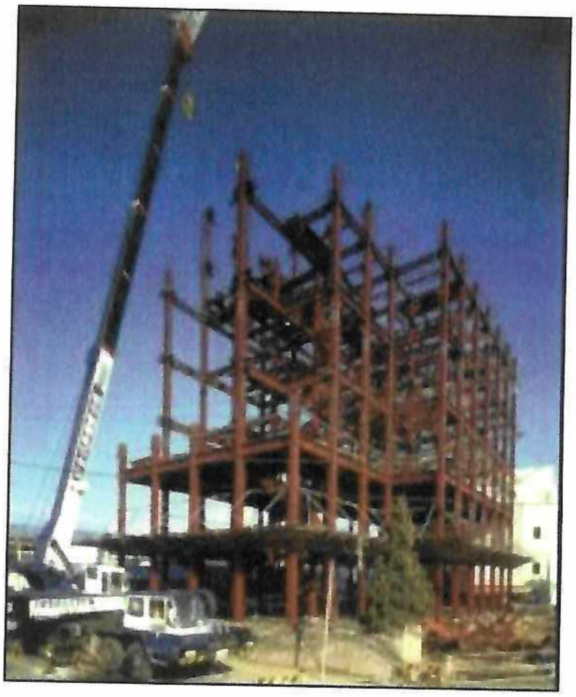
＜Bidirectional rigid frame structure＞

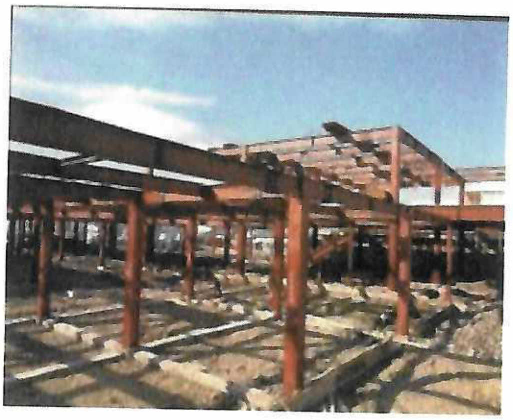
- Column-less wide space available
- Large deformation capacity during earthquake
- Main applications: Office, shop, etc

＜Unidirectional brace structure＞

- Restriction in planning
- Strength-type design
- Main applications: Factory, warehouse, etc.

Application of Cold-formed Steel Column: Steel-frame Installation



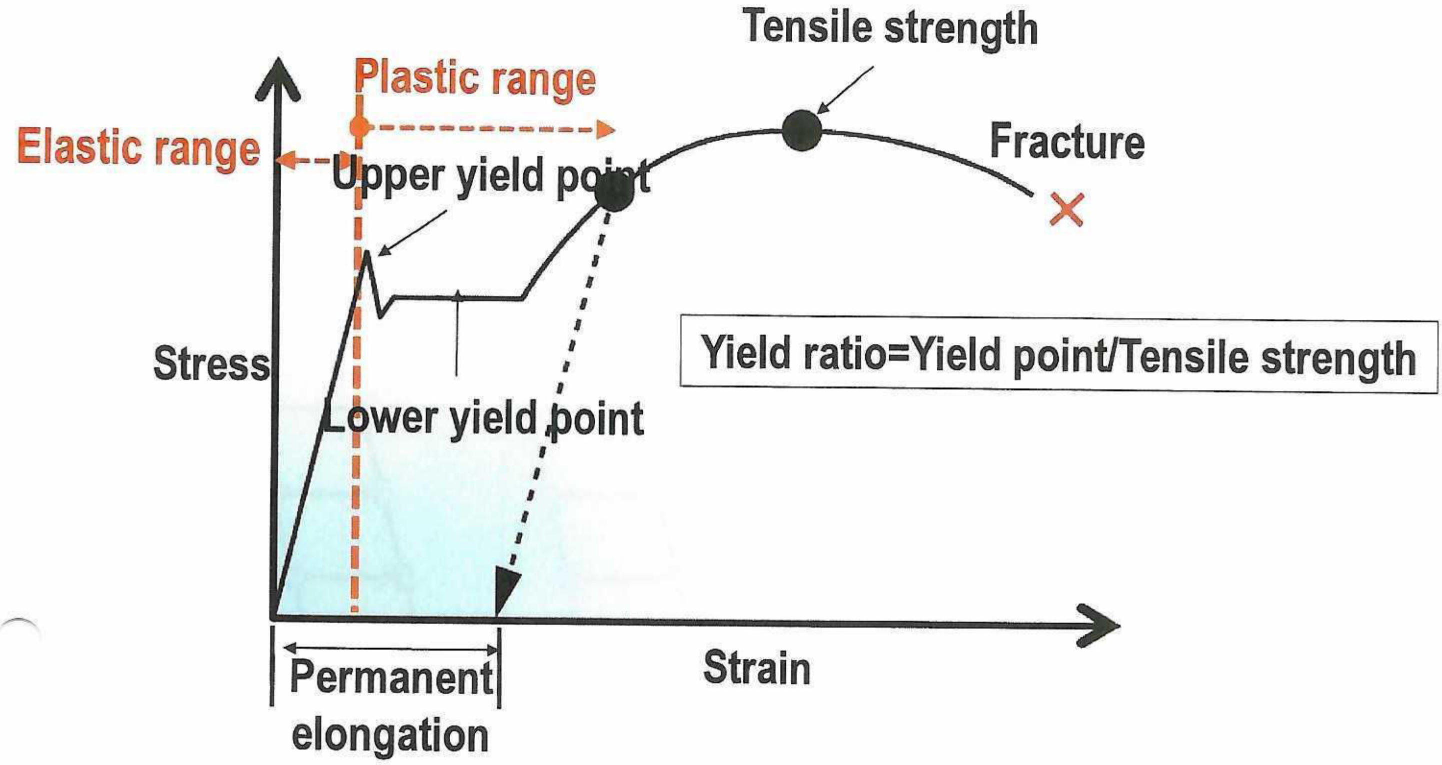


Column joint: On-site welding

Beam joint: Bolt joining

Application of Cold-formed Steel Column: Parking Lot

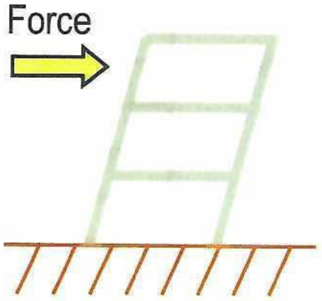
Material Properties of Steel Product

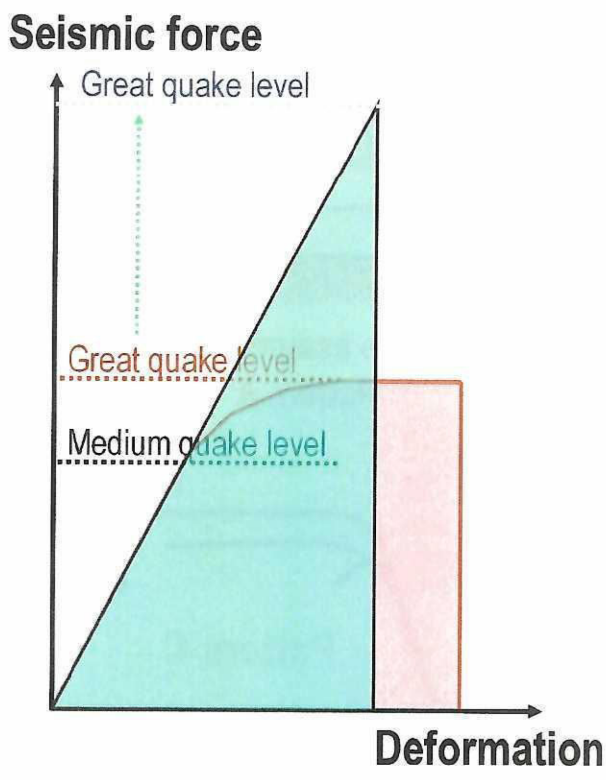


Stress-Strain Relation of Steel Product

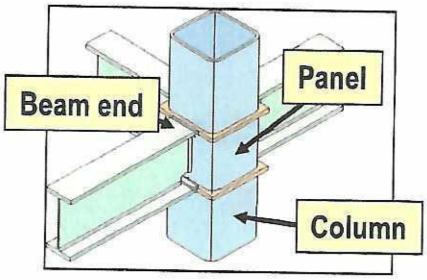
Seismic Design of Steel-frame Building (1)

- Framing is retained in elastic range during small and medium earthquakes (no damage)
- During great earthquake, damage (plasticization) is allowed only for framing, but building collapse is prevented, and human lives are protected.

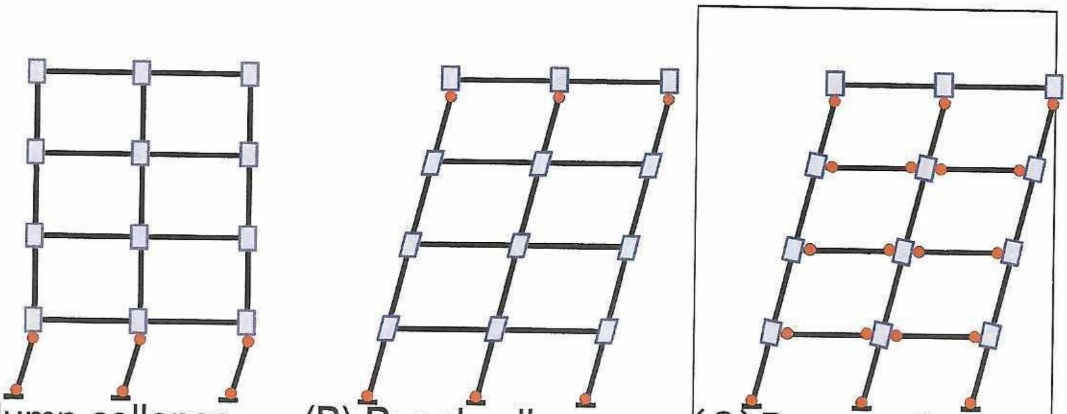




Seismic Design of Steel-frame Building (2)



Steel product that yields at prescribed strength is required.

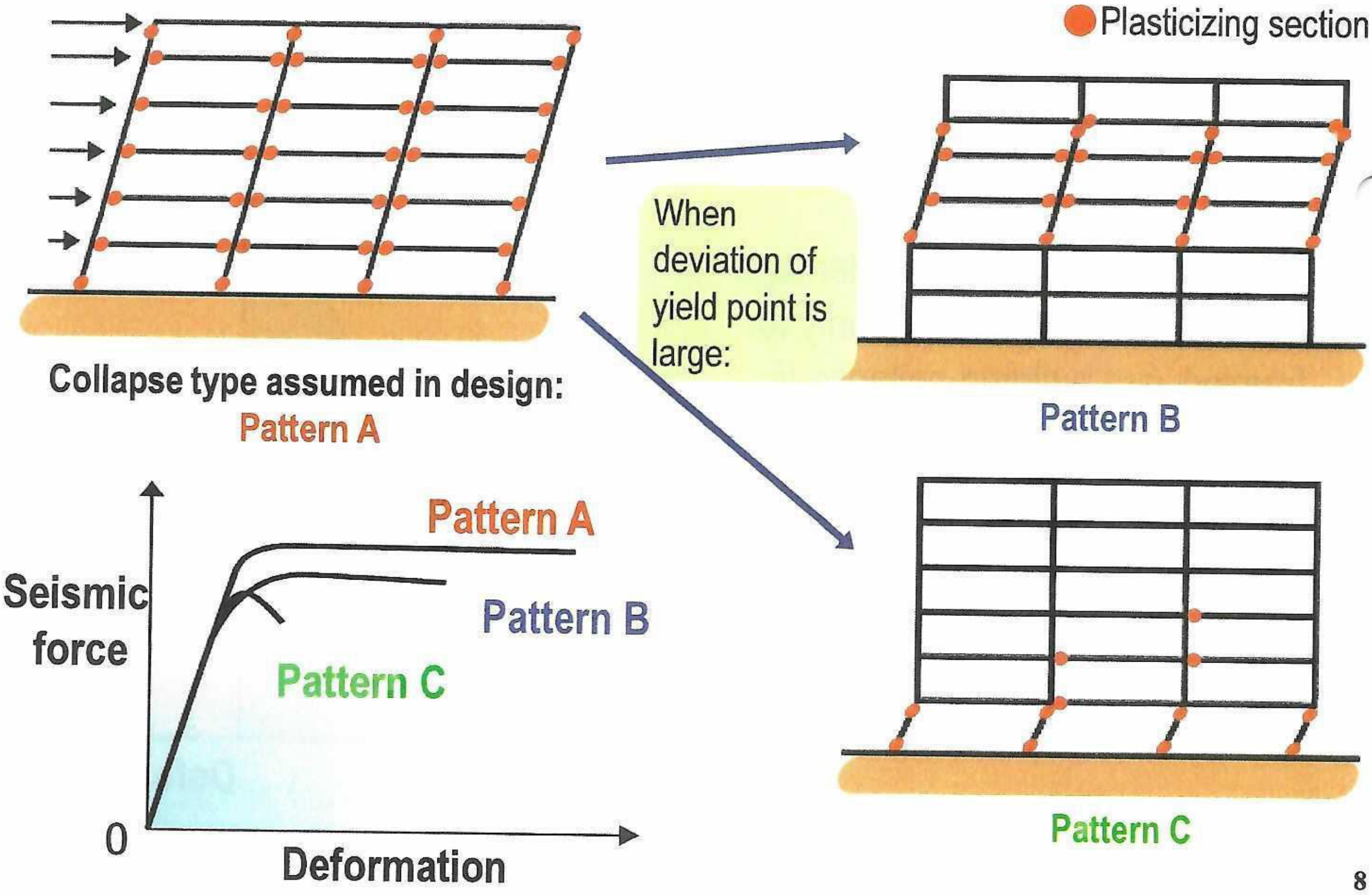


(A) Column collapse type

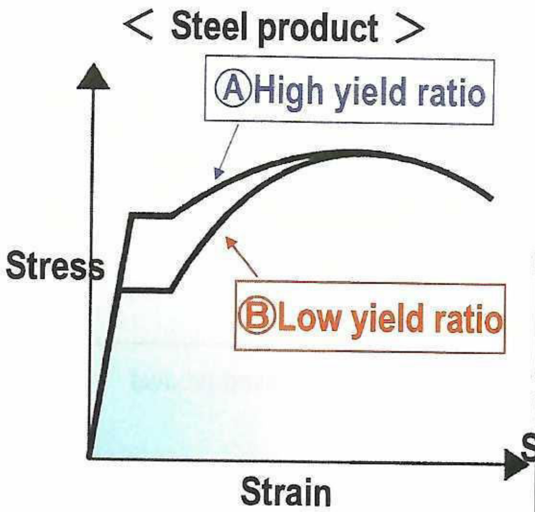
(B) Panel collapse type

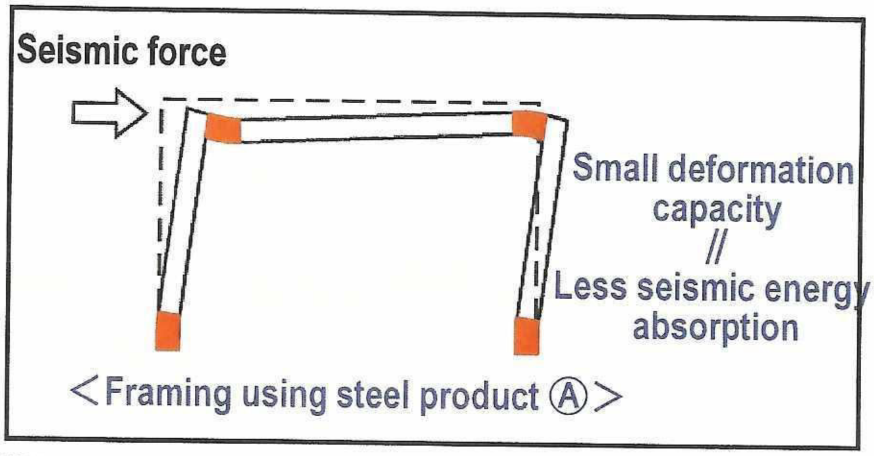
(C) Beam collapse type

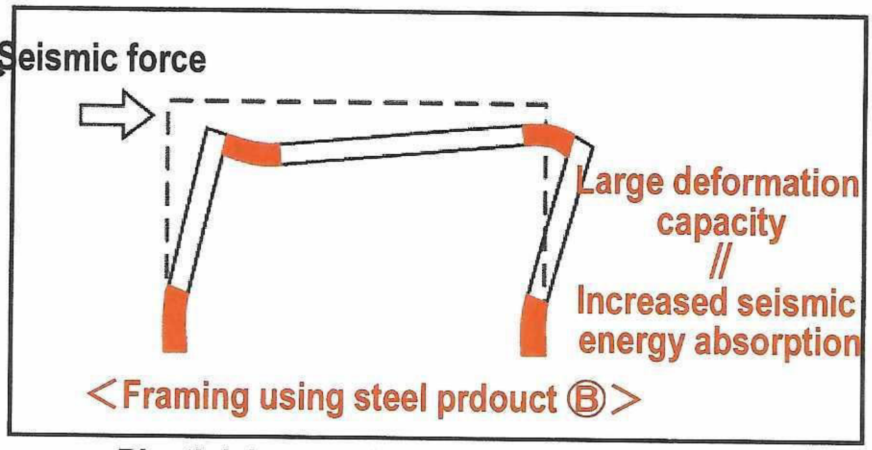
Effect of Yield Point Deviation on Seismic Resistance



Effect of Yield Ratio on Seismic Resistance







When yield ratio is low, plastic range become wide, and plastic deformation capacity become high.

Plasticizing section

Requirements for Steel Products for Building Structures

1. Securement of plastic deformation capacity
   Specification of upper limit for yield point and yield ratio
2. Securement of weldability
   Specification of upper limit for Ceq, Pcm
3. Securement of through thickness-direction properties
   Prescription of lower limit for thickness-direction reduction of area
4. Securement of nominal cross-section dimension
   Stricter allowable difference of minus-side thickness
5. Selection of optimum grade taking into account the application section (Grades A, B and C)

New Steel Products for Building Structures

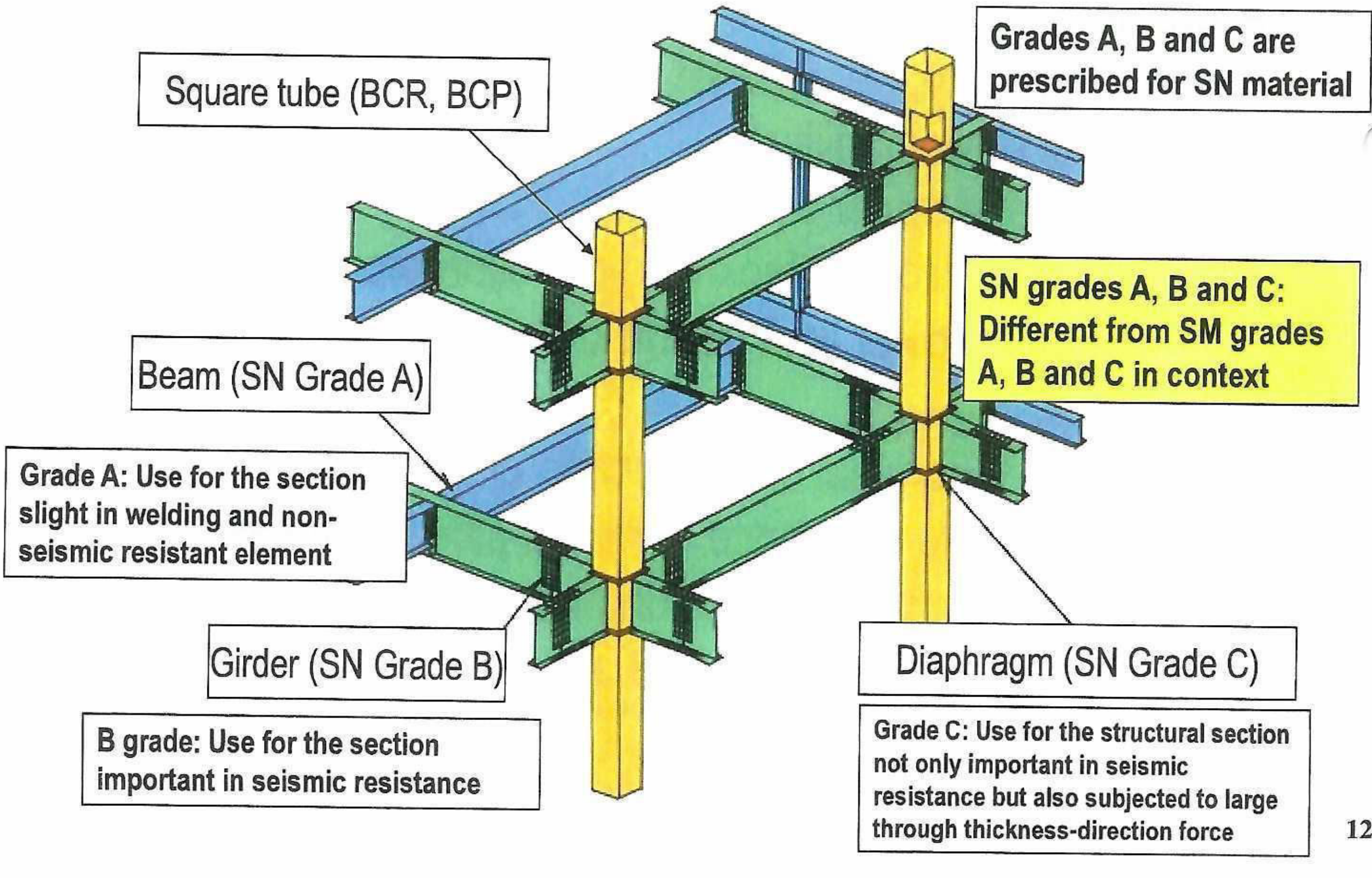
Standards	Symbol
Rolled Steel for Building Structure	SN400A·B·C, SN490B·C
Carbon Steel Pipe for Building Structure	STKN400W·B, STKN490B
Cold Roll-formed Square Steel Pipe for Building Structure※	**BCR295**
Cold Press-formed Square Steel Pipe for Building Structure※	**BCP235, BCP325, BCP325T**

※Ministerial-approved product

Conventional Steel Products

Standards	Symbol
Rolled Steel for General Structure	SS400, SS490
Rolled Steel for Welded Structure	SM400A·B·C, SM490A·B·C
Carbon Steel Pipe for General Structure	STK400, STK490
Square Steel Pipe for General Structure	STKR400, STKR490

Proper Use of Steel Products



Manual for Design and Construction of Cold-formed Square Steel Tubes (2008 Version)

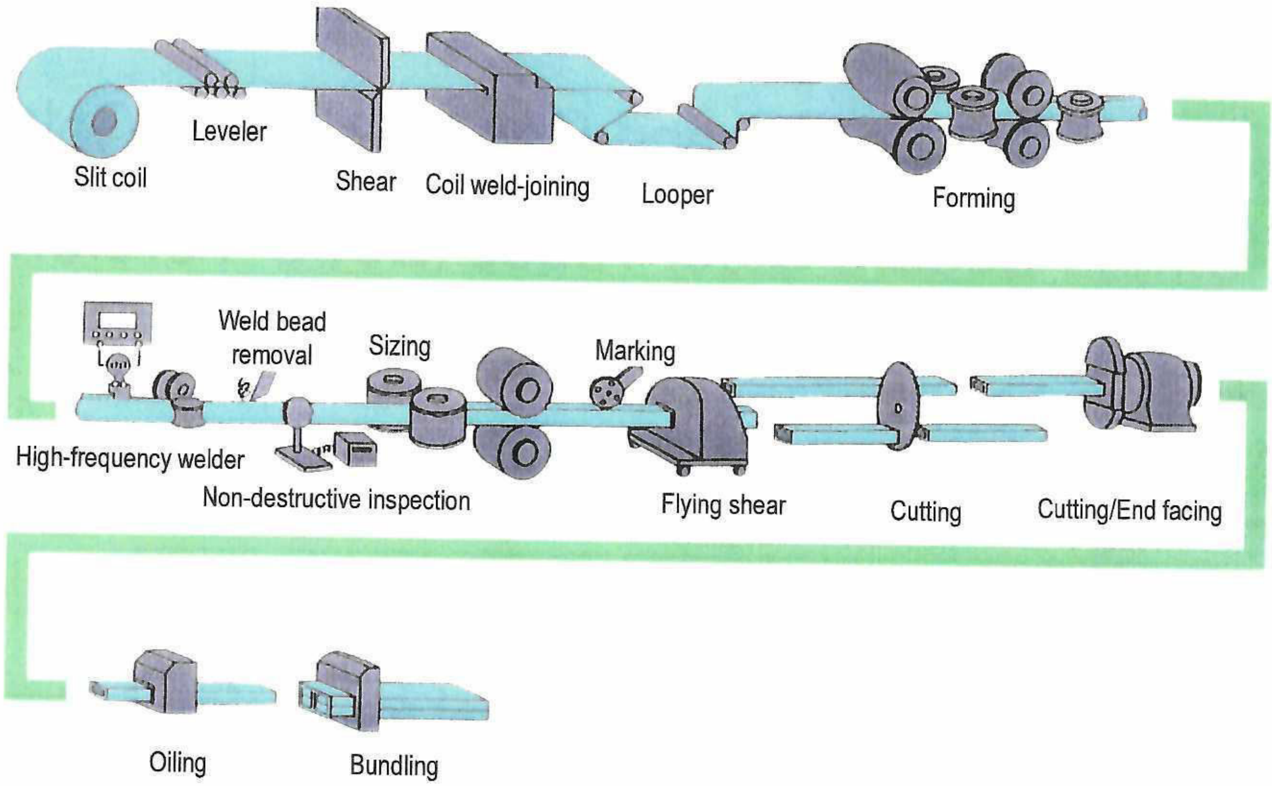
—Part 1—

January 2009

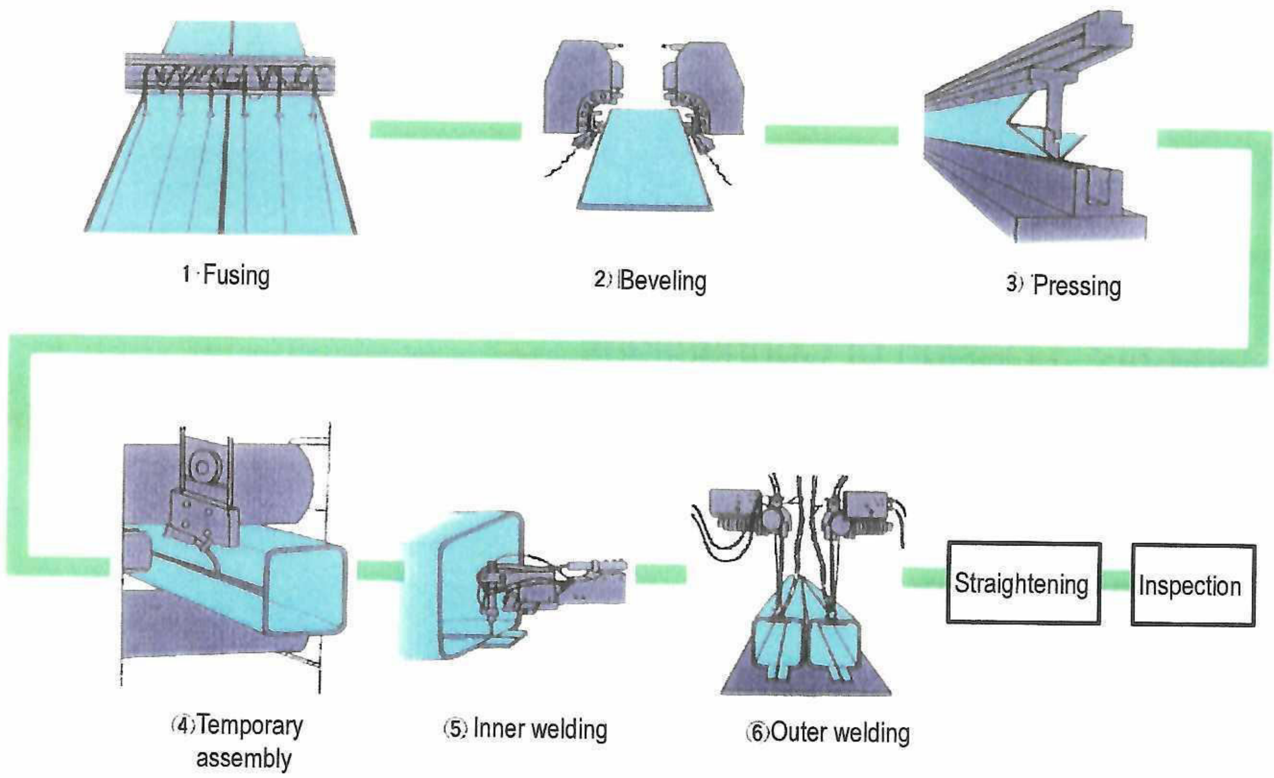
Editorial Committee on Manual for Design and Construction of Square Steel Tubes (2008 Version)

Manual: Contents

Roll-forming System (ERW Tube)



Press-forming System (2 Seams)

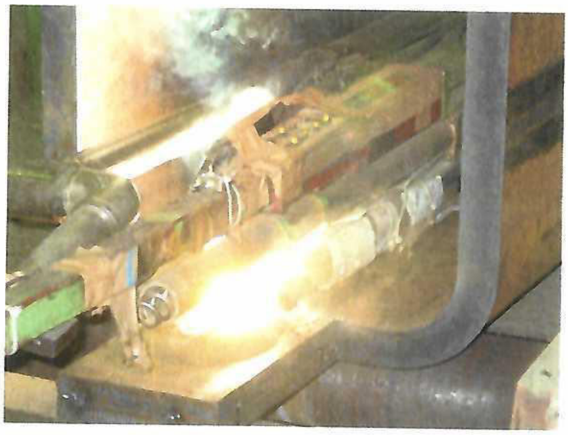


Cold Press-formed Square Steel Tube

1

2

3



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Manufacture Range for BCR and BCP

1. BCR295 (Cold roll-formed square steel tube for building structure)
   150X6＊～550X25
2. BCP235, 325 (Cold press-formed square steel tube for building structure)
   300X9～1000X40
3. BCP325T(High-performance cold roll-formed square steel tube for building structure)
   300X12～1000X40

(unit: mm)

※BCR, BCP: Registered trade name of the Japan Iron and Steel Federation

Manual for Design and Construction of Square Steel Tubes

"Design"

Application Range of the "Manual"

・・Applied to structural design of member and connection in using cold-formed square steel tube as column・・

①Description about cold-formed square steel tube
Notification enforced on June 20, 2007
→ MLIT Notification No. 593-1
MLIT Notification No. 594-4
MOC Notification No. 1791

②In the case of applying cold-formed square steel tube to CFT structure
→ MLIT Notification No. 464

③In the case of applying cold-formed square steel tube to brace
→ Not treated in the current Manual

MLIT: Ministry of Land, Infrastructure, Transport and Tourism; MOC: Ministry of Construction

Chemical Composition

Symbol	C	Si	Mn	P	S	N
BCR295	≦0.20	≦0.35	≦1.40	≦0.030	≦0.015	≦0.006
BCP235 (SN400B)	≦0.20	≦0.35	0.6 ~1.40	≦0.030	≦0.015	≦0.006
BCP235 (SN400C)	≦0.20	≦0.35	0.6 ~1.40	≦0.020	≦0.008	≦0.006
BCP325 (SN490B)	≦0.18	≦0.55	≦1.60	≦0.030	≦0.015	≦0.006
BCP325 (SN490C)	≦0.18	≦0.55	≦1.60	≦0.020	≦0.008	≦0.006
BCP325T	≦0.18	≦0.55	≦1.60	≦0.020	≦0.005	≦0.006
STKR400	≦0.25	—	—	≦0.040	≦0.040	—
STKR490	≦0.18	≦0.55	≦1.60	≦0.040	≦0.040	—

Reference

1) Alloying elements other than those listed in the above table can be added according to necessity

2) When Al and other elements that immobilizes N is added and containment of free N is 0.006% or under, N can be added up to 0,009% at maximum. Meanwhile, containment of total N is to be set at the upper limit for BCP325T

Mechanical Properties (1)

Symbol	Thick-ness (mm)	Yield point or strength (N/mm²)	Tensile strength (N/mm²)	Yield ratio (%)	Elongation		Charpy absorbed energy (J) 0℃
					Test piece	Elon-gation (%)	
BCR295	6≦ <12	295≦	400≦ ≦550	—	No. 5	23≦	27≦
	12≦ ≦16	295≦ ≦445		≦90			
	16< ≦22					27≦	
BCP235	6≦ <12	235≦	400≦ ≦510	—	No. 1A	18≦	27≦
	12≦ ≦16	235≦ ≦355		≦80			
	16< ≦40					22≦	

Mechanical Properties (2)

Symbol	Thick-ness (mm)	Yield point or strength (N/mm^2)	Tensile strength (N/mm^2)	Yield ratio (%)	Elongation		Cjharpy absorbed enery (J) 0℃
					Test piece	Elonga-tion (%)	
BCP325	6≦ <12	325≦	490≦ ≦610	—	No. 1A	17≦	27≦
	12≦ ≦16	325≦ ≦445		≦80			
	16< ≦40					21≦	
BCP325T	12≦ ≦16	325≦ ≦445	490≦ ≦610	≦80	No. 1A	17≦	70≦
	16< ≦40					21≦	
STKR400	—	245≦	400≦	—	No. 5	23≦	—
STKR490	—	325≦	490≦	—	No. 5	23≦	—

Ref. Charpy absorbed energy of BCP325T should satisfy the specified value at flat and corner sections.

Carbon Equivalent and Weld Cracking Sensitivity Composition

Symbol	Carbon equivalent[1] (%)	Weld cracking sensitivity composition[2] (%)
BCR295	≦0.36	≦0.26
BCP235	≦0.36	≦0.26
BCP325	≦0.44	≦0.29
BCP325T	≦0.44	≦0.29
STKR400	—	—
STKR490	—	—

Ref. 1) Carbon equivalent (%)

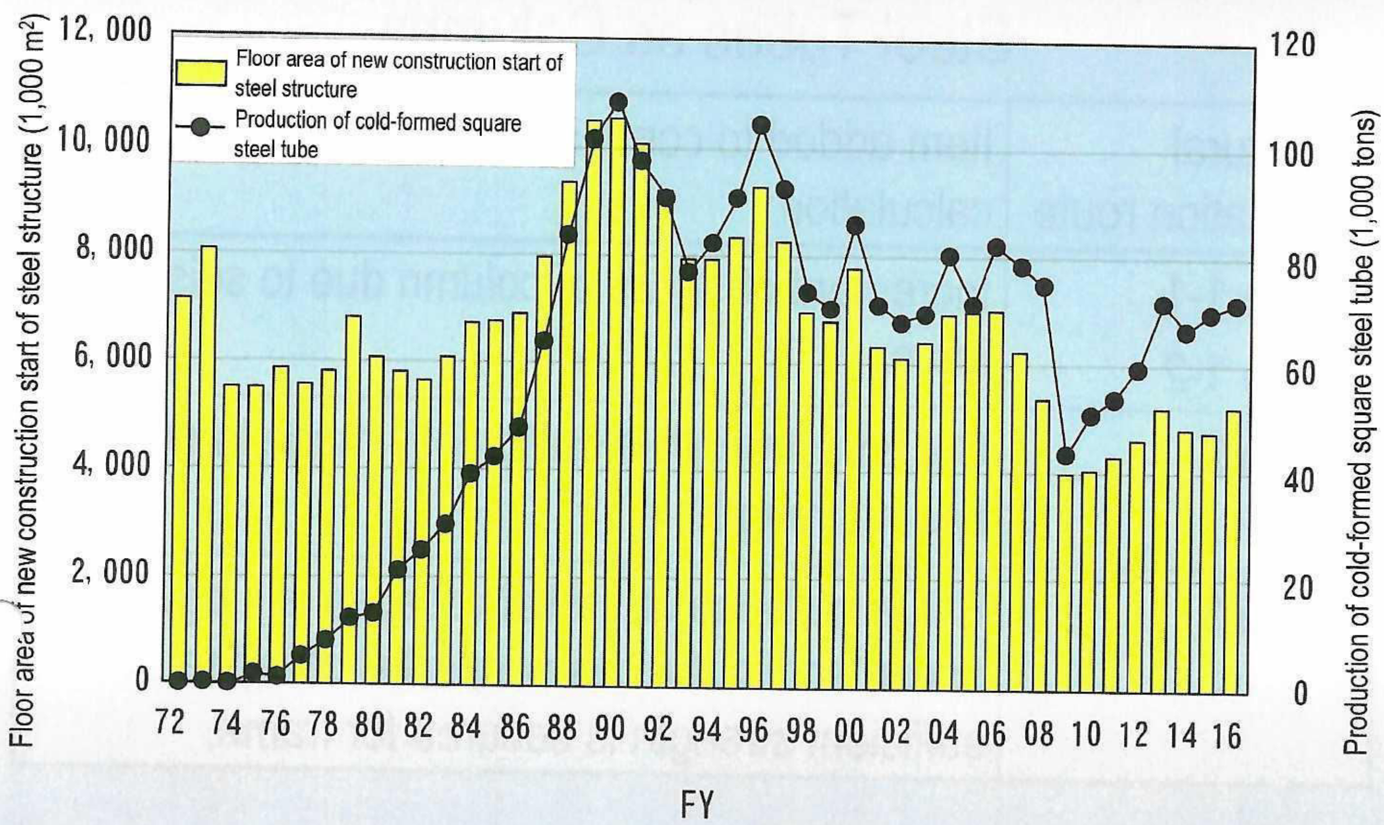
$$= C + Mn/6 + Si/24 + Ni/40 + Cr/5 + Mo/4 + V/14$$

2) Weld crack sensitivity composition

$$= C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B$$

3) For BCP325T, the parameter is additionally specified for toughness of MAG welding heat-affected zone.

Production of Cold-formed Square Steel Tubes



Cares in Structural Plan

■ General structural plan

There are many cases in which section is decided by deformation restriction of medium/small column H-shape structure, and thus care is paid to secure rigidity.

■ Collapse type and strength ratio of respective section

Because the structural plan is made so that frame does not cause column collapse type, care is paid to column-to-beam strength ratio and column-to-panel strength ratio to decide structural member.

■ Selection of members

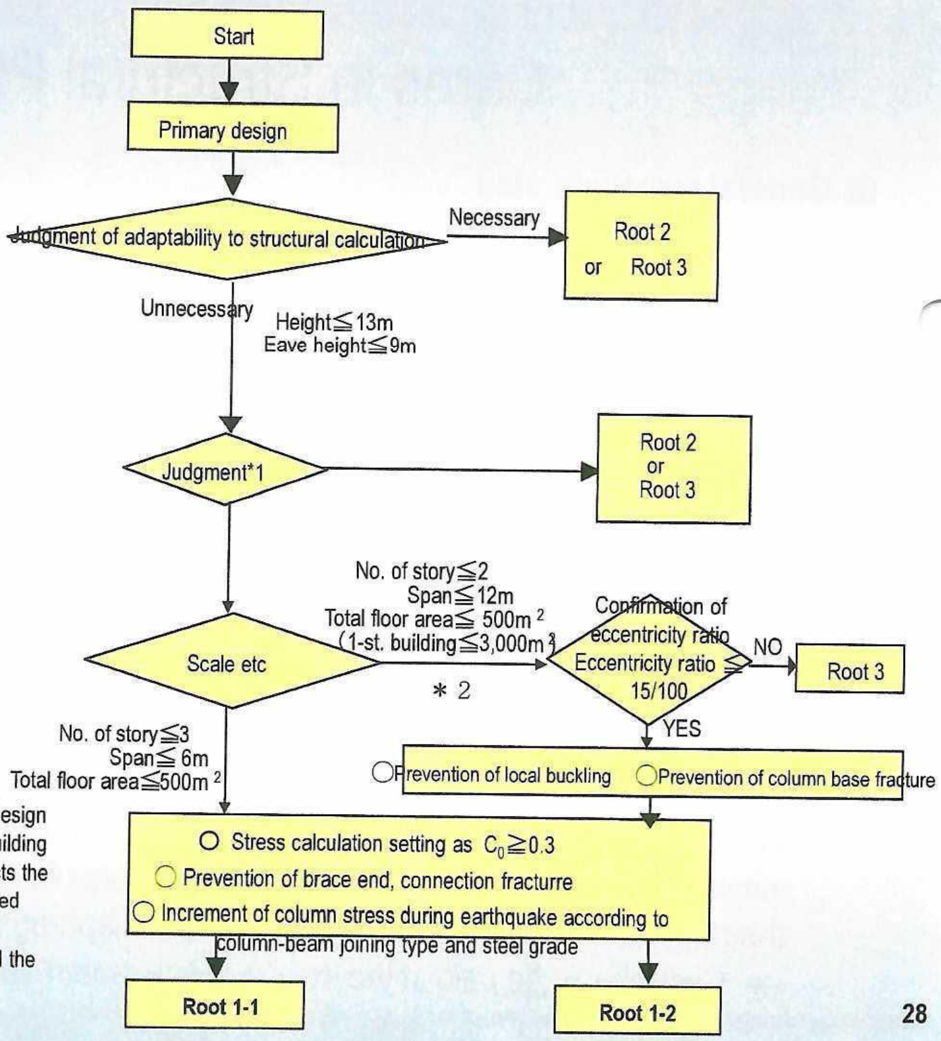
Because selection is related to construction method, the following cares are paid in design stage.

- Column corner R differs depending on thickness.
  → Care is paid to column joint details.
- Basically, accessory metal fitting is not welded to column corner. In the case of inevitable use of welding, secondary member should not be welded to corner within the range of 1.5D (D: column diameter) from diaphragm.
  → Care should be paid in the design of equipment and finishing.

Additional Items in Using Cold-formed Square Steel Tubes as Columns

Structural calculation route	Item added to common seismic force calculation
Route 1-1 Route 1-2	Increment of stress of column due to seismic force
Route 2	Column strength is sufficiently made larger than beam strength.
Route 3	Entire collapse or partial collapse is judged to occur, and in the case of partial collapse, sufficient strength is secured for frame.

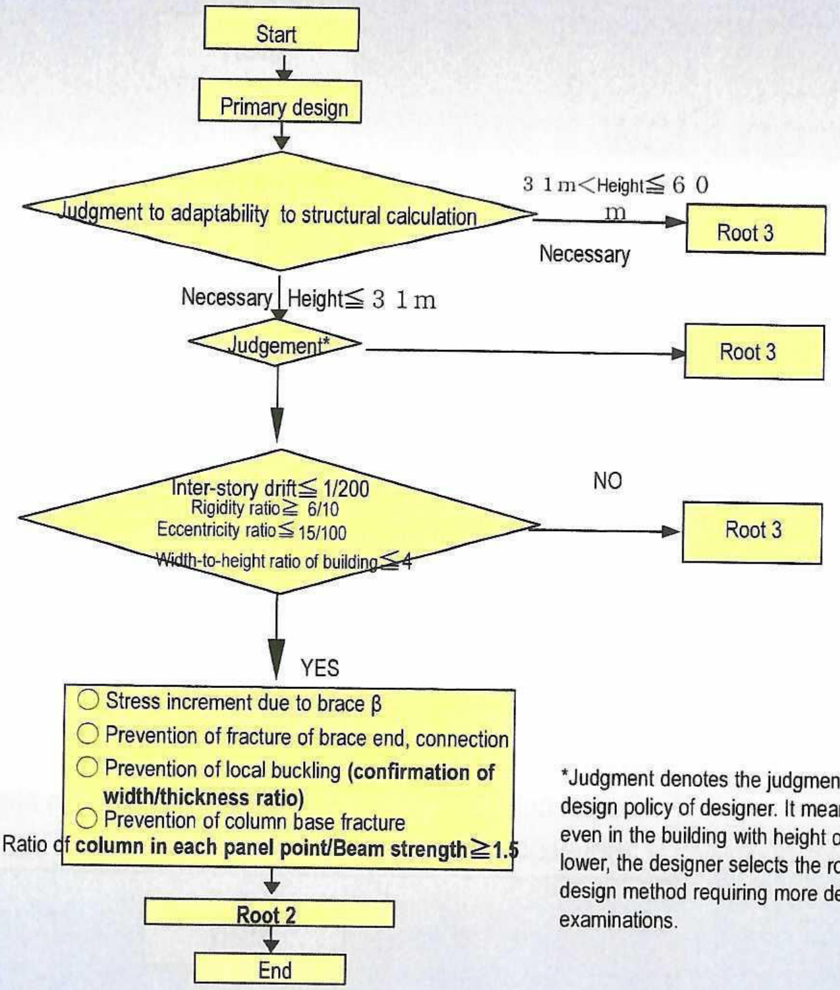
Design Flow in Root 1



*1 Judgment denotes the judgment based on design policy of designer. It means that, even in the building with height of 31 m or lower, the designer selects the root 3, the design method requiring more detailed examinations.

*2 Excepting the light-gauge steel structure and the building in which large loading is applied to the rooftop.

Design Flow in Root 2



*Judgment denotes the judgment based on design policy of designer. It means that, even in the building with height of 31 m or lower, the designer selects the root 3, the design method requiring more detailed examinations.

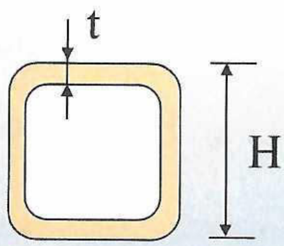
Restrictions in Width-to-Thickness Ratio

		Width-to-thickness ratio	Width-to-thickness ratio (Ref. *)
Column	BCR295	$33\sqrt{235/F}$	29
	BCP235		33
	BCP325		28
	BCP325T		28
	STKR400		33
	STKR490		28

*The value rounding off decimals is shown as the reference value, but in the practical design, the ratio is calculated using F value and it is necessary to take into account the value less than decimals.

Width-thickness ratio＝H／t

F : Design standard strength



Design Flow in Root 3

Start

↓

Primary design

↓

Confirmation of inter-story drift
Inter-story drift≦ 1/200

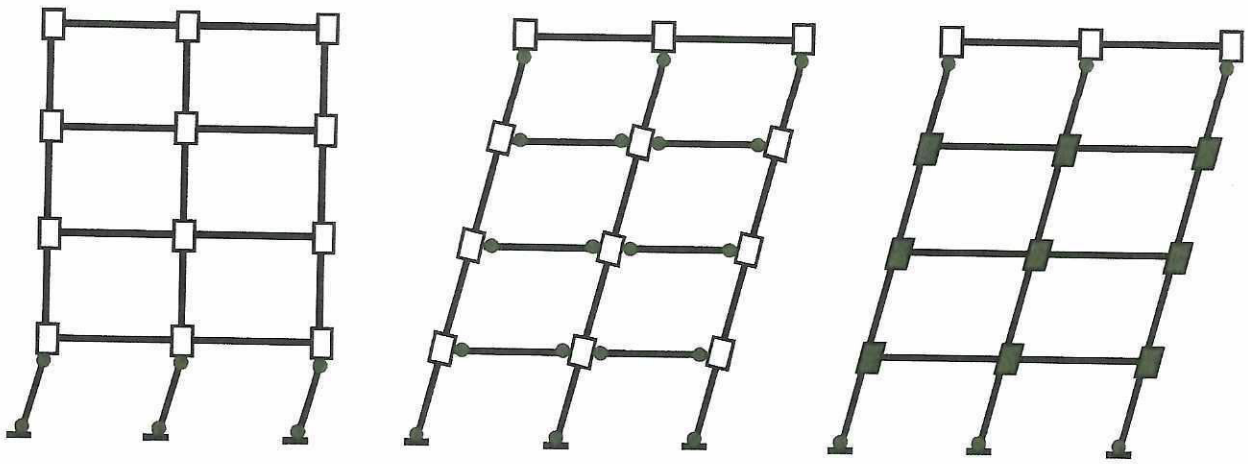
↓

○ Confirmation of retained horizontal strength
Qu ≧Qun, Qun＝Ds・Fes・Qud
○ Examination of overturn (in the case of building's width-to-height ratio＞4)
○ Collapse type (cold-formed square steel tube column)
・Full collapse type
・Partial collapse type→Confirmation of column strength reduction and retained horizontal strength

↓

Start

Collapse Type of Rigid Frame Structure



(a) Column collapse type (partial collapse type)

(b) Beam collapse type (full collapse type)

(a) Panel collapse type (full collapse type)

● Plastic hinge ▰ Plasticized panel

Additional Items in Root 3 (1)

In the design Root 3, judgment is made on thee occurrence of entire collapse type or partial collapse type, and sufficient frame strength should be secured for partial collapse type. However, in the case of applying STKR to column member, only the entire collapse type is allowed that satisfies the column strength 1.5 times or more the beam strength in all panel points except for column base at lowest floor and column head at topmost floor.

(1) Judgment of collapse type: $\gamma_k = \Sigma(Mpci) / \Sigma\ [\min(1.5Mpbi,\ 1.3Mppi)]$
Entire collapse type: ($\gamma_k \geqq 1.0$) or partial collapse type ($\gamma_k < 1.0$)

(2) Method to secure sufficient frame strength in the case of partial collapse type
Using the following two methods, confirmation is made to that the retained horizontal strength surpasses the necessary retained horizontal strength.
① Confirmation of retained horizontal strength using the conventional method
② Confirmation of retained horizontal strength taking into account the column reduction coefficient

Additional Items in Root 3 (2)

Coefficient of column strength reduction

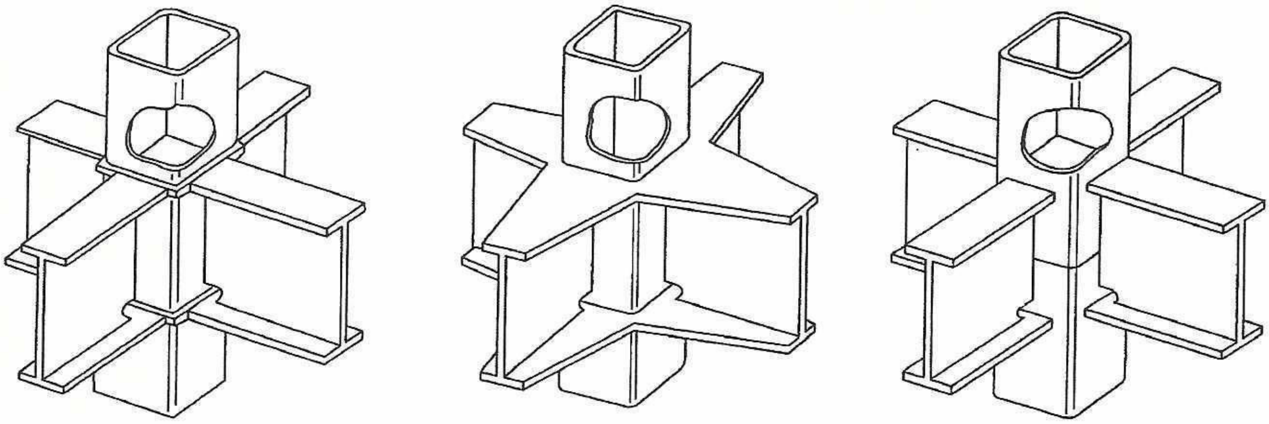
Symbol	(1) Inner diaphragm type*1	(2) Types other than (1)*2
BCP*3	0. 85	0. 80
BCR	0. 80	0. 75
STKR	—	—

*1 Diaphragm insertion type is treated as the type in (2)

*2 Type in (2): Through diaphragm type and outer diaphragm type

*3 BCP235、325、BCP325T

Type of Column-Beam Connection



Through diaphragm Outer diaphragm Inner diaphragm

Specifications for Through Diaphragm Type

(1) Material: Similar or superior to the strength of beam and column
Grade C of SN materials (as a rule)

(2) Projection dimension: e = 25mm (tc<28mm)
e = 30mm (tc≧28mm)

(3) Thickness: Heavier thickness than flange thickness (2 sizes up)

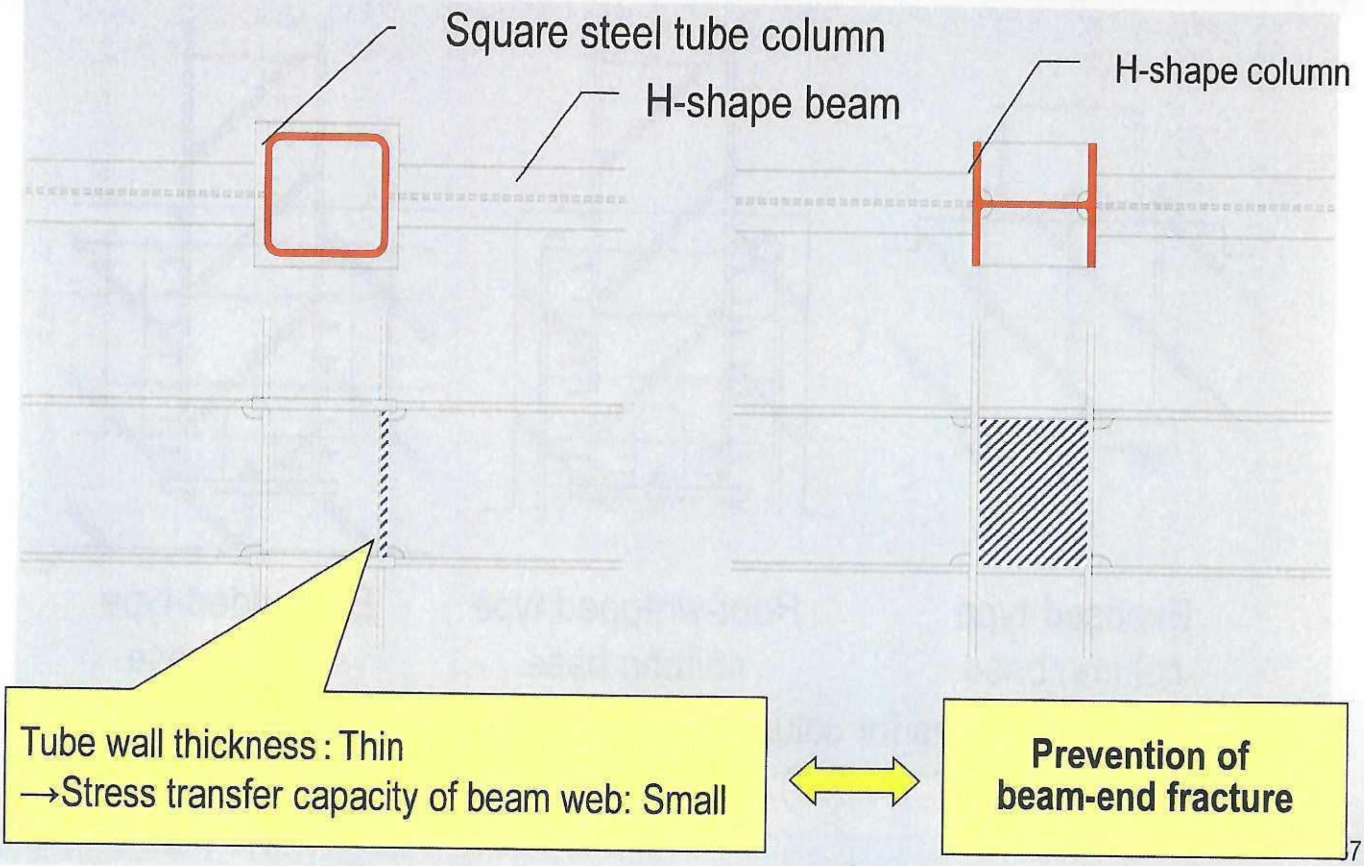
(4) Panel thickness: Either of heavier thickness of upper or lower floor column

(5) Different column size in upper or lower floor: Use of tapered tube (approved tapered tube)

Method for direct joining by increasing the thickness of through diaphragm: It is desirable to set at □300 or lower and diameter difference of 50 or lower

(6) Weld joining of cold-rolled column and diaphragm: Fully penetrated welding

Beam-end Plastic Deformation Capacity and Column-Beam Connection



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Design of Beam-end Connection

(1) Beam flange connection is prepared by means of full penetration welding so that the connection retains the strength similar or superior to nominal strength of beam flange base metal.

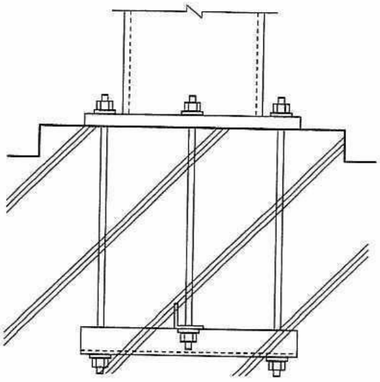
(2) Web connection bears all shear force to be borne by the beam, and the connection is prepared by use of welding and high-strength joining so that the connection can bear the maximum flexural strength prescribed in the following.

Stress transfer from beam is basically borne as in the following and is designed referring to "Design Guidelines for Steel-structure Connections".

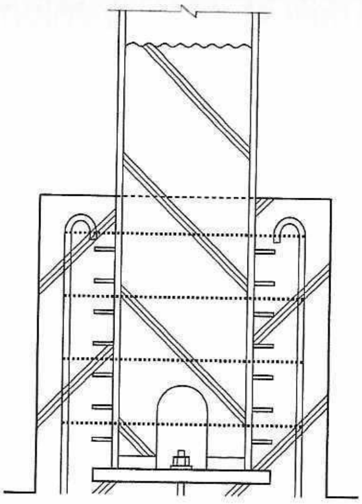
① Bending moment is transferred at beam flange connection and beam web connection. Beam web connection strength is examined taking into account the occurrence or no occurrence of scallop and other defects and out-of-plane rigidity of column flange.

② The bending strength of beam web is 10~40% the bending strength of full beam section, and when the moment that can be practically borne by beam end in ultimate limit state of frame is assessed, the web bending burden is appropriately assessed from the aspect of preventing fracture of beam flange weld.

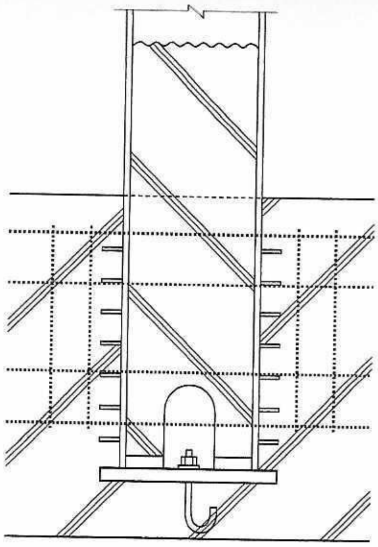
Type of Column Bases (MOC Notification No.1456 in 2000)



Exposed-type column base



Root-wrapped type column base



Embedded-type column base

Specific specifications for column base (Enforcement Order Art. 66, MOC Notification No. 1456 in 2000)   MOC: Ministry of Construction

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27 Feb (Tue) PM

<Lecture>

Composite Deck Slabs

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Ministry of Economy, Trade and Industry

AOTS

The Association for Overseas Technical Cooperation and Sustainable Partnerships

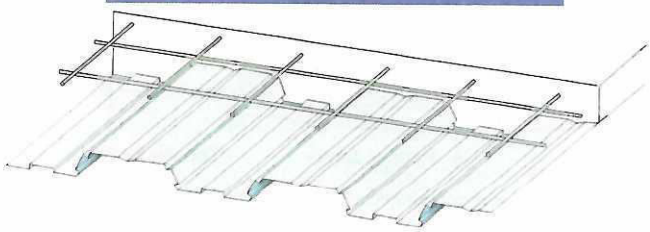
Confidentiality

Composite Deck Slabs

·Revision of the Building Standards Act and the 9th Revision of the Regulations on Composite Deck Slabs

Structural Methods for Designing the Structures of Deck Plate Floor Slabs

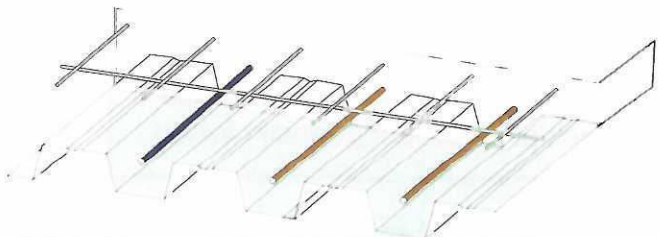
i. Composite deck slab



- **A composite structure** consisting of a **deck plate** and **concrete**.
- The use of **welded wire mesh** is only for **preventing the expansion of cracks.**

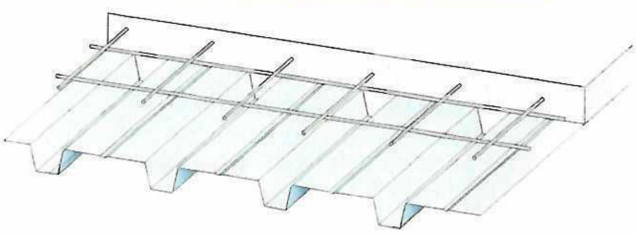
*However, welded wire mesh is also expected to bear loads when a slab needs to resist a fire.

ii. Complex composite deck slab



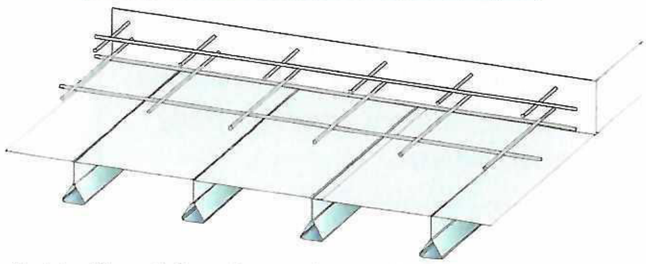
- **A deck plate supports the weight of the concrete itself.**
- **Reinforcing bars in grooves bear tensile force, as is the case with RC structures.**
- The use of **welded wire mesh** is only for **preventing the expansion of cracks**.

iii. Structural deck slab



- **The deck plate alone can support the entire load.**
- The use of **concrete** is for **surface finish** for pedestrians.
- Dry construction **external heat insulation roofs with deck substrates** fall under this structural method.

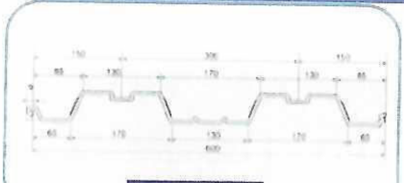
iv. RC slab with deck formwork



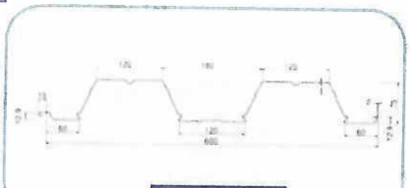
- A slab with a **reinforced concrete structure**.
- A **deck** plate is used as **temporary formwork** until concrete hardens.
- **A structural type not subject to JIS G 3352.**

Types of Deck Plates

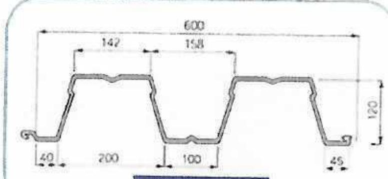
i. Composite slab deck plate



H50

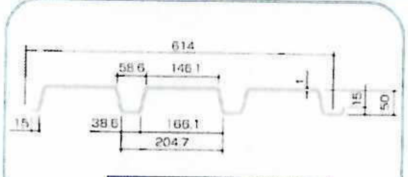


H75

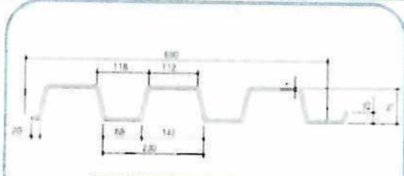


H120

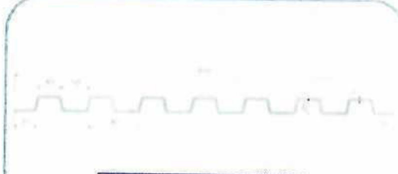
ii. Plane deck (for complex composite and structural deck slabs)



H50 (V50)

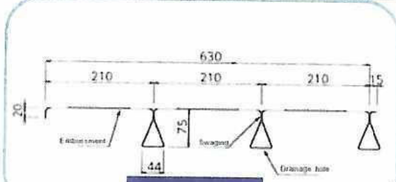


H75 (UKA-N)

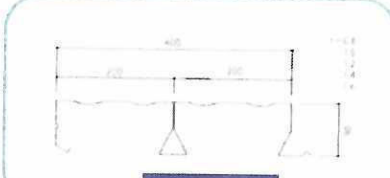


H25 (KP)

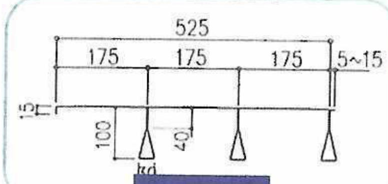
iv. Flat deck (for RC slab with deck formwork)



H75



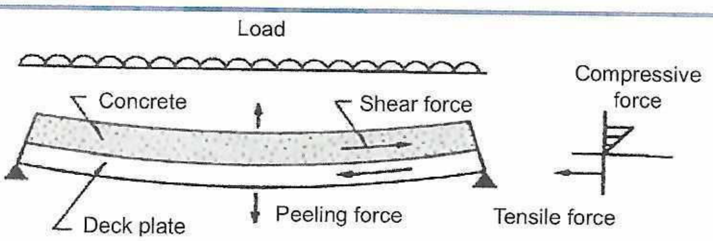
H90



H100

Features of Composite Deck Slabs

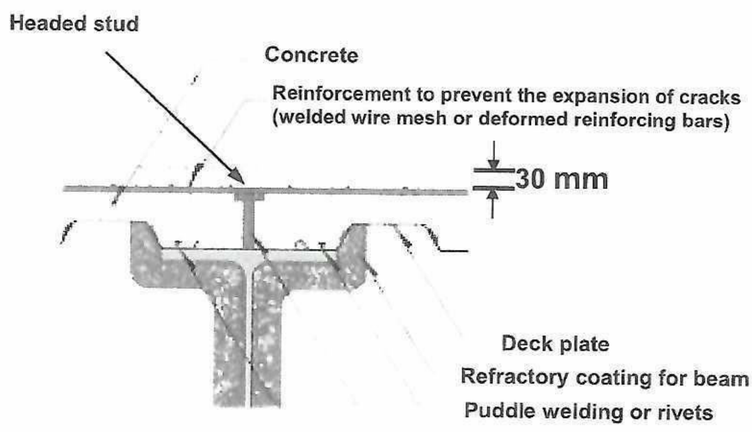
1. Large bearing capacity and toughness
Composite structure of concrete (bearing compressive force) and a deck plate (bearing tensile force)



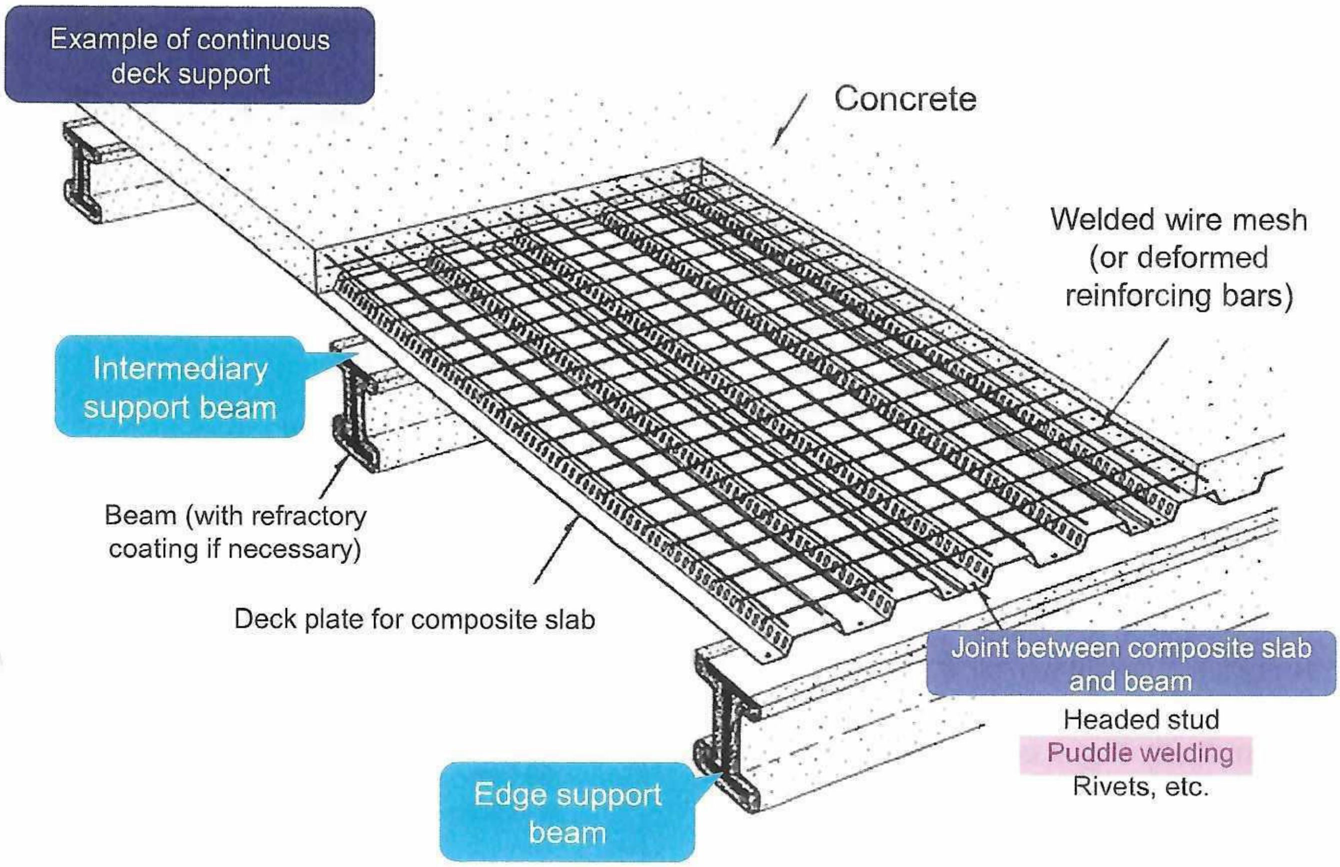
2. No structural reinforcing bars required
Welded wire mesh prevents the expansion of cracks on concrete.

3. No horizontal braces required
A deck slab with large in-plane stiffness functions as a horizontal resisting element when properly fixed to beams.

4. No refractory coating required
Acquisition of the certificate for a fire-resistant structure without refractory coating

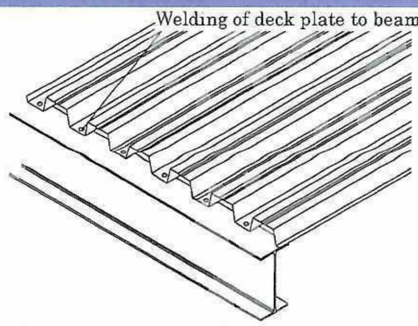


Explanation Drawing of the Structure of Composite Deck Slab

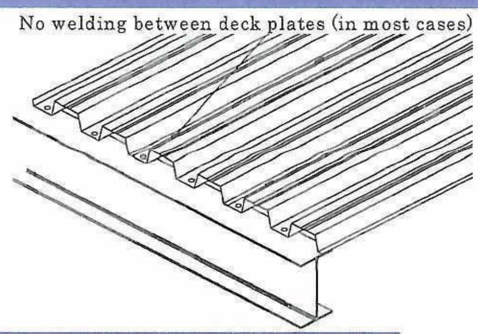


Types of Joints among Deck, Composite Slab and Beam

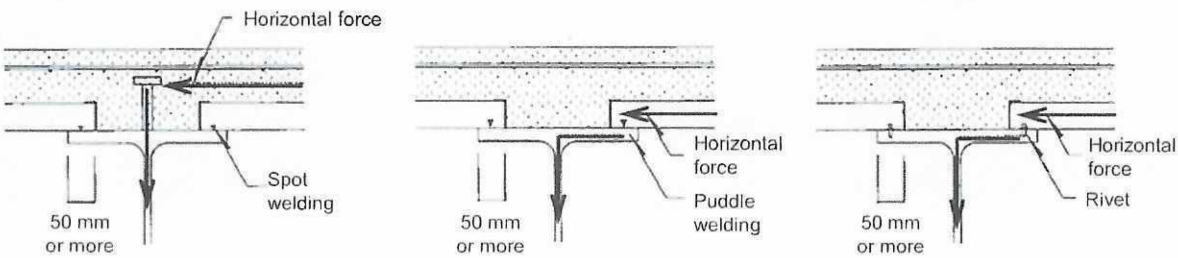
(1) Joint between deck plate and steel frame beam



(2) Joint between deck plates



(3) Joint between composite deck slab and steel frame beam



(1) Headed stud
Composite deck slab ⇒ Headed stud ⇒ Beam

(2) Puddle welding
Composite deck slab ⇒ Puddle welding ⇒ Beam

(3) Rivet
Composite deck slab ⇒ Rivet ⇒ Beam

Figure 3.B Method for joining composite deck slab and beam

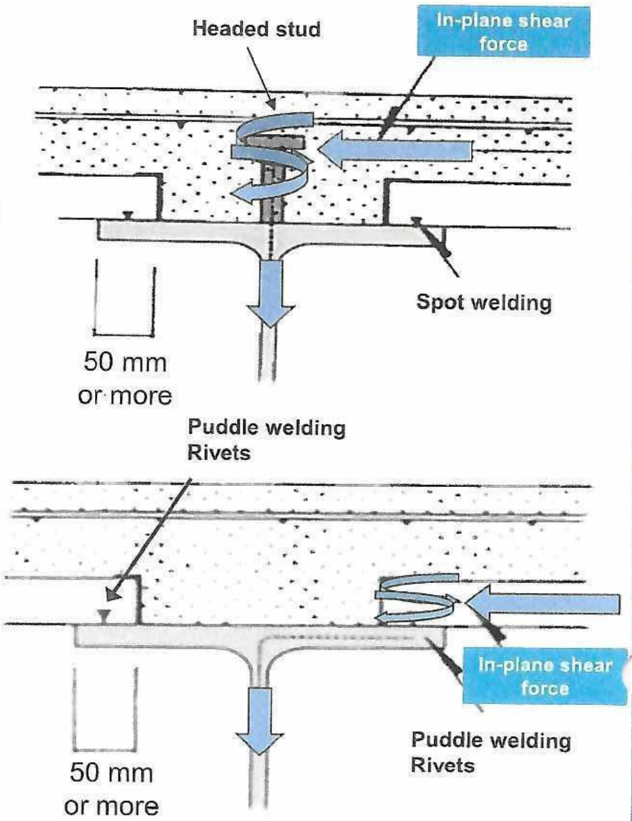
Method for Joining Composite Deck Slab and Beam

1. A composite deck slab and a beam shall be joined through the following methods so as to allow the in-plane shear force on a floor slab to be transferred.
   - **Headed stud**
   - **Puddle welding**
   - **Rivets**

2. When joining a composite deck slab and a beam through a headed stud, a deck plate shall be welded to the beam through **arc spot welding** or fillet welding.

* In the case of **continuous deck support** (refer to P.13), a deck plate shall be welded to **an interim support beam**.

3. When **designing a composite beam**, a **headed stud** shall be used.



Outline of the Design of Composite Deck Slabs

Design and Construction Standards of Floor Deck Plates (2018)

Mechanical Properties of JIS Deck Plates

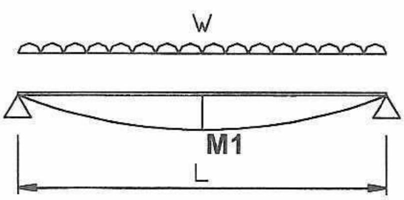
Type of deck plate	YP (N/mm^2)	TS (N/mm^2)	Compression (%)	YR (%)	Remarks
SDP1T SDP1TG	≧205	≧270	≧18	— —	Ordinary steel *The letter "G" in the type names denotes steel with plating.
SDP2 SDP2G	≧235	≧400	≧17	— —	
SDP3	≧315	≧450	≧15	—	Weather-resistant steel
SDP4 SDP5	≧235	≧520	≧40	≦60	Stainless steel
SDP6	≧325	≧690	≧35	≦60	

Outline of the Design of Deck Plates

Study on construction conditions (1)

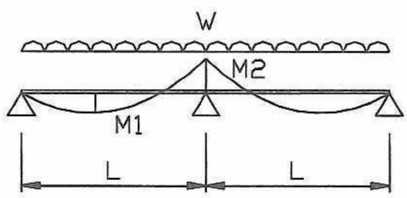
Stress calculation: Support conditions vary depending on the actual situation. General situations are as shown below.

Simple support



$$M1= \frac{WL^2}{8}$$

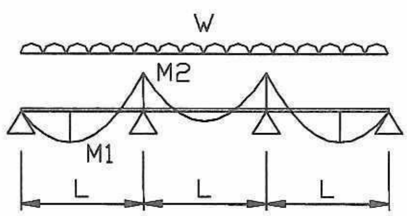
2-span continuous support



$$M1= \frac{9WL^2}{128}$$

$$M2= \frac{WL^2}{8}$$

3-span continuous support



$$M1= \frac{2WL^2}{25}$$

$$M2= \frac{WL^2}{10}$$

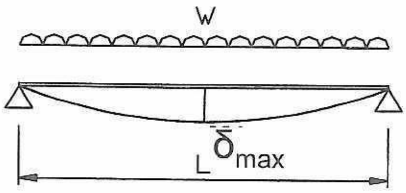
Outline of the Design of Deck Plates

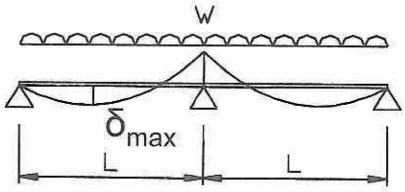
Study on construction conditions (2)

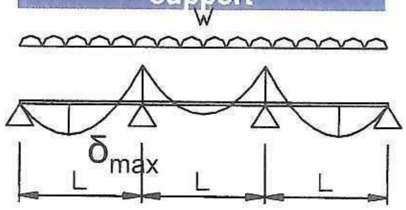
Deflection calculation: Support conditions vary depending on the actual situation. General situations are as shown below.

$\delta_{max} \leqq L/180$ and 20 mm

Simple support	2-span continuous support	3-span continuous support







$$\delta_{max} = C \times \frac{5WL^4}{384EI} \fallingdotseq 13.0/1000$$

$$\delta_{max} = C \times \frac{WL^4}{185EI} \fallingdotseq 5.4/1000$$

$$\delta_{max} = C \times \frac{WL^4}{145EI} \fallingdotseq 6.9/1000$$

In the case of simple support, deflection is a dominant factor in design.

Coefficient C used for calculating deflection	bD > be	bD ≦ be
Long-term	1.16	1.00
Short-term	1.20	1.00

* The evaluation of the deflection during construction shall be based on the value obtained by multiplying the second moment of area of the entire cross-section, without considering the effective width of a steel plate, by the coefficient used for calculating deflection C.

Outline of the Design of Deck Plates

Width-thickness ratio and effective width

The design of deck plates shall meet the specified limit value to prevent local buckling of thin steel plates, because a single deck plate is required to support the concrete placement load and other loads during construction.

Width-thickness ratio (in compliance with AIJ Design Standard for Steel Structures)

$$\frac{d}{t} \leqq 1.6 \times \sqrt{\frac{sE}{F}}$$

* F denotes standard strength

Effective width

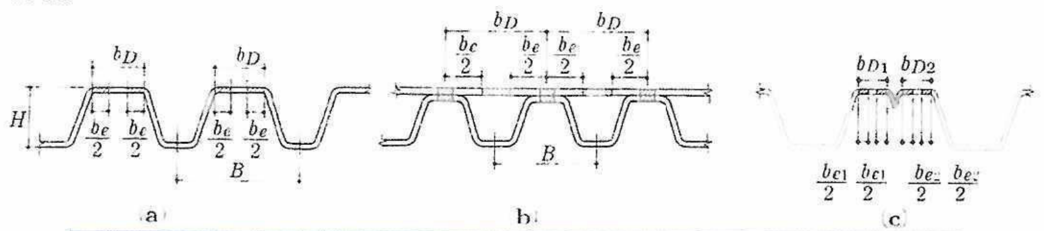
$$b_e \leqq 1.6t \times \sqrt{\frac{sE}{F}}$$

The definitions of effective width are as follows (Figure 5.A):

(a) For a bent section, be shall be set with respect to the flat plate section between the ends of bends (ends of bending radius R).

(b) When combined with a slab, be shall be set with respect to the flat plate section between the mid points of joints.

(c) In the case of a deck plate with a central rib, be shall be set with respect to the flat plate section from the ends of the rib.



When F is 205 and 235, be < 51 t and 48 t → be < 50 t

Figure 5.A Definitions of effective width

Different F values lead to different effective widths. → It is necessary to study cross-sectional properties in detail.

Outline of the Design of Composite Deck Slabs

Allowable stress

Allowable stress for deck plates and F values for the standard strength to calculate the allowable stress

Type of deck plate	F value N/mm^2	Long-term			Short-term
		Tensile	Compressive	Shear	
SDP1T, SDP1TG	205	$\frac{F}{1.5}$	$\frac{F}{1.5}$	$\frac{F}{1.5\sqrt{3}}$	1.5 times the long-term value
SDP2, SDP2G	235				
SDP3					
SDP4, SDP5					
SDP6	235 (325)				

Allowable shear force for puddle welding and a single rivet (unit: N)

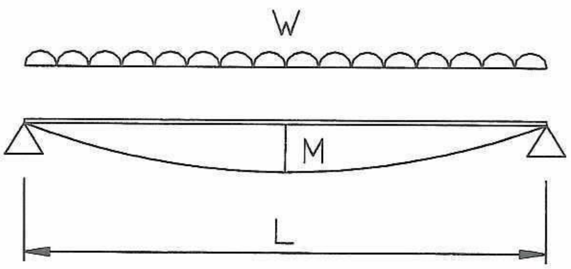
Thickness of deck plate (mm)	Puddle welding	Rivet (Revised in 2018 edition)
	Short-term	Short-term
1.2	7,350	4,000
1.6	11,025	5,300

Outline of the Design of Composite Deck Slabs

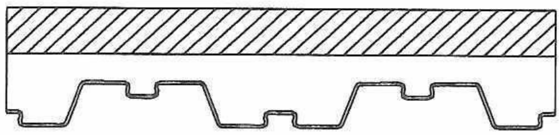
Study on design conditions (1)

Stress calculation

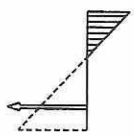
Regardless of the support conditions of a deck plate, calculation shall be made based on **simple support** to confirm the resistance of concrete with respect to compressive stress and that of the deck plate with respect to tensile stress.



$$M = \frac{WL^2}{8} \leqq \min(Zc \times fc, Zf \times ft)$$



Effective equivalent cross-section



W: Full load acting on a floor

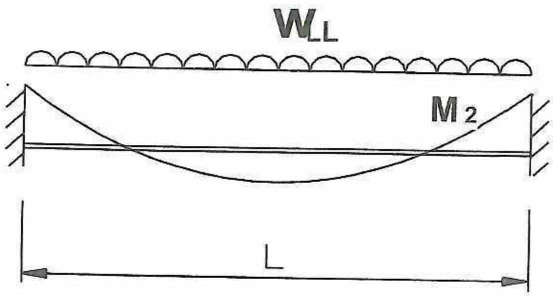
fc: Long-term compressive strength of concrete

ft: Long-term tensile stress of deck plate

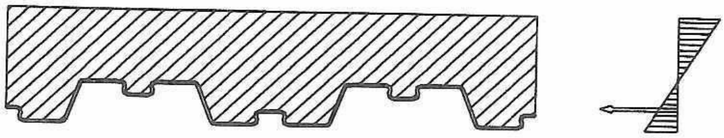
Outline of the Design of Composite Deck Slabs

Study on design conditions (2)

Study on interferences in use, part 1 (Study on cracks)
Regardless of the support conditions of a deck plate, calculation shall be made based on **continuous support** to confirm whether or not cracks can be generated on a concrete surface due to negative bending stress.



$$M_2 = \frac{WL^2}{12} \leqq Ze \times 0.62\sqrt{Fc}$$



Effective equivalent cross-section

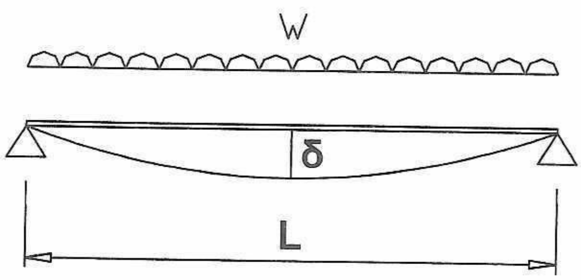
W_{LL}: Full load acting on a floor
* Excluding the fixed loads w_{DL} on the floor if scaffolding is not used.

$0.62\sqrt{Fc}$: bending crack strength of concrete
* Slightly higher than the median value of the distribution of crack strength.

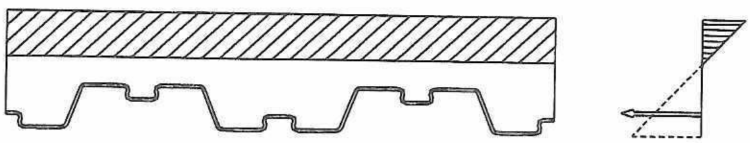
Outline of the Design of Composite Deck Slabs

Study on design conditions (3)

Study on interferences in use, part 2 (Study on design deflection) Regardless of the support conditions of a deck plate, calculation shall be made based on **simple support**.



$$\delta_{max} = \frac{5WL^4}{384sE(cIn/n)}$$



- Second moment of area: Effective equivalent cross-section
- Young's modulus: n = 15

Effective equivalent cross-section

Outline of the Design of Composite Deck Slabs

Study on design conditions (3)

Study on interferences in use, part 2 (Limit to design deflection)

Deflection: lx/250 or less
Natural vibration frequency: 15 Hz or more

* Notice on Regulations: Paragraph 1 stipulating the specifications of the ratios of thickness t to length lx (t/lx ≧ 1/25)
Paragraph 2 stipulating the evaluation based on the calculation of deflection

$$\delta_k = k \times \delta \leqq \frac{lx}{250}$$

k: deformation enhancement factor (= 1.5)

In the case of an evaluation based on the calculation of deflection, the calculated deflection shall be multiplied by a deformation enhancement factor k.

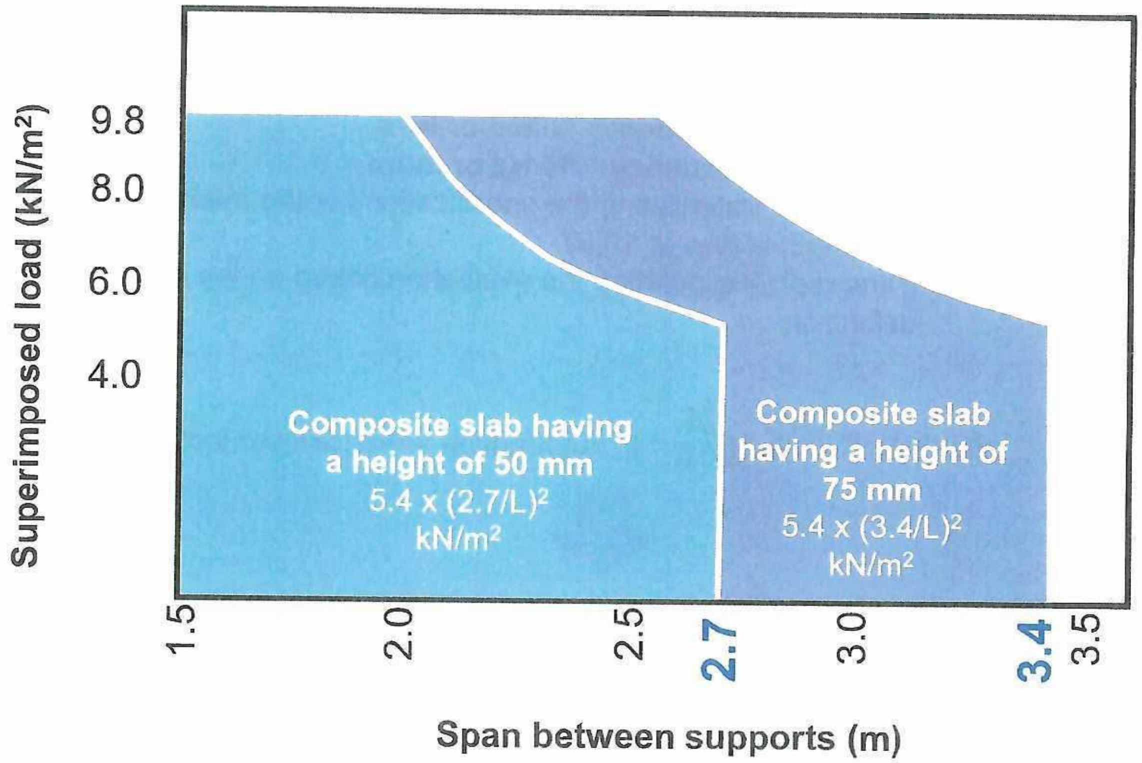
Current prescribed value: lx/375 (= 250*1.5)

Fire-resistant Design Routes

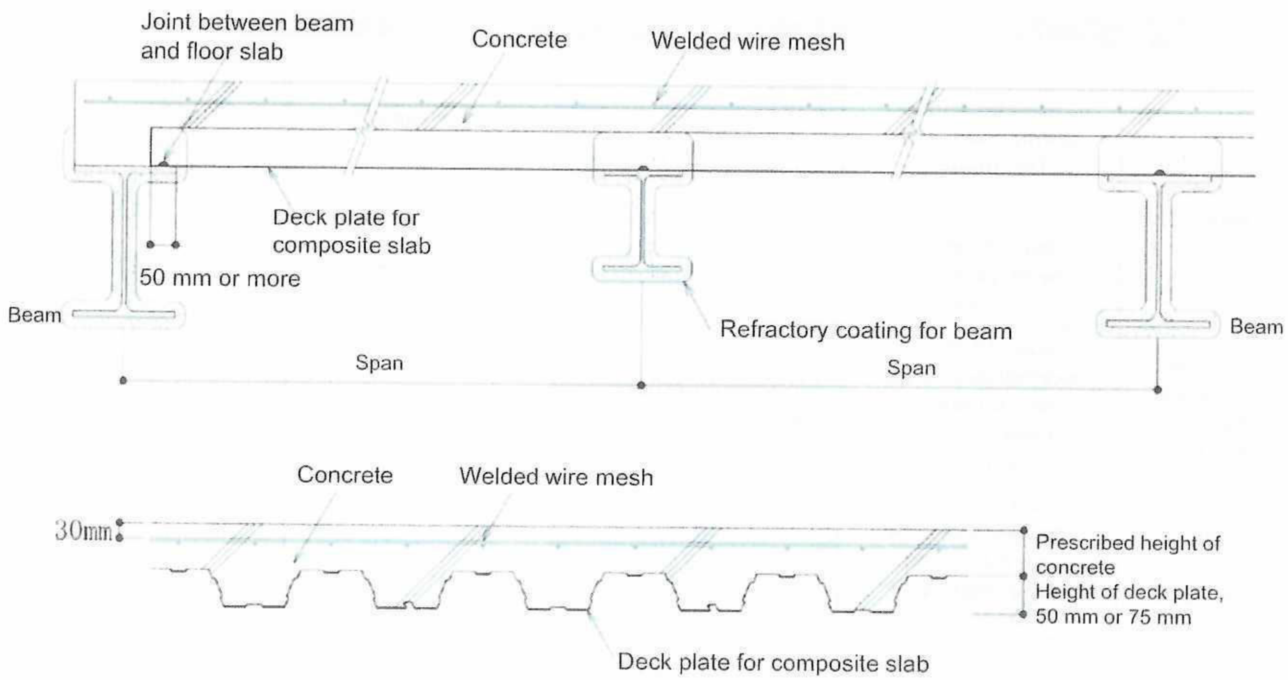
Fire-resistant design route		Composite deck slab	Complex composite deck slab	Structural deck slab
(1) Route A: Specification design	Specifications exemplified in the Notification	–	○: Fire-resistant structure	×: Fire-resistant structure ○: Semi-fire-resistant structure ○: 30-minute fire-resistant roof
	Specifications certified as fire-resistant	○	○	○
(2) Route B: Fire-resistant verification method	Specifications exemplified in the Notification or certified as fire-resistant	Floors with other fire-resistant structures	–	–
(3) Route C: Minister's certification	Specifications based on performance confirmation experiment and analysis	–	–	–

Fire-resistant design for floors is generally based on the **specifications certified as fire-resistant (Route A).**

Specifications of Composite Deck Slabs Certified as Fire-resistant

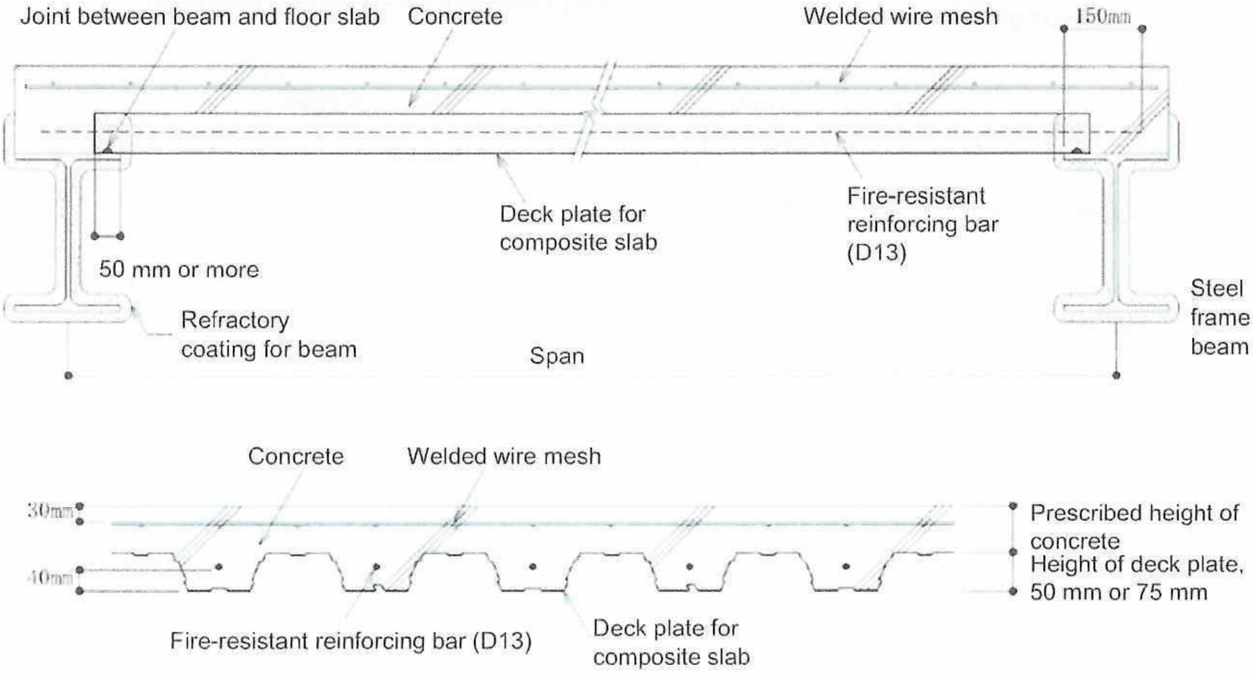


Certified Fire-resistant Structure of Continuous Deck Support



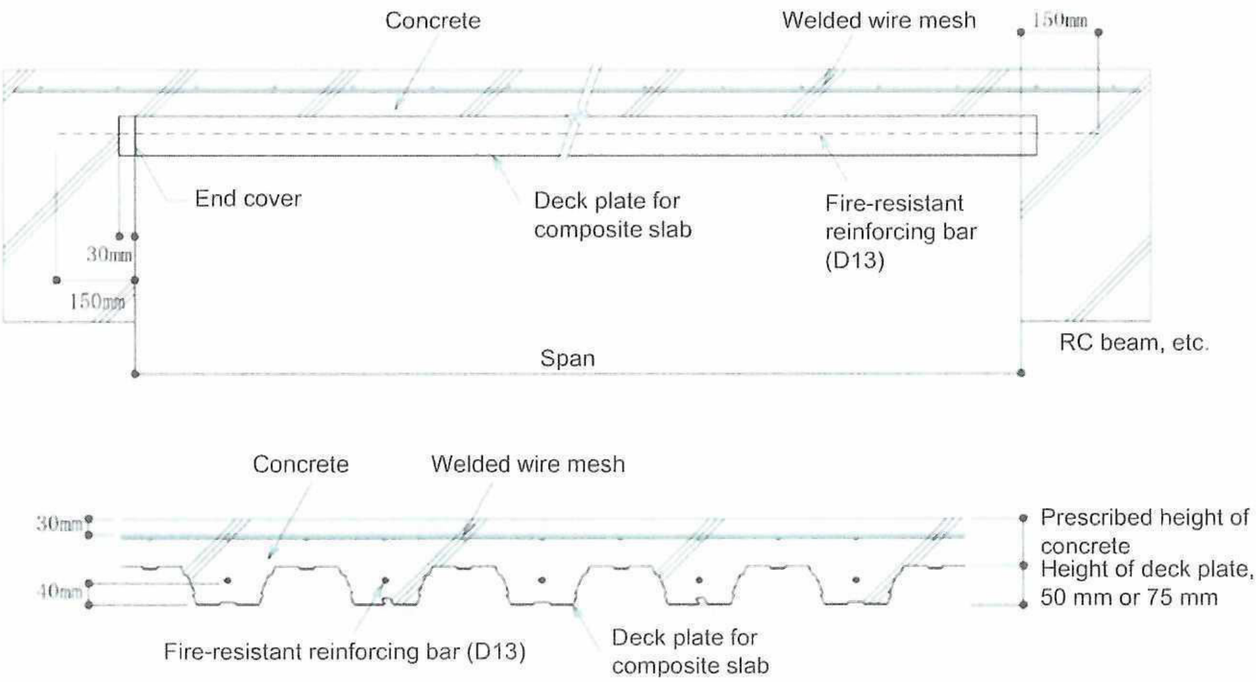
(a) Continuous support composite deck slab

Certified Fire-resistant Structure of Simple Deck Support (Steel Structure)



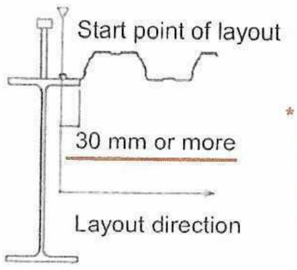
(b) Simple support composite deck slab

Certified Fire-resistant Structure of Simple Deck Support (RC Structure)



(b) Simple support composite deck slab

Example 1: Standard Details of Composite Deck Slab



* 50 mm or more in principle, but 30 mm or more is acceptable for a headed stud.

Figure 8.B Start point of layout in the width direction

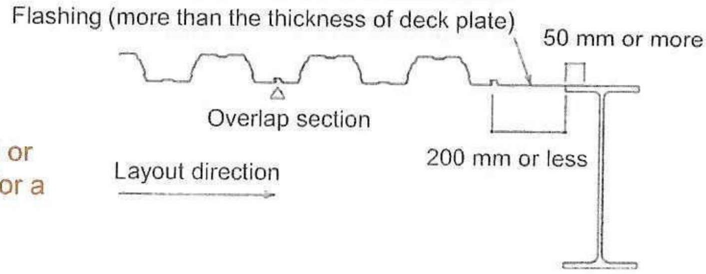


Figure 8.C Example of using flashing for adjustment

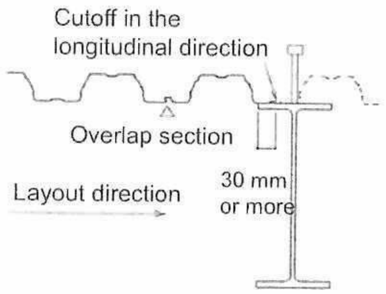


Figure 8.D Example of deck plate cut in the longitudinal direction

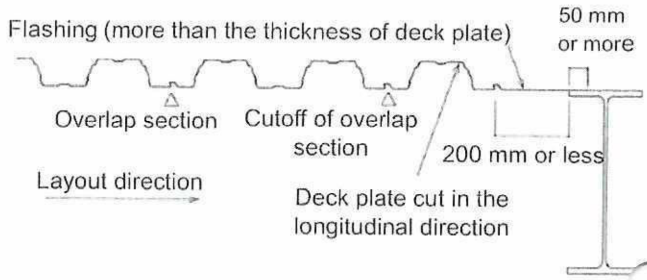
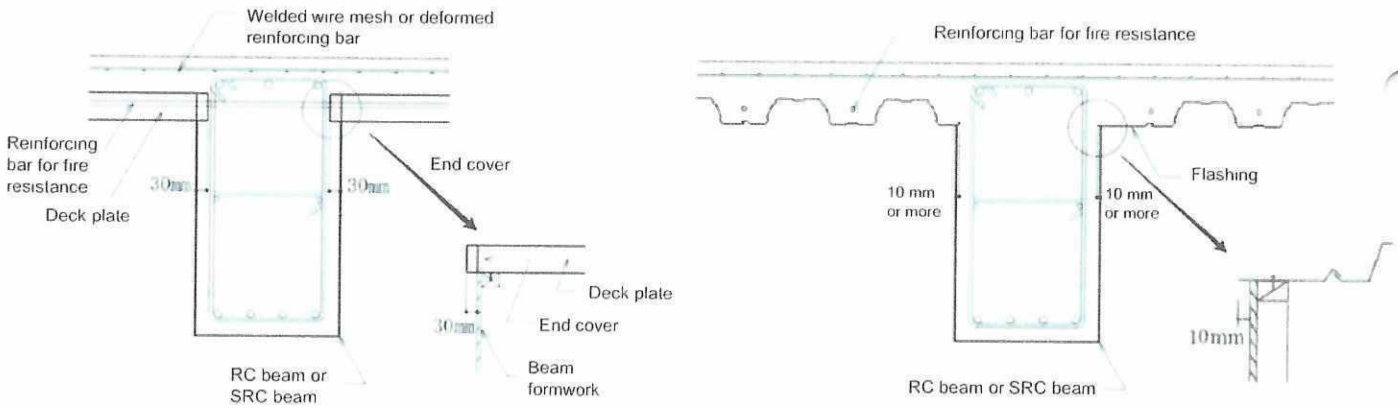


Figure 8.E Example of using the deck plate cut in the longitudinal direction and flashing for adjustment

Example 2: Standard Details of Composite Deck Slab



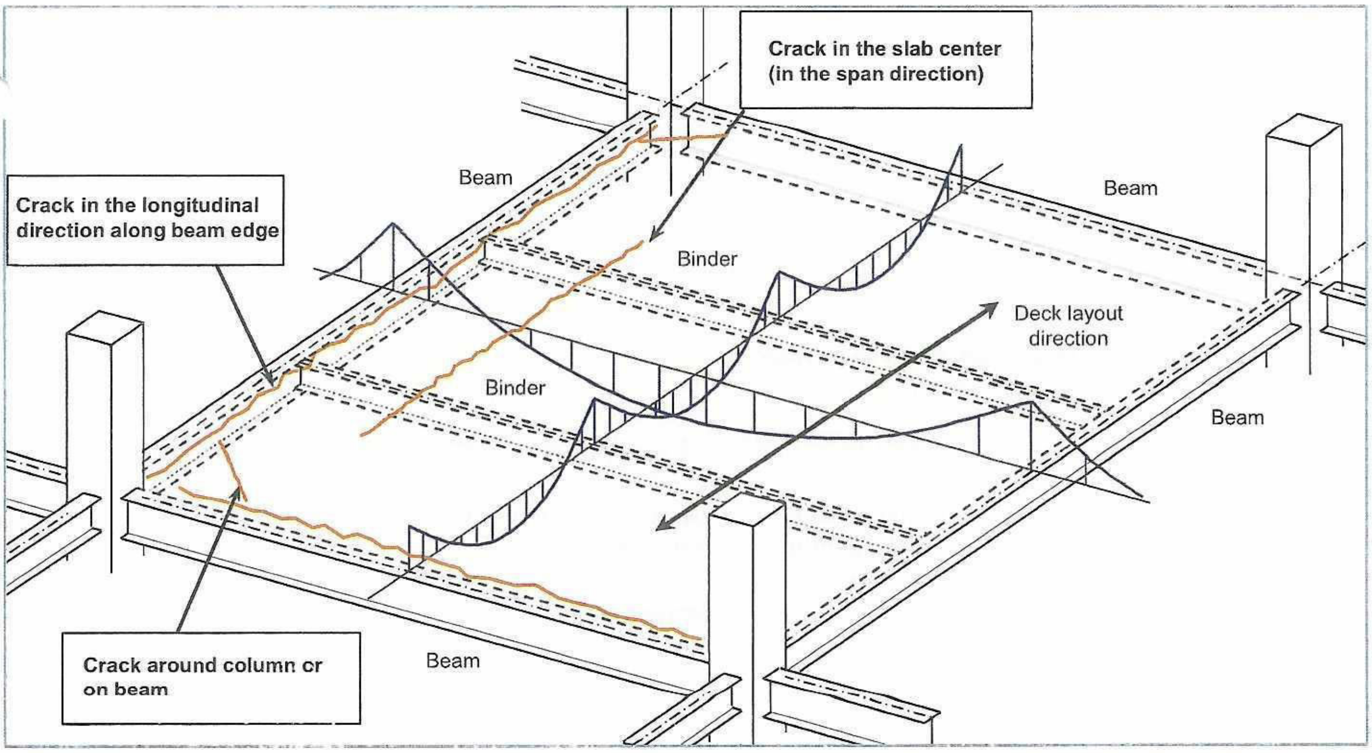
Note) This drawing shows the specifications of a simple support composite deck slab without refractory coating certified to conform to the provisions in Article 107, Paragraph 1 of the Enforcement Order.

Figure 8.G Interface with RC beam or SRC beam

Causes of Cracks on Composite Deck Slabs and Countermeasures against Cracks

2) Cracks on Composite Deck Slabs

Example of cracks on a composite deck slab



3) Cautions for Preventing the Expansion of Cracks

Cautions when designing composite deck slabs

i) Increase the stiffness of binder.

Low stiffness of a binder results in a large difference in stiffness compared to that of a beam.
⇒ Cracks occur on a beam or around a column due to the bending tensile force generated by the deformation of a slab.

ii) Install reinforcing bars to prevent the expansion of cracks.

It is preferable to **install appropriate reinforcing bars** on a beam and around a column (refer to Figures 1 and 2).

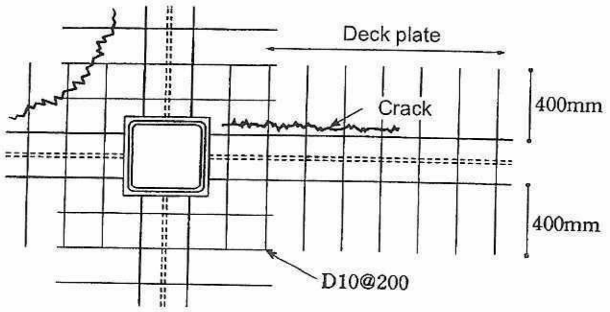


Figure 1 Example of additional arrangement of reinforcing bars on a beam

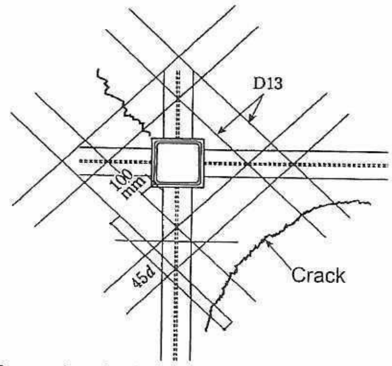


Figure 2 Example of additional arrangement of reinforcing bars around a column

3) Cautions for Preventing the Expansion of Cracks

Cautions when designing composite deck slabs

iii) Reduce the ratio of span to slab thickness and increase the amount of reinforcing bars.

- The regulations require the thickness of concrete in a composite slab to be 50 mm or more measured from the top of the deck plate ridge.
  ⇒ **Increase the thickness to 80 to 100 mm** measured from the top of the deck plate ridge.
- The regulations require the amount of reinforcing bars in a composite slab to be 0.2% or more.
  ⇒ **Increase the amount as much as possible.**

iv) Join a groove of a deck plate to a beam.

- Deck plates are prone to deformation because they are made from thin steel plates through molding.
- Welding at only one location on each deck plate is insufficient to maintain the cross-sectional shapes of the deck plates when concrete is cast onto them.

⇒ **Deformation can cause cracks on concrete.**

[Countermeasures]

* Puddle welding: **Apply puddle welding to each groove of a deck plate.**
* Headed stud: Preferably apply arc spot welding to **each groove of a deck plate** when joining it to a support beam.

3) Cautions for Preventing the Expansion of Cracks

Cautions when constructing composite deck slabs

i) Use concrete with a small water-cement ratio.

- Concrete cannot prevent dry shrinkage in principle.
  ⇒ Dry shrinkage inevitably causes concrete to develop cracks to some extent.
- However, it has been suggested that stiff consistency concrete with a reduced amount of water can help suppress the dry shrinkage of floor slabs.
- The following is the recommended concrete mix (for floors).
  Unit water content: 175 L/m^3 or less
  Slump: 15 cm
  A E water reducing agent: Apply

3) Cautions for Preventing the Expansion of Cracks

Cautions when constructing composite deck slabs

ii) Reliably install welded wire mesh in the correct position.

- Investigation result of cracked locations
  Locations where the installation heights of welded wire mesh are significantly deeper than designed heights
  ⇒ Confirmed tendencies to **develop more cracks**.
- Welded wire mesh
  Welded wire mesh is used to prevent the expansion of cracks.
  Welded wire mesh needs to be set with a predetermined concrete cover (of approximately 30 mm) for rust prevention
  ⇒ As **close to a concrete surface** as possible.
- The following are the essentials for using spacers to set welded wire mesh.
  Select the **appropriate size** while taking into consideration **concrete cover, diameters, and pitches of the welded wire mesh**.
  Use products with **suitable shapes and strength to prevent movement during concrete casting**.
  Arrange **wires at the shortest intervals possible to minimize deformation of the welded wire mesh.**

3) Cautions for Preventing the Expansion of Cracks

Cautions when constructing composite deck slabs

iii) Appropriately cure concrete after casting.

・**Ensure sufficient curing period by implementing wet curing** during the initial stage of concrete curing after casting.
Design concrete based on its 28-day strength, including when studying its resistance to negative bending moment.
In the first **3 to 4 days** after casting, **concrete can develop strength of approximately 30%** of the 28-day strength (or much lower in winter).
⇒There are many cases of cracks developing within 1 week to 1 month after concrete casting.

・In the first 4 to 7 days after concrete casting, **keep slabs free from vibration or loads.**
Composite deck slab floors appear neatly finished and resistant to loads and can actually support construction workloads even immediately after concrete casting, so **construction work have been done on them on the following days of concrete casting.**
⇒ This can lead to the **expansion of dry shrinkage cracks** and the **development of structural cracks**.

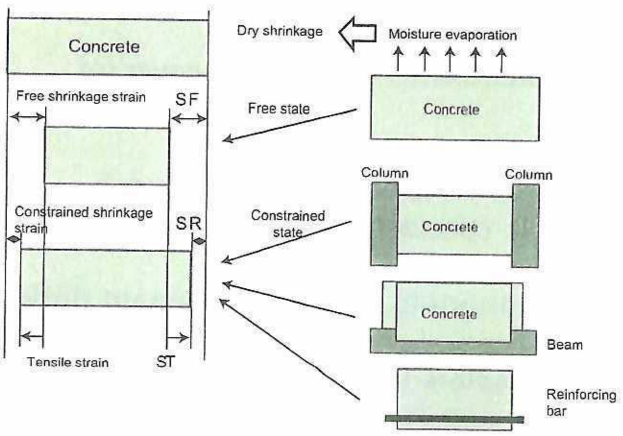
＊**Prevent abrupt dry shrinkage, and the development and expansion of cracks** in the initial stage after concrete casting.
⇒ Implement **wet curing** by sprinkling water over the cast concrete or covering it with curing sheets, in addition to enforcing a **ban on accessing the cast concrete**.

4) Crack Prevention Countermeasures

Dry shrinkage of concrete

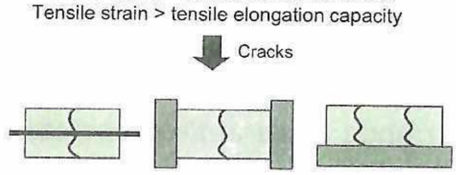
<Mechanism of cracks due to dry shrinkage>

・Ordinary concrete: Strain of approximately 500 to 800 x 10^{-6} (based on the material age of one day).
* 800 micrometers = A shrinkage of 0.8 mm in concrete with a unit length of 1 m.
・Slab concrete **undergoes significant tensile stress** when its movement is constrained by steel frame beams and columns, which behave differently from the slab under loads.



Constraining the dry shrinkage or other types of shrinkage of concrete with columns, beams, reinforcing bars, etc., causes the concrete to undergo <u>tensile strain (or tensile stress)</u>.

Tensile stress > tensile resistance stress
Tensile strain > tensile elongation capacity



4) Crack Prevention Countermeasures

Application of expansive concrete

<Countermeasure against cracks due to dry shrinkage>

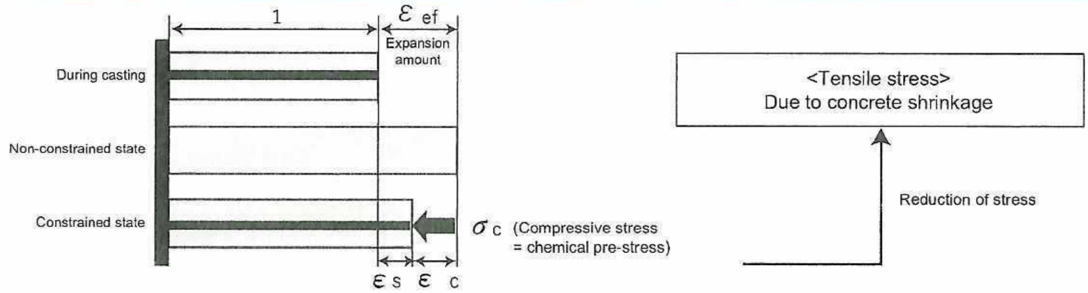
<What is **expansive concrete**?>

Definition of expansive additives: "**Admixtures that expand concrete** by forming ettringite, calcium hydrate, etc., through hydration when mixed with cement and water." (JIS A 6202: Expansive additive for concrete, 1980)

<Crack reduction effects of expansive additives>

- Introduction of compressive stress → Cancellation or reduction of tensile stress
- Reducing the concrete shrinkage ratio to a value equal to or lower than the limit value of non-constrained shrinkage rate (crack development limit)

⇒ **Allows the concrete to forcefully expand to cancel its dry shrinkage and thereby suppressing cracks.**



4) Crack Prevention Countermeasures

Application of expansive concrete

<Experiment to compare crack development between expansive and ordinary concrete>

An experiment was conducted to observe the development of cracks on two types of concrete under identical conditions simulating an actual construction site for:

- the comparison of the development of cracks on ordinary and expansive concrete, and
- the quantitative evaluation of the effects based on the comparison results.

Before casting

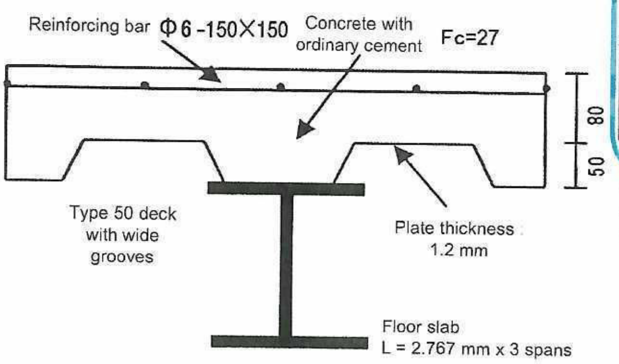
After casting

Concrete casting in the Kanto region in March 2004

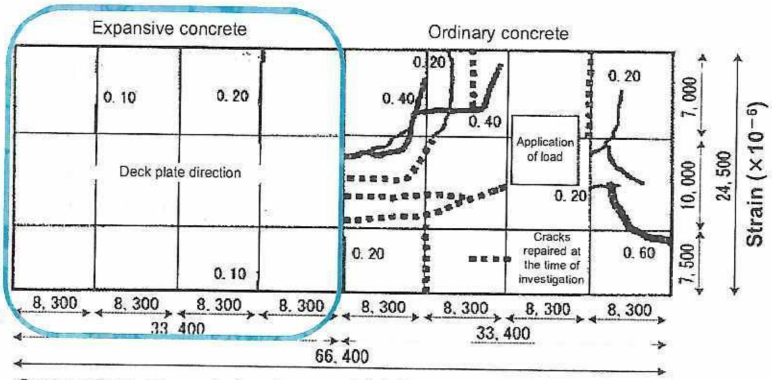
4) Crack Prevention Countermeasures

Application of expansive concrete

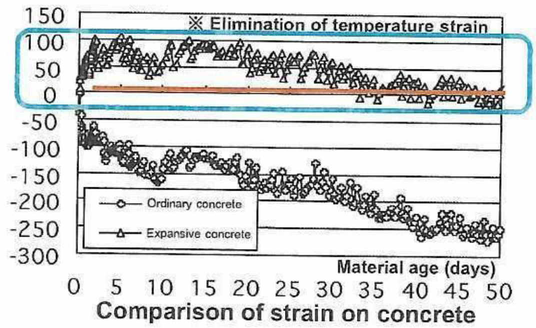
<Experiment to compare crack development between expansive and ordinary concrete>



Cross sectional specifications of composite deck slab



Comparison of crack development (at the material age of 51 days)



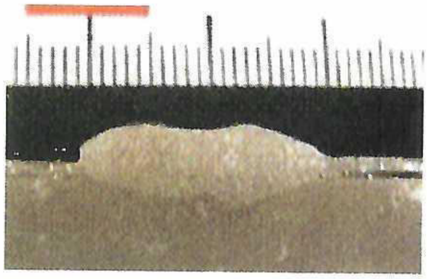
Comparison of strain on concrete

Joints of Composite Deck Slabs (Puddle Welding)

What is Puddle Welding?

A welding method to first create a hole of a pre-determined diameter on a deck plate closely placed on a beam through penetration fusing of arc heat from a low-hydrogen type welding electrode, and then subsequently build up welding metal in the hole.

External view of puddle welding



Weld penetration state

Explanations of Specifications

- **Gap between deck plate and beam:** 0 to 2 mm ← for burnout prevention
- **Welding diameter:** 18 mm or more ← a target diameter of about 20 mm (similar to the size of a one-yen coin)
- **Beam flange thickness:** 6 mm or more ← for burn-through prevention
- **Required qualification of a welder:** certification of the basic class of either one of the following qualifications.

  JIS Z 3801 (Standard qualification test and acceptance requirements for manual welding technique)

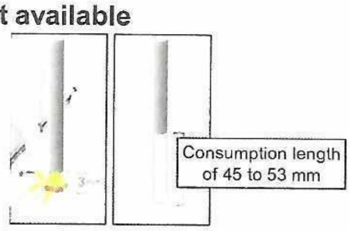
  JIS Z 3841 (Standard qualification test and acceptance requirements for semi-automatic welding technique)

- **Allowable shear force at one location of puddle welding**

Thickness of deck plate	Long-term	Short-term
1.2 mm	4,900 N	1.5 times that of the long-term
1.6 mm	7,350 N	Same as above

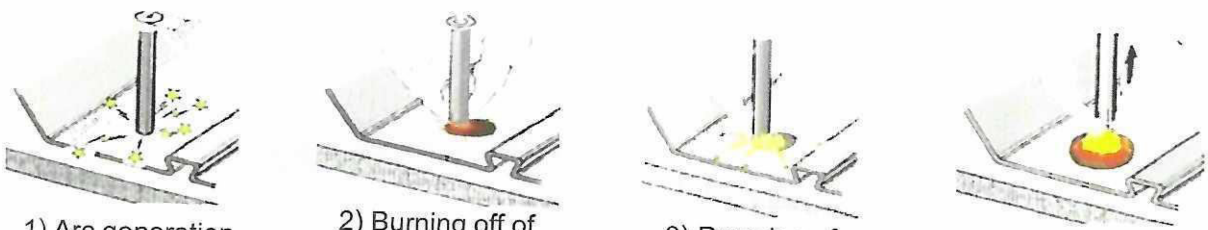
- **Method for confirming electric current when a galvanometer is not available**

Confirmation that the consumption length of a welding electrode is 45 to 53 mm when performing welding for 10 seconds while keeping the arc length at approximately 3 mm using an unused low-hydrogen type shielded metal arc welding electrode.



Welding Procedures

1. **Preparation**
   1) Closely place a composite deck plate on the flange of a beam while ensuring that the gap between them is kept within **2 mm or less**, and temporarily fasten them together.
   2) **Remove dust and moisture** from the location of puddle welding.
   3) Prepare a **new** low-hydrogen type shielded metal arc welding electrode and **unseal it immediately before welding**.
2. **Environmental conditions for welding**
   The **environmental conditions** such as temperature and weather when performing welding shall be **as specified in JASS6**.
3. **Confirmation of electric current**
   Measure electric current with a galvanometer, etc.
4. **Welding electrode manipulation method**



1) Arc generation　2) Burning off of deck plate　3) Pressing of electrode and welding　4) Shaping