Third Brazilian Meeting
on
the Integration of Research-Design-Production
in the Field of Precast Concrete

Precast Concrete
Research, Design and Construction
in Japan

Minehiro Nishiyama

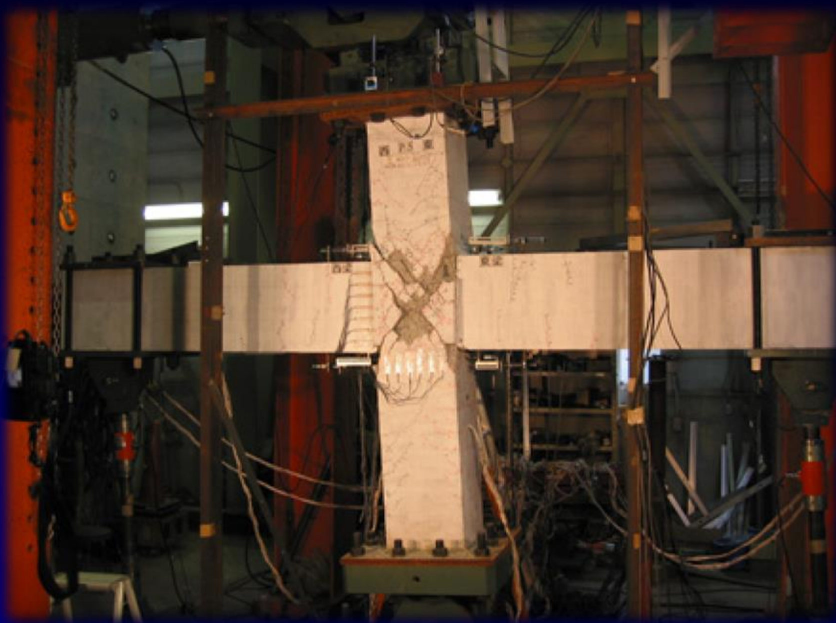
Kyoto University

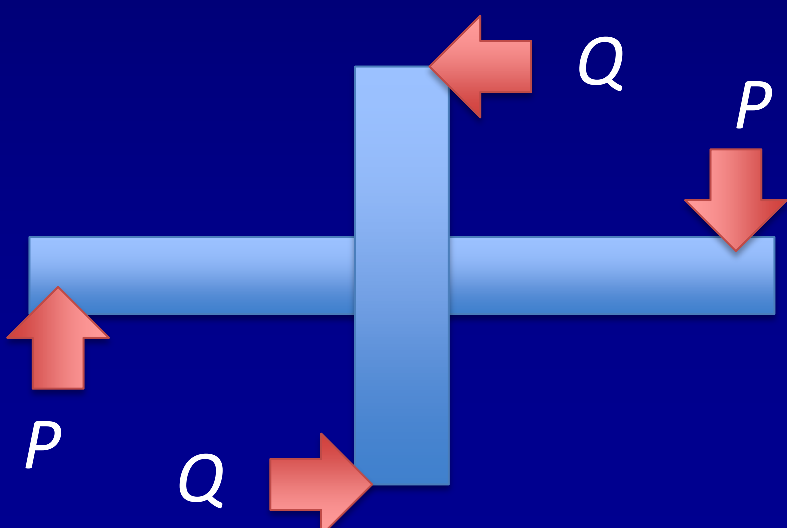
Japan

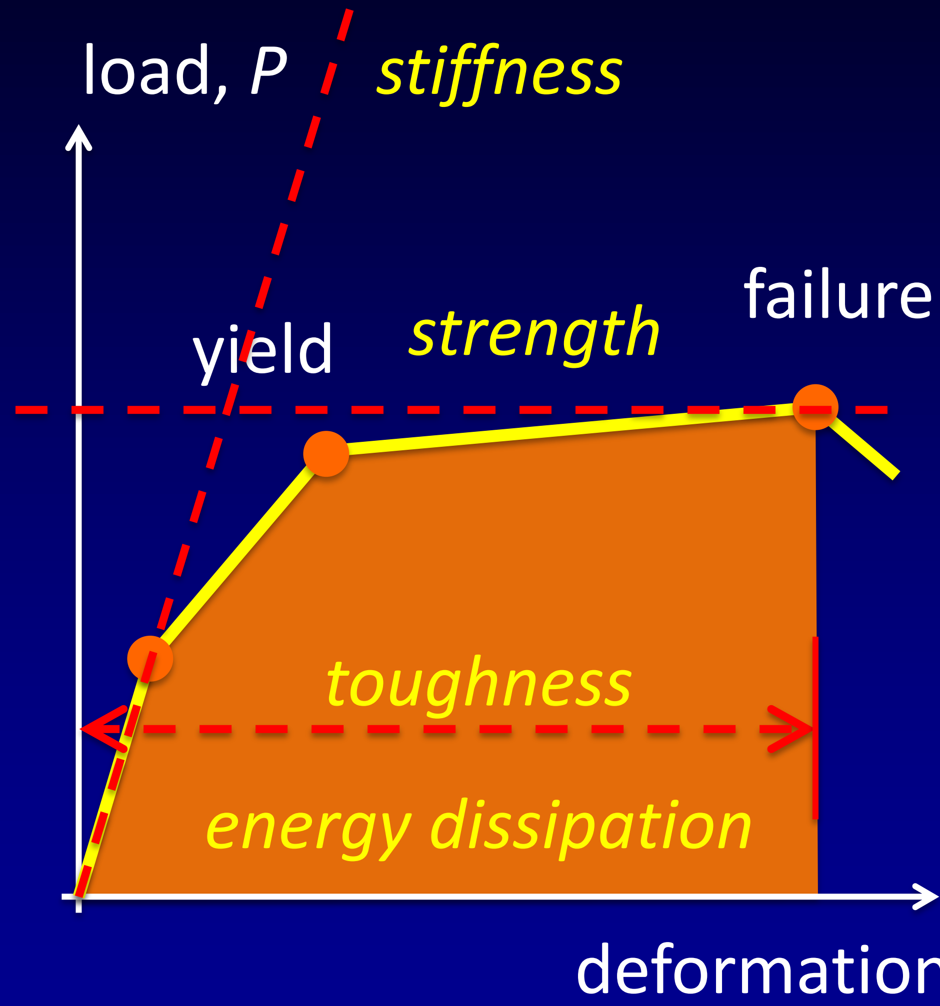
precast concrete in Japan

- "seismic resistance" or "earthquake resistance" is a main concern.
- preacast frames should be "equivalent to cast-in-situ frames" in terms of seismic performance.
- "equivalence" in seismic performance
  - stiffness, strength, toughness (ductility), energy dissipation
- the same "integrity" as cast-in-situ

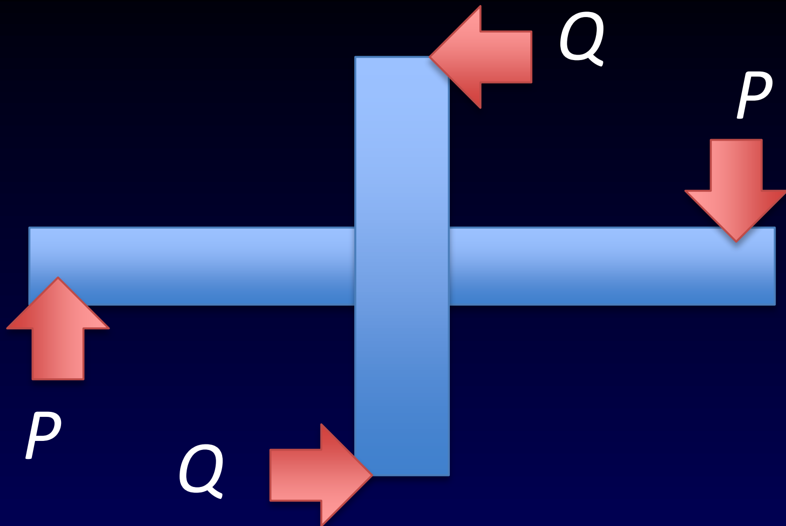
equivalence in seismic performance

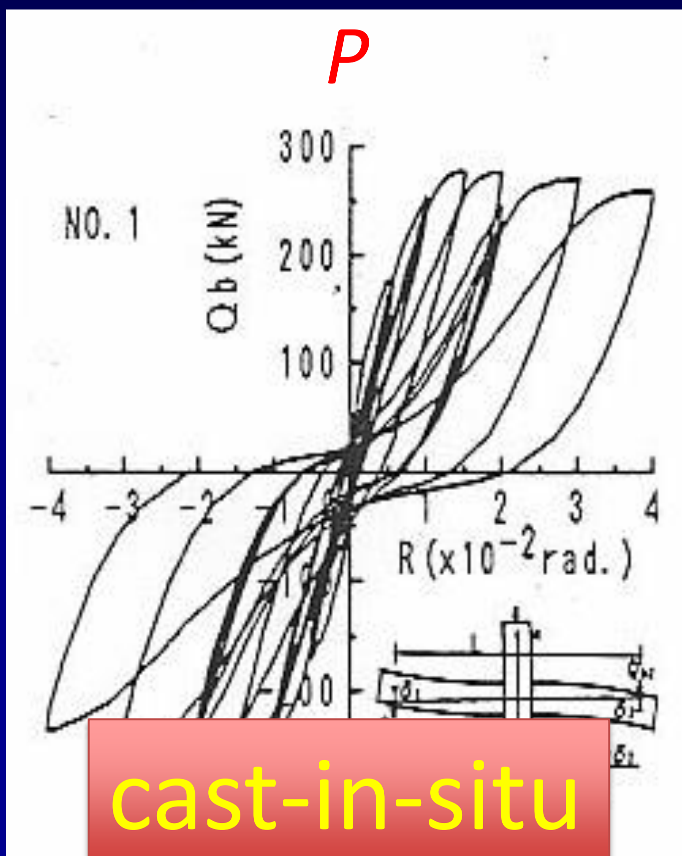


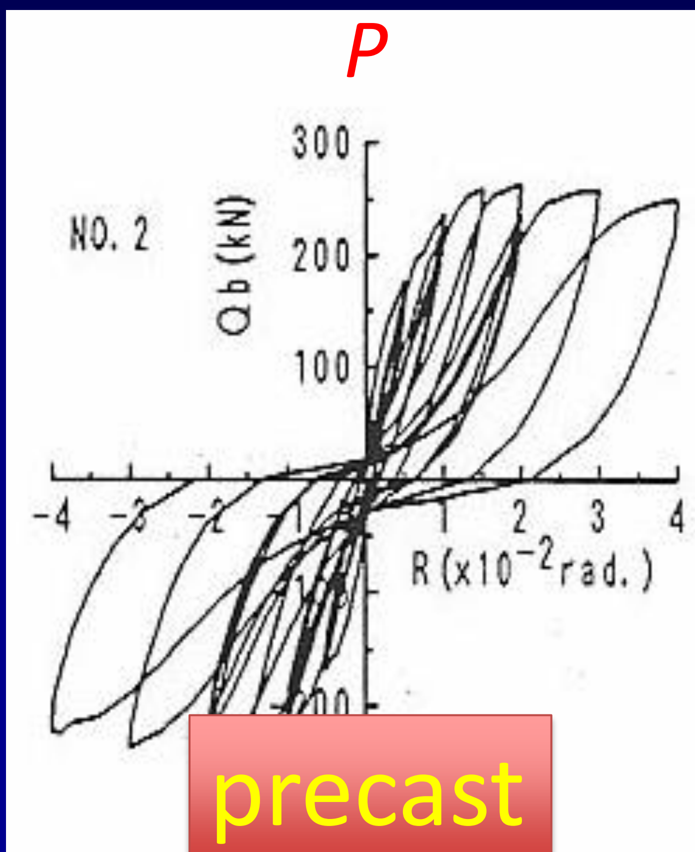




which is precast?
which is cast-in-situ?







contents

- *precast slab*
  - codes
  - design
  - construction
- *precast frames*
  - equivalent to cast-in-situ or monolithically emulation
    - confirmed by experiments
  - design
  - construction
- *outstanding precast buildings*

precast concrete in Japan

- *pros*
  - high-quality
  - eco-friendly and saving forest
  - lots of reinforcement needed for seismic resistance are arranged at the factory
- *cons*
  - higher cost than cast-in-situ
  - unable to change member dimensions at the site
  - unable to make holes at the site
  - long, large and heavy members cannot be transported

precast floor in Japan

- "Full" precast floor
  – precast floor without topping concrete
  – very few application
  – tight and strong connection between panels
  – when concreting is difficult because of, e.g., steeply slanting roof
- "Half" precast floor (composite slab)
  – precast floor with topping
  – many applications

design of precast floors in Japan

codes and guidelines for design of precast floors

- AIJ: Architectural Institute of Japan
  - Recommendations for Design and Construction of Prestressed Concrete Composite Slabs
  - AIJ Guidelines for Structural Design of Precast Concrete Connection Emulating Cast-in-place Reinforced Concrete (2002)
  - Standard for Structural Design and Construction of Prestressed Concrete Structures (PC standard)
  - AIJ Standard for Structural Calculation of Reinforced Concrete Structures (RC standard)

Recommendations for Design and Construction of Prestressed Concrete Composite Slabs

- published by Architectural Institute of Japan or AIJ in 1994
- pre-tensioned composite slabs with cast-in-place topping
- allowable stress design for service load
- ultimate strength design for overload (load factor x service load)

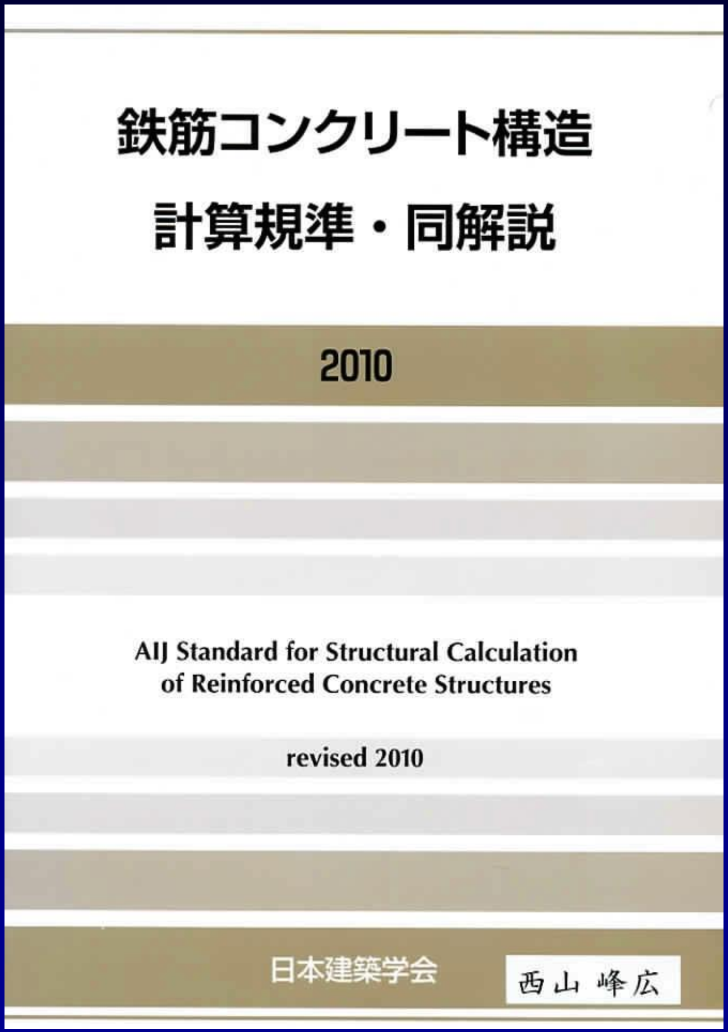
AIJ Guidelines for Structural Design of Precast Concrete Connection Emulating Cast-in-place Reinforced Concrete (2002)

- based on PRESSS (PREcast Seismic Structural Systems)
- frames equivalent to monolithically cast reinforced concrete moment resisting frames
- equivalent in strength, stiffness and ductility

Standard for Structural Design and Construction of Prestressed Concrete Structures (PC standard)

- monolithically cast and precast prestressed concrete buildings
- ultimate strength design for $1.2D+2.0L$, $1.7(D+L)$ and $D+L+1.5E$

AIJ Standard for Structural Calculation of Reinforced Concrete Structures (RC standard)



- allowable stress design for conventional reinforced concrete buildings
- ultimate strength is calculated according to other standards and guidelines

design manuals for commercial products

- all the precast slab products available commercially in Japan have their design manuals
- structural designers
  - follow design manuals
  - do not need to calculate
  - do not need to know what kind of performance they have to check
  - do have to worry about money

design summary

- RC (reinforced concrete) slabs:
  - allowable stress design
    - $G+P$ (G: dead load, P: live load)
  - according to RC standard
- PC (pre-tensioned concrete) slabs:
  - allowable stress design for service load and ultimate strength design for overload
    - $G+P$, $1.7(G+P)$, $1.2G+2.0P$
  - mainly according to Recommendations for PC composite slabs and PC standard

performance required

- Service load
  - carry service load
  - transfer service load to beams, walls and columns
  - deformation (< L/300) and vibration
- Earthquake load
  - transfer horizontal load from upper floors to columns and walls in lower floors
  - rigid and strong enough to make assumption in structural calculation valid -> diaphram action
- Other issues
  - fire resistance, noise and heat insulation, and durability

design issues *before* topping is cast

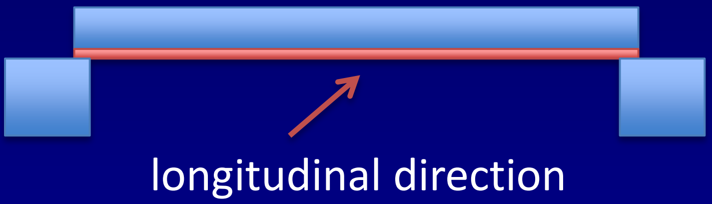
- structural component
  - precast slabs
- allowable stress design for vertical load
  - dead load
  - work (0.7 – 1.5 kN/m^2) and impact (20% of cast-in-place concrete) loads
  - load from topping concrete
- support condition
  - one-way

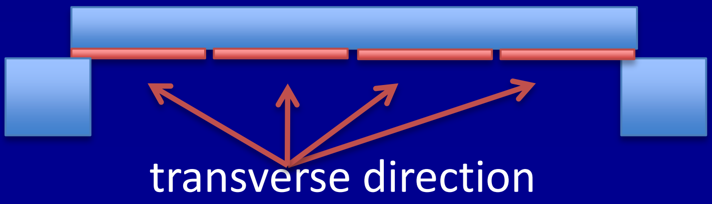
design issues *after* topping is cast

- structural component
  - precast slabs working with topping concrete
- allowable stress design for vertical load
  - dead load (precast slabs, cast-in-place concrete and other components)
  - live, work and impact loads
- support condition
  - one-way
  - two-way if precast slab units are tightly connected

design for *out-of-plane flexure* in *pre-tensioned* slabs (*service load*)

- longitudinal direction (one-way)
  - pc at middle of span
    - allowable stress and strength designs
  - rc at ends
    - allowable stress design
- transverse direction
  - rc at all parts
    - allowable stress design





design for *in-plane shear* (*seismic load*)

- Shear stress should be carried by cast-in-place topping concrete only
  - no shear transfer mechanism between precast slab units

$$Q_A / l \times t \leq f_s$$

  - Q_A: shear force to be transferred during a moderate earthquake (C_o=0.2)
  - l, t: width and thickness of cast-in-place concrete
  - f_s: allowable shear stress in concrete for a moderate earthquake

allowable stress in concrete

Service load		Earthquake load (C_o=0.2)	
Compression	Shear	Compression	Shear
1/3 x F_c	1/30 x F_c 0.49+1/100 x F_c	2 x 1/3 x F_c	1.5 x 1/30 x F_c 1.5 x (0.49+1/100 x F_c)

F_c: design compressive strength of concrete

allowable stress in concrete (in case of design strength, F_c = 30 MPa)

Service load		Earthquake load (Co=0.2)	
Compression	Shear	Compression	Shear
10	0.79	20	1.185

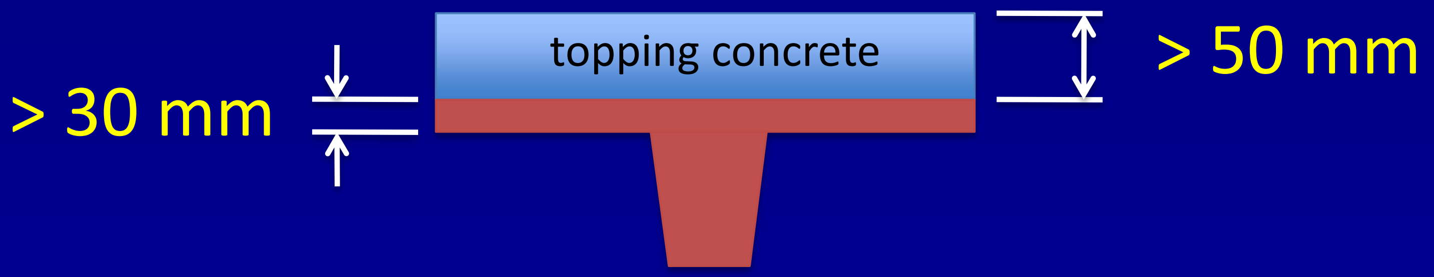
F_c: design compressive strength of concrete

design for *out-of-plane shear*

- same as design for in-plane shear
- not critical in practical design

reinforcing details and thickness

- minimum reinforcement ratio = 0.2%
  - for precast slab and topping
- minimum thickness for total slab = 80 mm
- minimum thickness for topping = 50 mm
  - for precast slab = 30 mm

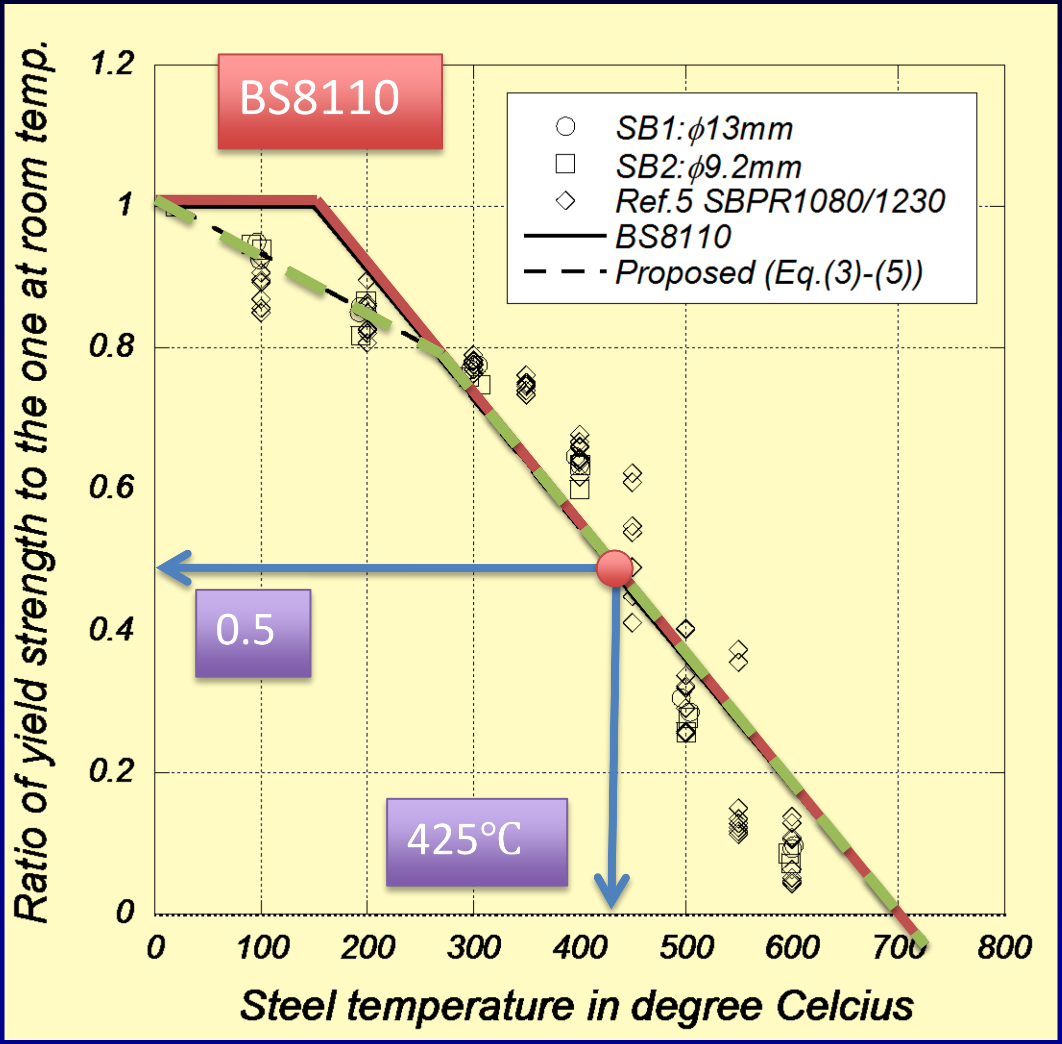


fire resistance for pre-tensioned floor slabs

- minimum cover thickness to bar and strand

fire resistance (hours)		0.5		1		2	
member		beam column	floor	beam column	floor	beam column	floor
member minimum thickness (mm)		150	70	150	70	200	100
minimum cover thickness (mm)	bar	30	20	35	30	60	45
	strand or wire	30	20	45	40	75	55

Fire resistance of prestressing bar and strand



- 50% reduction in yield strength

construction of precast floors in Japan

construction examples of precast *reinforced concrete* slabs

- precast slab unit construction at site

construction examples

- precast slab unit construction at site

construction examples

- precast slab units installation

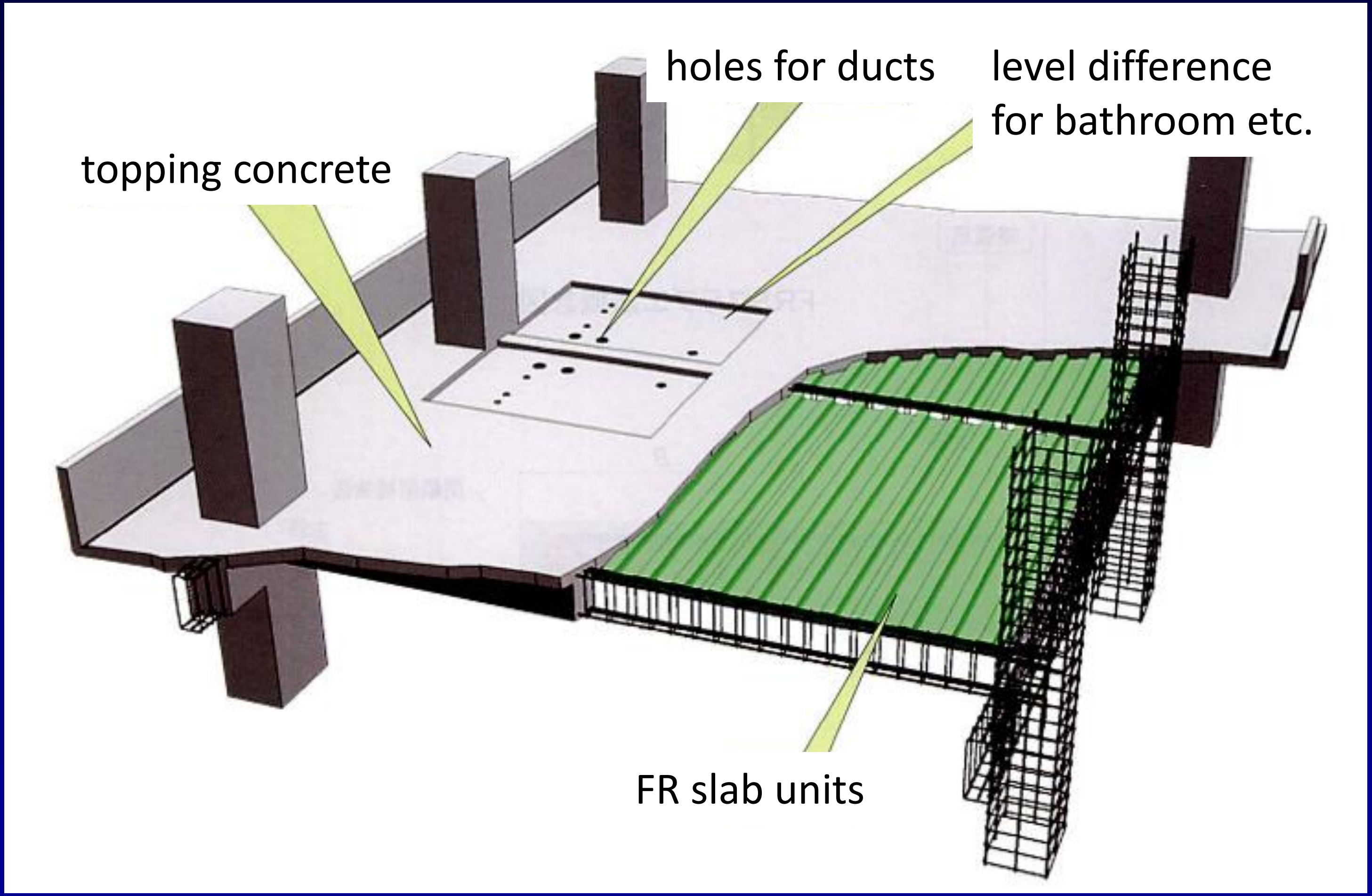
construction examples

- arrangement of reinforcement in topping

construction examples

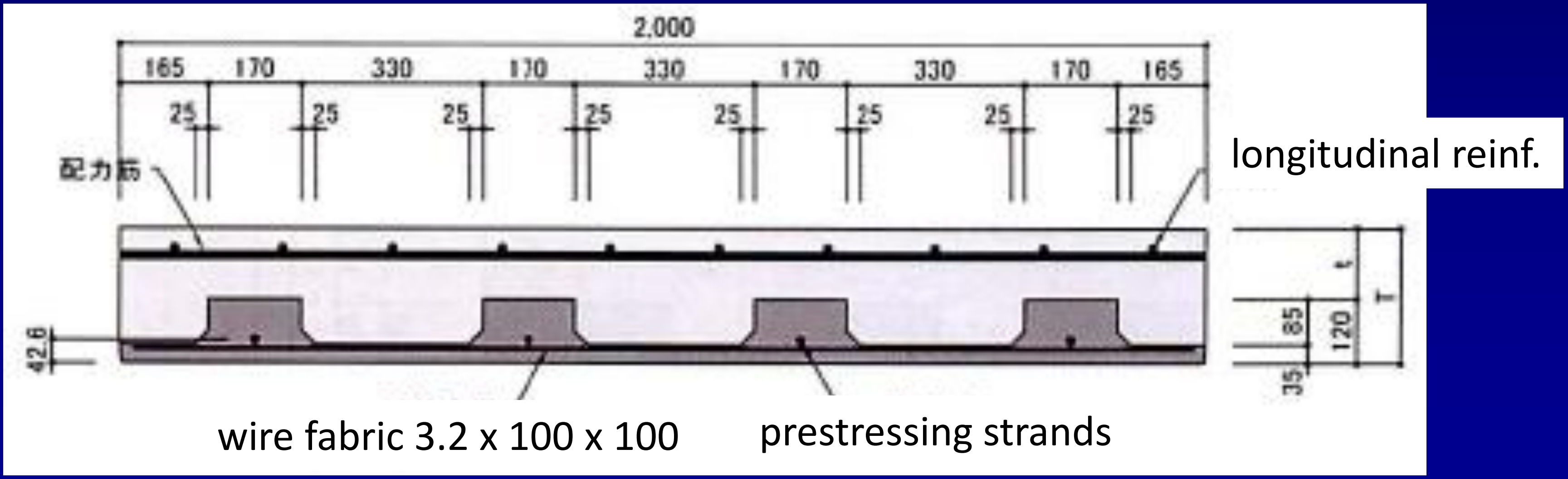
- supports

example of precast pre-tensioned floor (FR slab unit: Fuji PS)



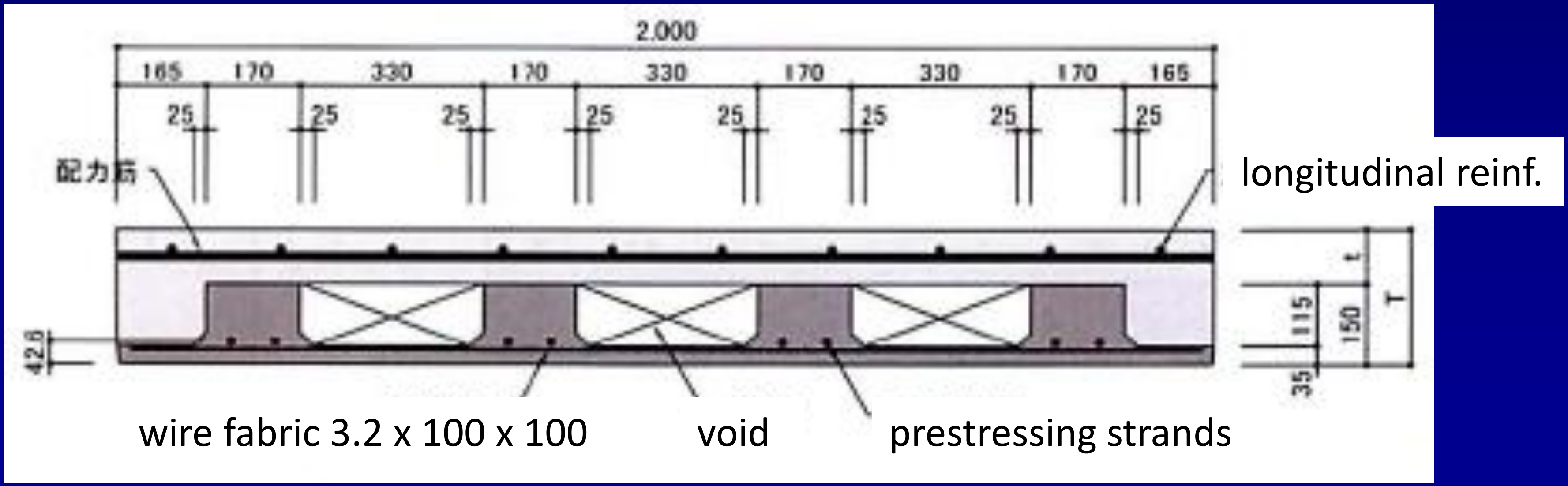
FR12

- panel weight: 1.56 kN/m^2
- total weight: 4.8 – 6.72 kN/m^2
- average topping thickness: t + 55 mm
- span length: 7 – 10 m



FR15V15

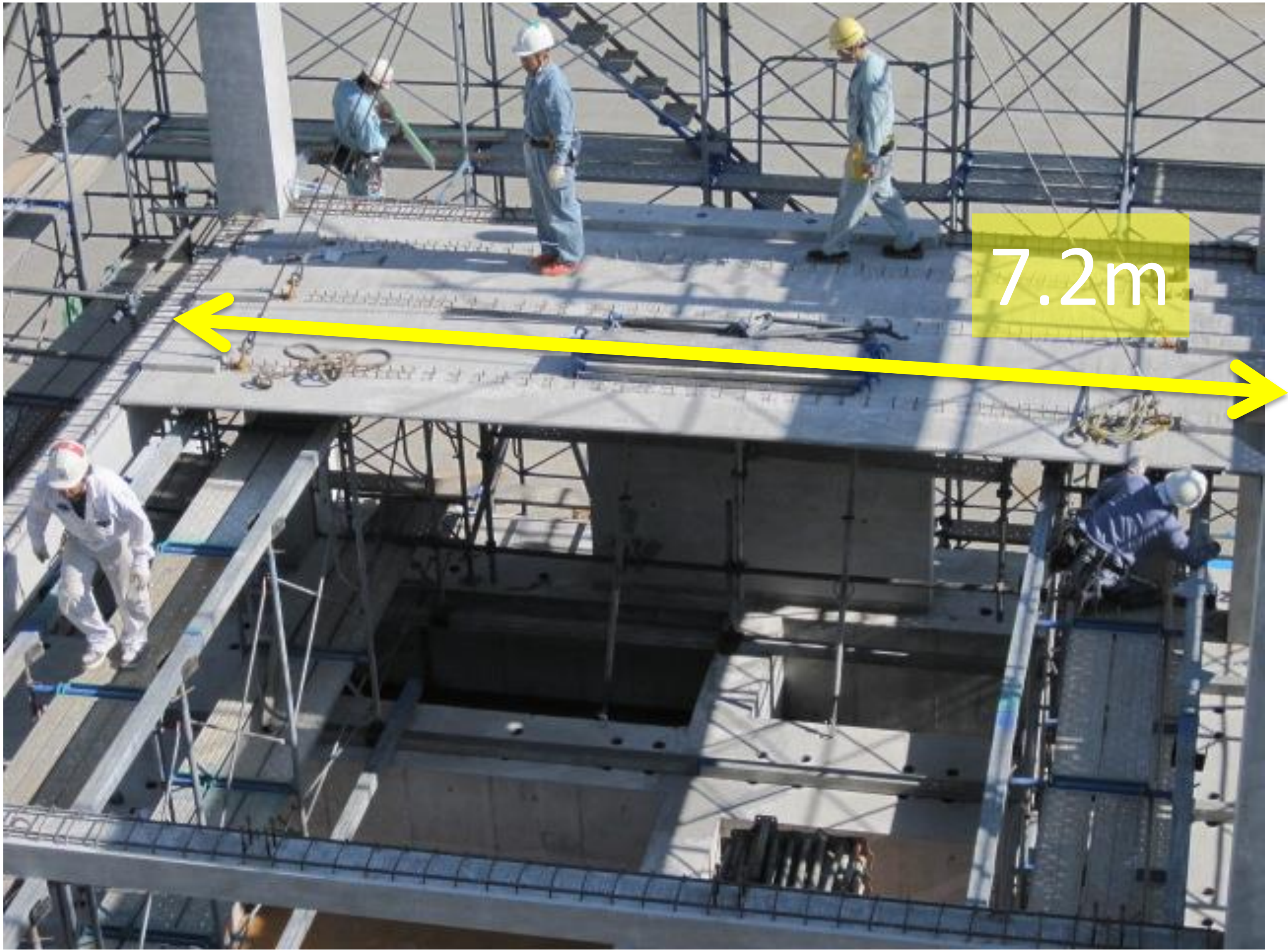
- panel weight: 1.81 kN/m^2
- total weight: 6.11 – 7.31 kN/m^2
- average topping thickness: *t* + 30 mm
- span length: 11 – 13 m

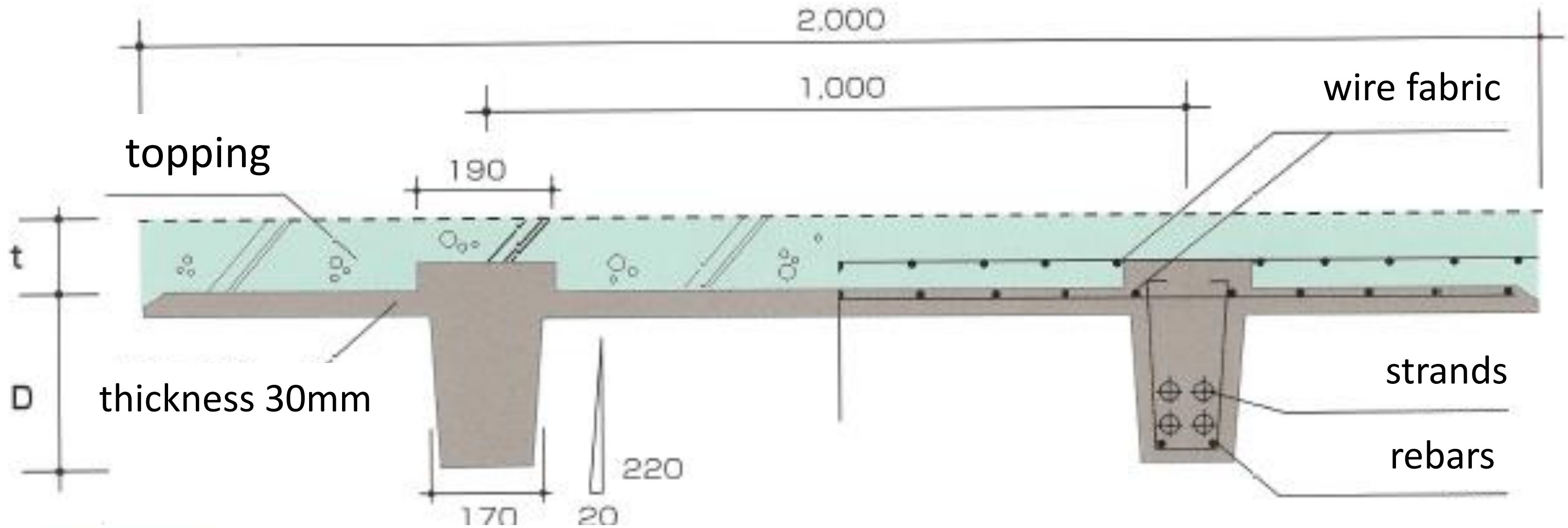


CS precast floor unit

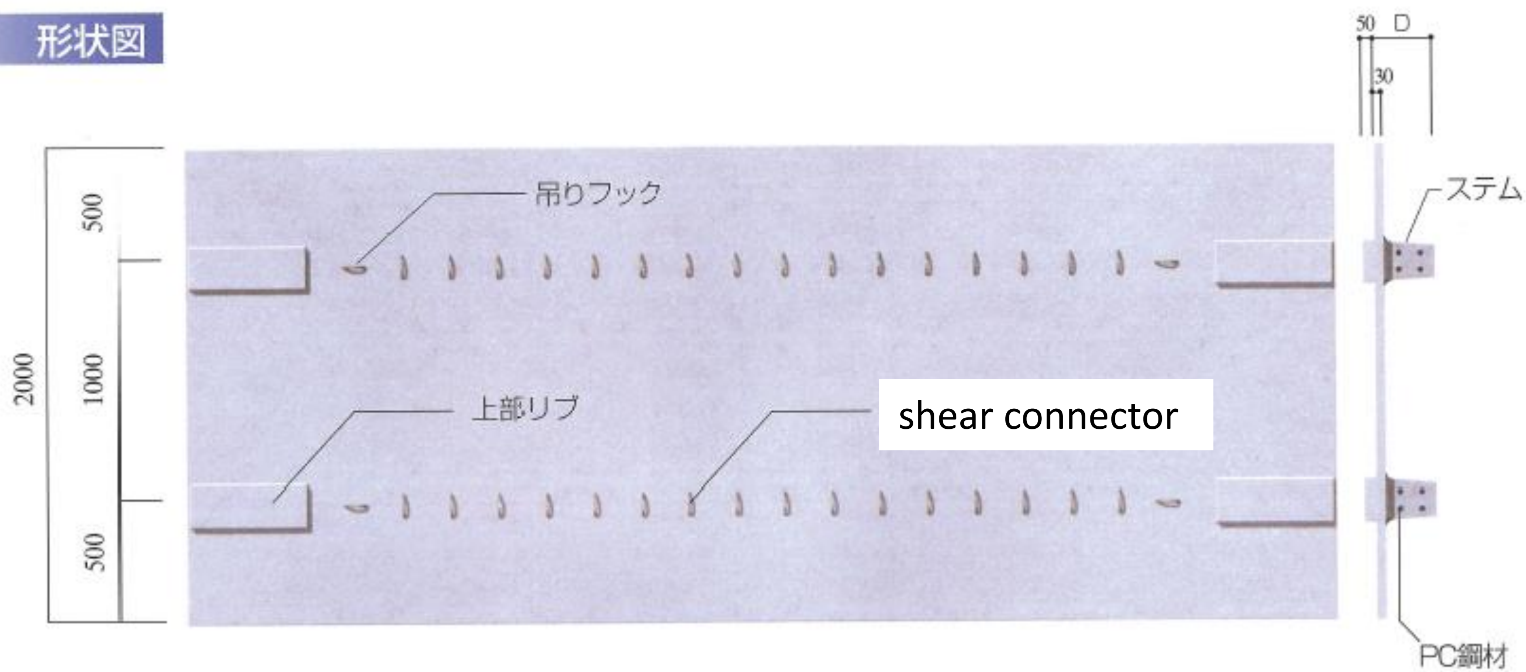
P. S. Mitsubishi Construction Co., Ltd.

Installation of slab panels

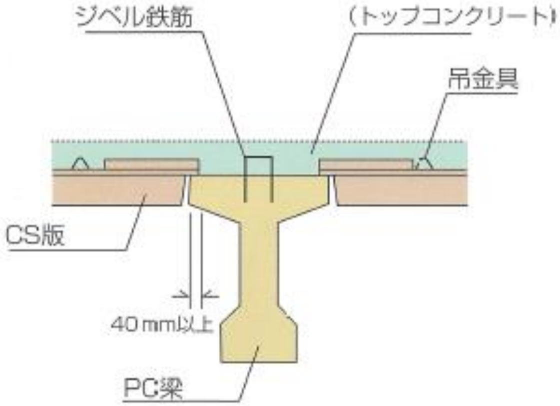



2,000
1,000
190
topping
wire fabric
t
D
thickness 30mm
strands
rebars
220
170
20

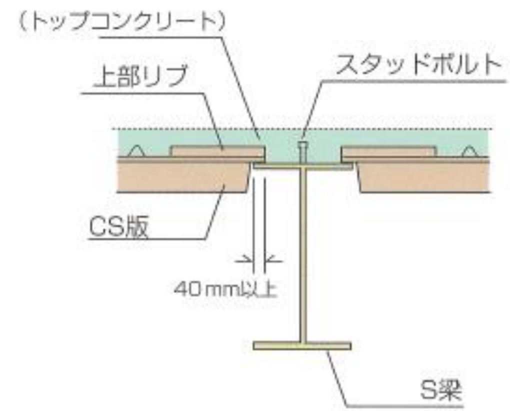
形状図


50
D
30
吊りフック
ステム
500
1000
2000
500
上部リブ
shear connector
PC鋼材

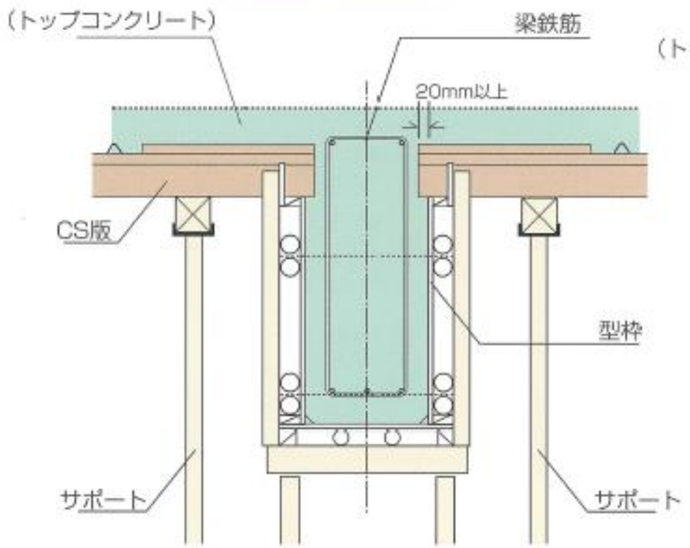
PC造への架設（切り欠き支承）



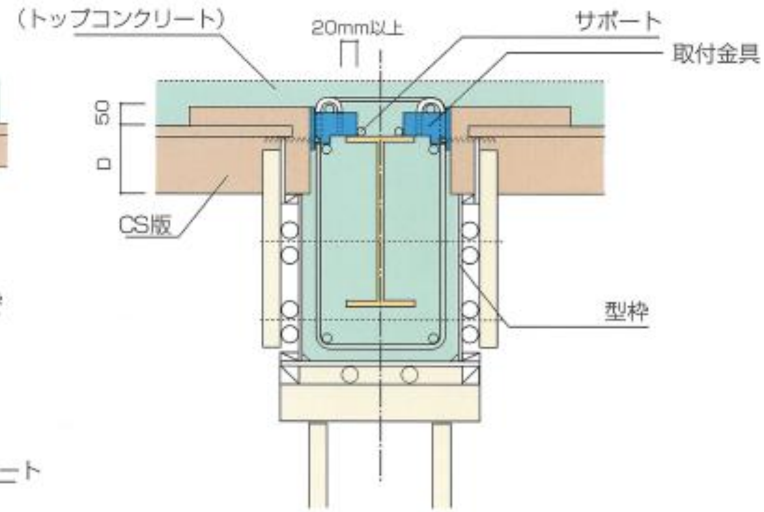
S造への架設（切り欠き支承）



RC造への架設（のみ込み支承）



SRC造への架設（のみ込み支承）



CS panel

	CS-15	CS-20	CS-25
D (mm)	150.0	200.0	250.0
self-weight (N/m^2)	123	141	158
floor weight (N/m^2)	363	381	398
span length (m)	4 – 6.5	5.4 – 7.6	6.4 – 9.0

connection between panels

welding of connecting reinforcement

single-T slab

Construction of PT

Construction of PT

Construction of PT

Construction of PT

Construction of PT

precast frames

precast construction

PCa : Pre-cast   PCF : Pre-cast Form

Column
using PCF

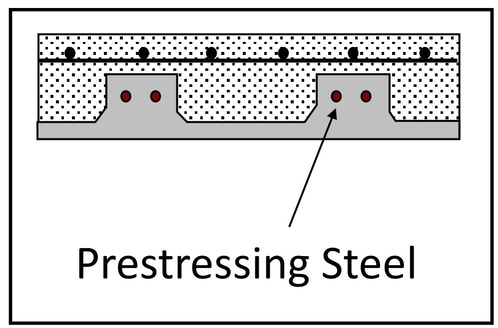
Half PCa Girder

Half Precast Slab（Balcony）

Half PCa Slab

PCa Column

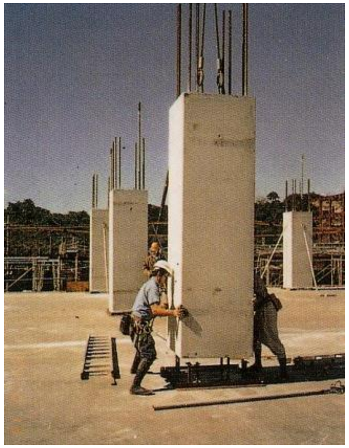
PCa Girder



Half PCa Slab
with Prestressing

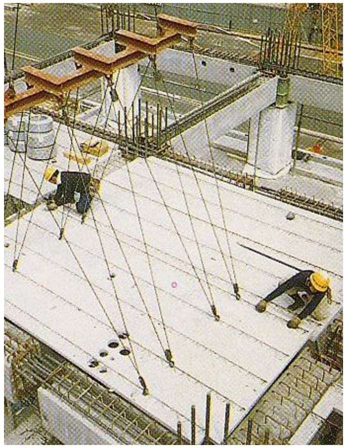
Courtesy of Dr. Tsutomu Komuro
Taisei Corporation

Construction method（Construction work flow）

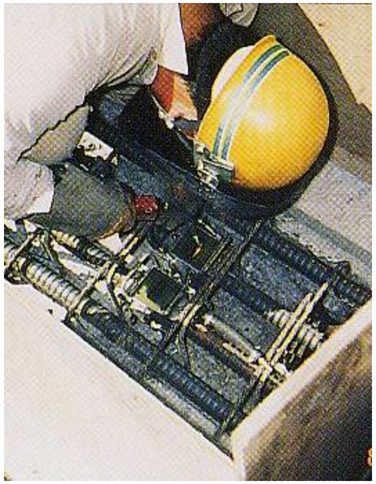


① Erection of PCa Column

② Placing of PCa Girder



③Placing of PCa Slab

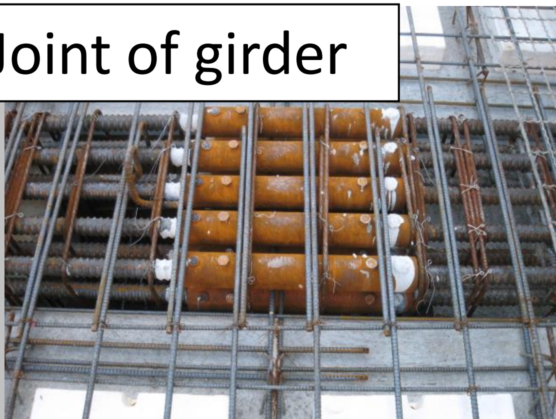


④Joint of Re-bars

⑤Casting Concrete

joints for rebars

Joint of girder



Mechanical joint

Joint by welding

Joint of column

Mechanical joint
(Cast-in-situ)

Mechanical joint
(Pre-cast)

Anchor plate

mechanical properties specified in JIS G 3112 for reinforcement

Grade	yield strength or 0.2% offset yield strength, N/mm^2	tensile strength, N/mm^2	elongation, %
SR235	≥ 235	380 ~ 520	≥ 20 or ≥ 24*
SR295	≥ 295	440 ~ 600	≥ 18 or ≥ 20
SD295A	≥ 295	440 ~ 600	≥ 16 or ≥ 18
SD295B	295 ~ 390	≥ 440	≥ 16 or ≥ 18
SD345	345 ~ 440	≥ 490	≥ 18 or ≥ 20
SD390	390 ~ 510	≥ 560	≥ 16 or ≥ 18
SD490	490 ~ 625	≥ 620	≥ 12 or ≥ 14

mechanical properties for high-strength reinforcing bars

Grade	yield strength or 0.2% offset yield strength, N/mm^2	yield strength/ tensile strength, or tensile strength	elongation	
			length of yield plateau, %	elongation, %
longitudinal reinforcement				
USD685A	685 ~ 785	≥ 85 %	≥ 1.4	≥ 10
USD980	≥ 980	≥ 95 %	-	≥ 7
shear reinforcement				
USD785	≥ 785	≥ 930 N/mm^2	-	≥ 8
USD1275	≥ 1275	≥ 1420 N/mm^2	-	≥ 7

joints for reinforcing bars

mechanical joint

splice joint

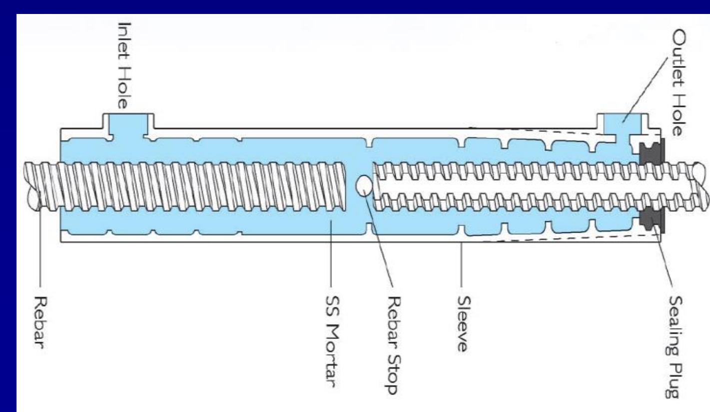
arc welded splice

gas pressure welded splice

threaded rebar joint

Threaded bar and sleeve with grout mortar injected are commonly used for high-rise buildings.

sleeve with grout mortar injected



welded joint

grades for joints of reinforcing bar under cyclic loading simulating earthquake excitation Building Center of Japan (BCJ)

- *Class SA*: *strength, stiffness and ductility* are almost equivalent to those of rebars themselves,
- *Class A*: *strength and stiffness* are almost equivalent, while other performances are slightly inferior to those of rebars,
- *Class B*: *strength* is almost equivalent, while other performances are inferior to those of rebars,
- *Class C*: every performance is inferior to those of rebars

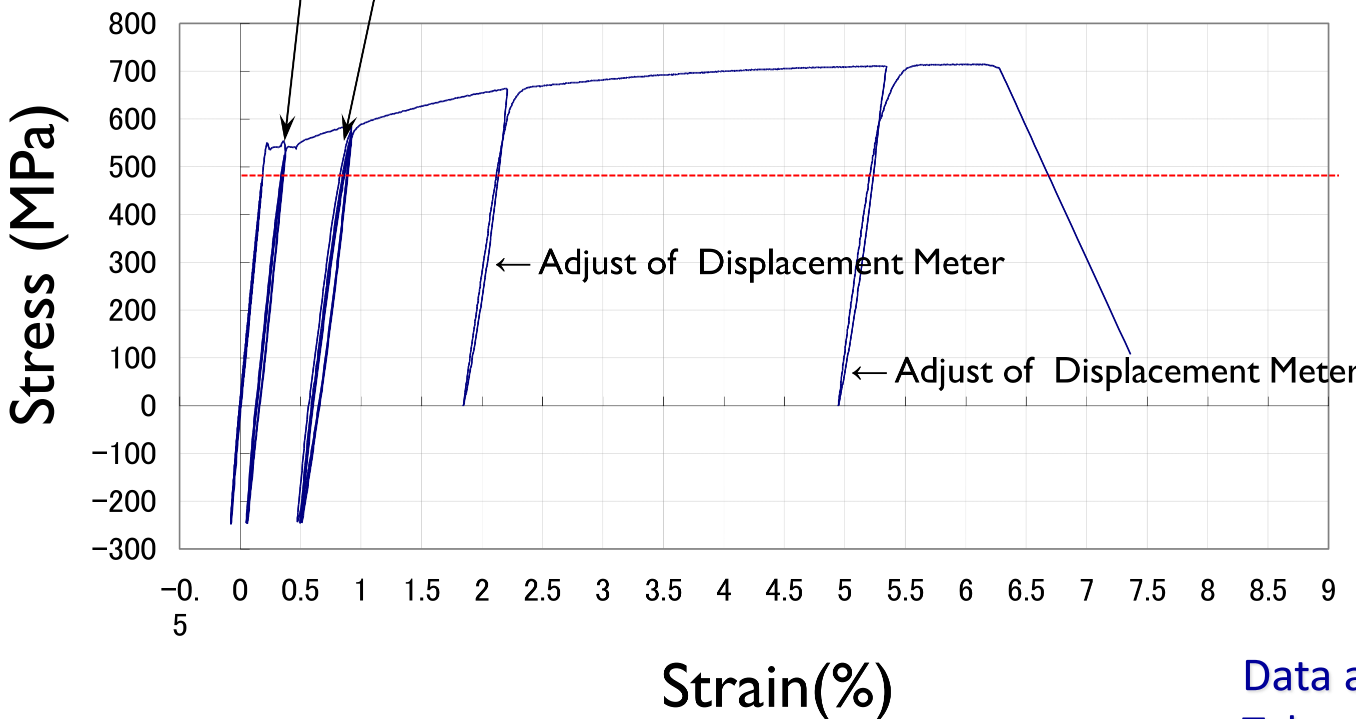
loading sequences of cyclic loading tests on joints for rebars

Alternative (tensile and compressive) and repeated loading tests in plastic region

Rebar joint performance requirements for SA rank in Japan are confirmed

+2εy(tension) ⇔ -0.5σy(compressive) x 4 cycles

+5εy(tension) ⇔ -0.5σy(compressive) x 4 cycles



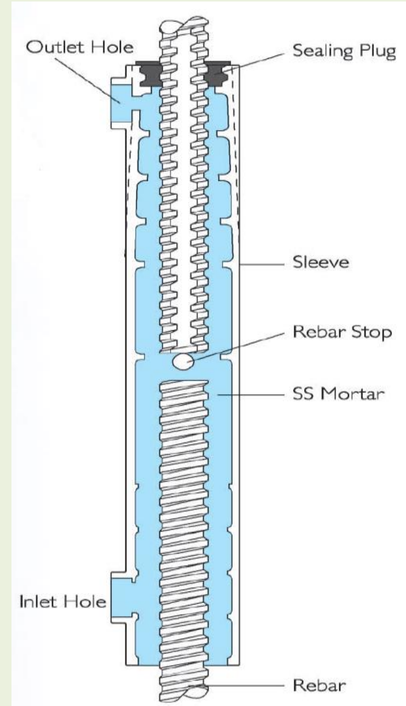
Data and photo: Courtesy of Tokyo Tekko Co., Ltd. (TTK)

Grouted Mechanical Rebar Splice

Slim Sleeve
for Cast-in-Situ
Application

Super UX
for Precast Application

Non-metallic, non-shrinkage, high strength grout to be injected into the sleeve



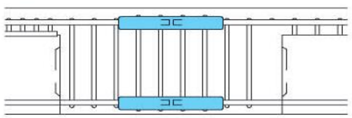
Worldwide Major Approvals and Certifications

- Japan - BCJ Class SA
- Rumania - SR EN 13515-1
- USA & Middle East - ICC-ES AC133 Type 2
- Mongolia – National Standard
- Asia BS 8110 Part 1
- Bulgaria - Technical Approval
- Singapore - Housing & Development Board
- Others

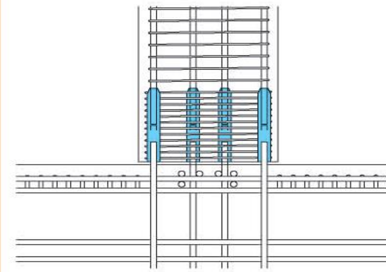
NMB
SPLICE-SLEEVE SYSTEMS

Splice Sleeve System for Precast Application

Slim Sleeve for connecting Precast beams

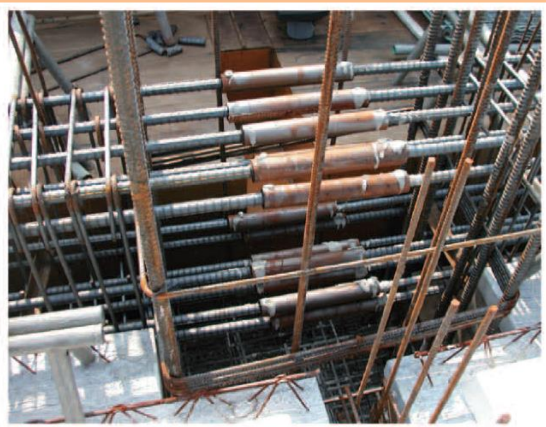


Super UX, NX II Sleeve for Precast column



Splice Sleeve System for Rebar Cages or Single Rebar Connection (Cast-in-situ Application)

Slim Sleeve for connecting rebar cage



Slim Sleeve for connecting beam rebar

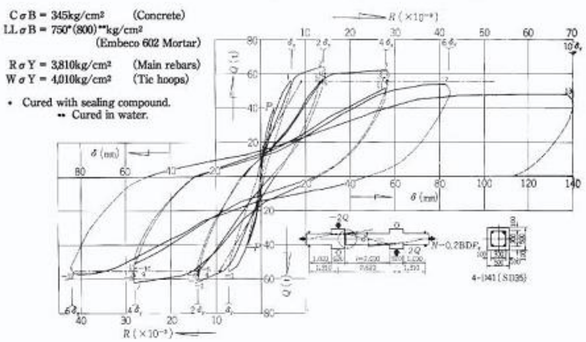
Akashi Channel Bridge

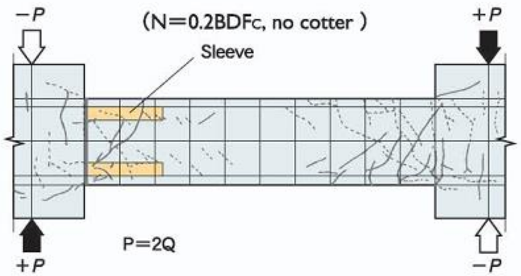
NMB SPLICE-SLEEVE SYSTEMS

seismic performances verified by cyclic loading tests on joints and structural members

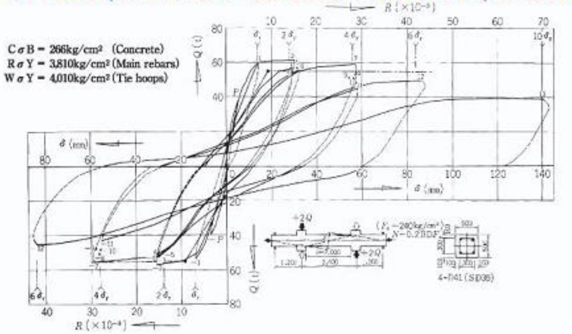
Structural tests on full size column and beam

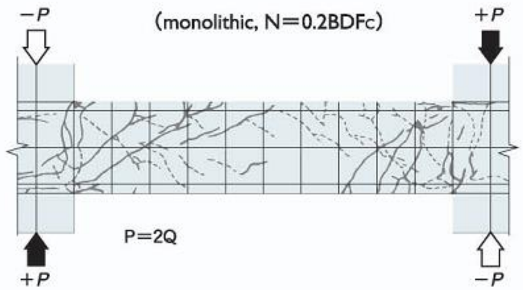
Q- δ Curve (N= 0.2BDFC, spiral hoop) with NMB Splice Sleeve





Q- δ Curve(monolithic, N= 0.2BDFC) without NMB Splice Sleeve

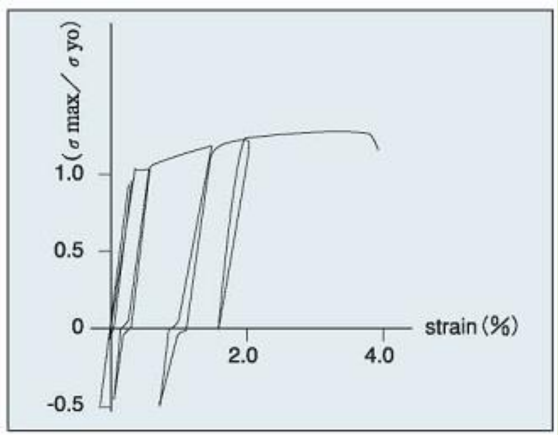




Structural test on full size column with high strength rebar, cement and NMB Splice Sleeve

Fc= 60 N/mm²
SD 490 rebar
axial force ratio (N/No)=−0.7 - +0.5
loading direction: 45°

250 ton Fatigue testing machine



cyclic loading tests in elastic and plastic regions

NMB SPLICE-SLEEVE SYSTEMS

Threaded-rebar joint
ACE-JOINT

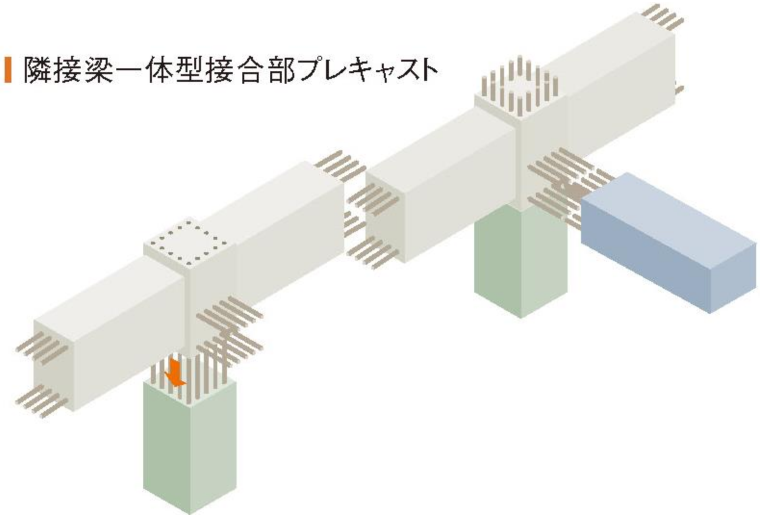
Mortar-grouted joint
TOPS-JOINT

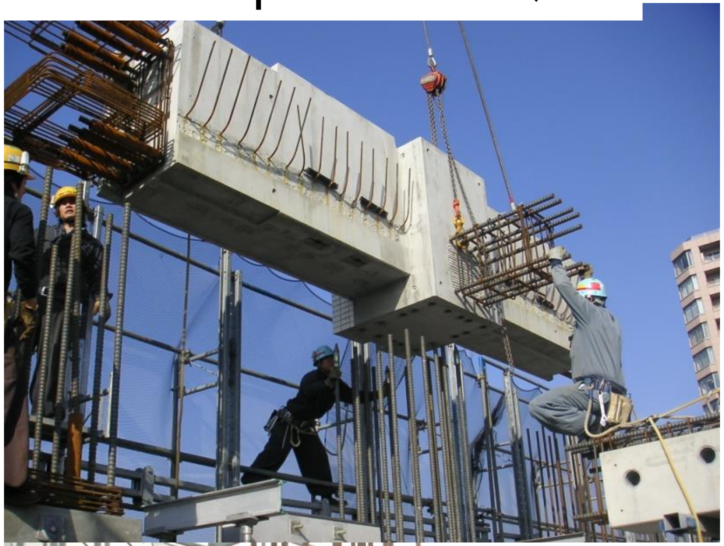
Cross-section of NEJI-TETSU-CON
and mechanical joint

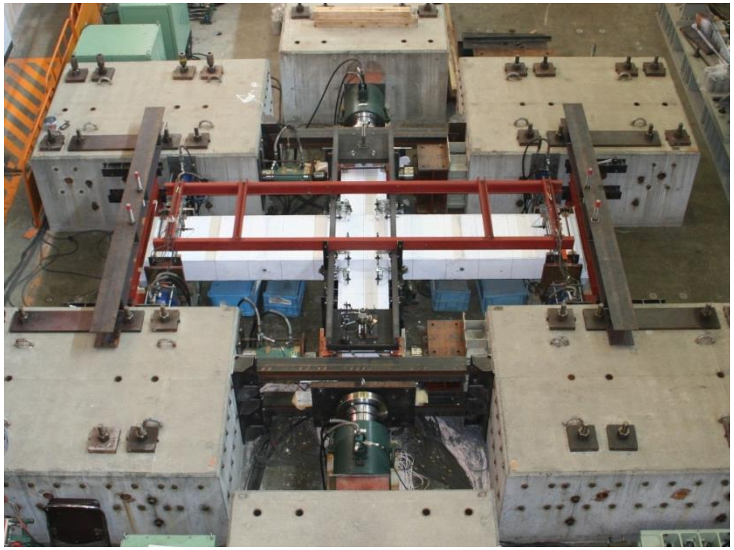
Data and photo: Courtesy of
Tokyo Tekko Co., Ltd. (TTK)

Construction Method (Assembling precast members and their seismic performance)

T-RC+
TAISEI - Reinforced Concrete Plus



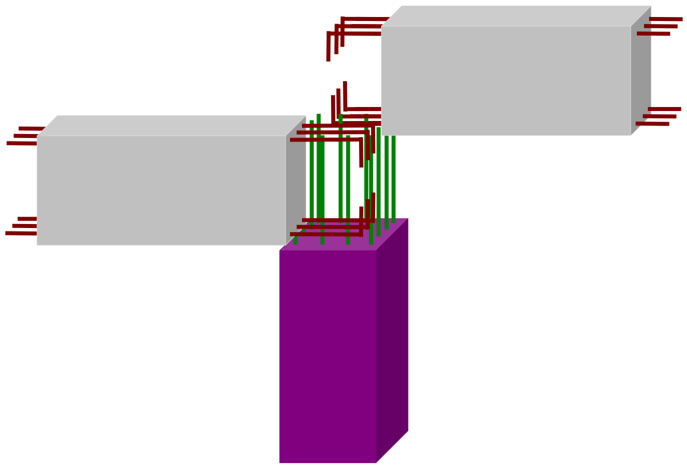




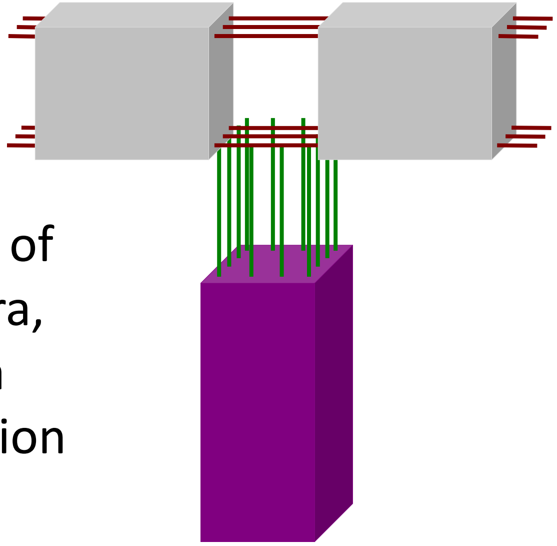
Seismic performances of precast beam-column joint should be equivalent to cast-in-situ joint

Evolution of Precast Construction System

Early Stage

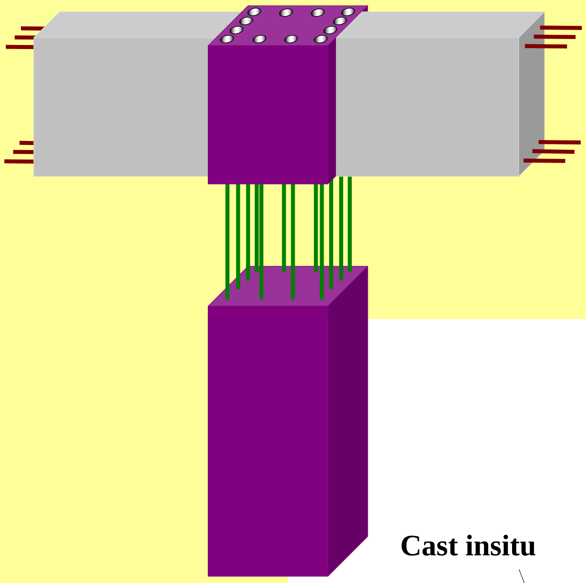


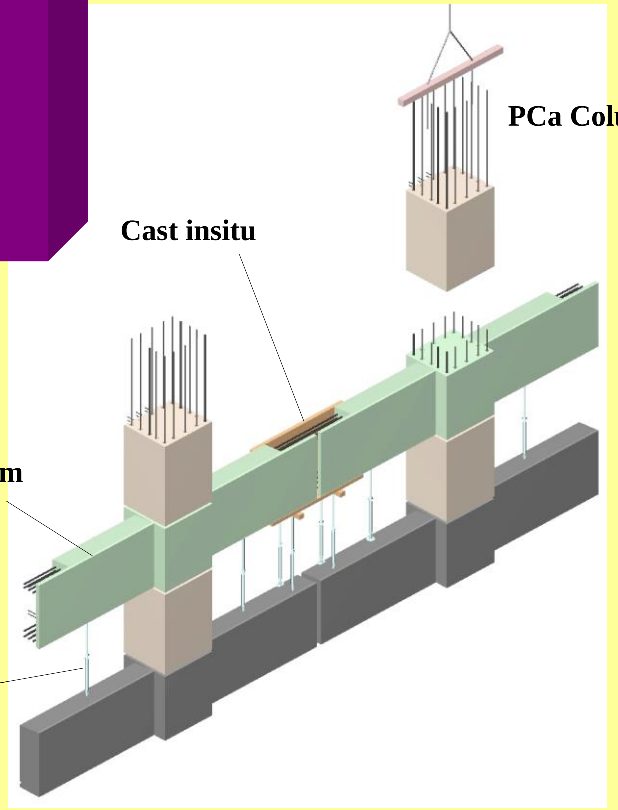
Second Stage



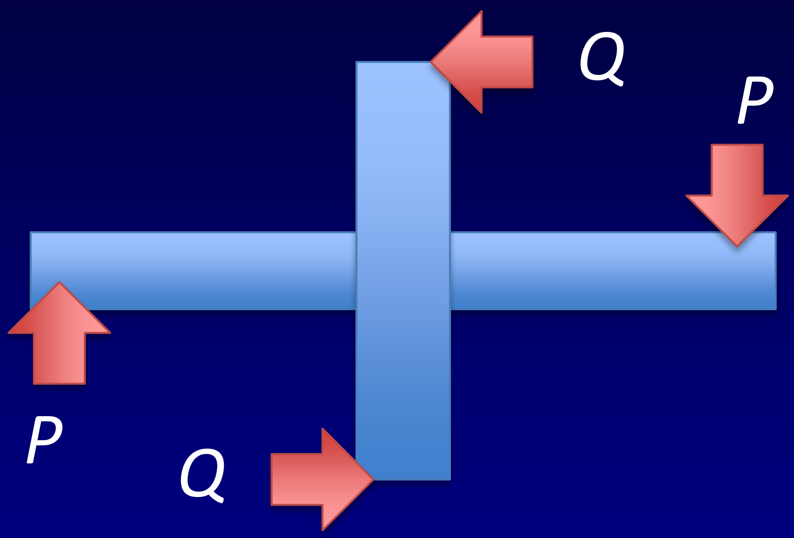
Courtesy of
Dr. Kimura,
Takenaka
Corporation

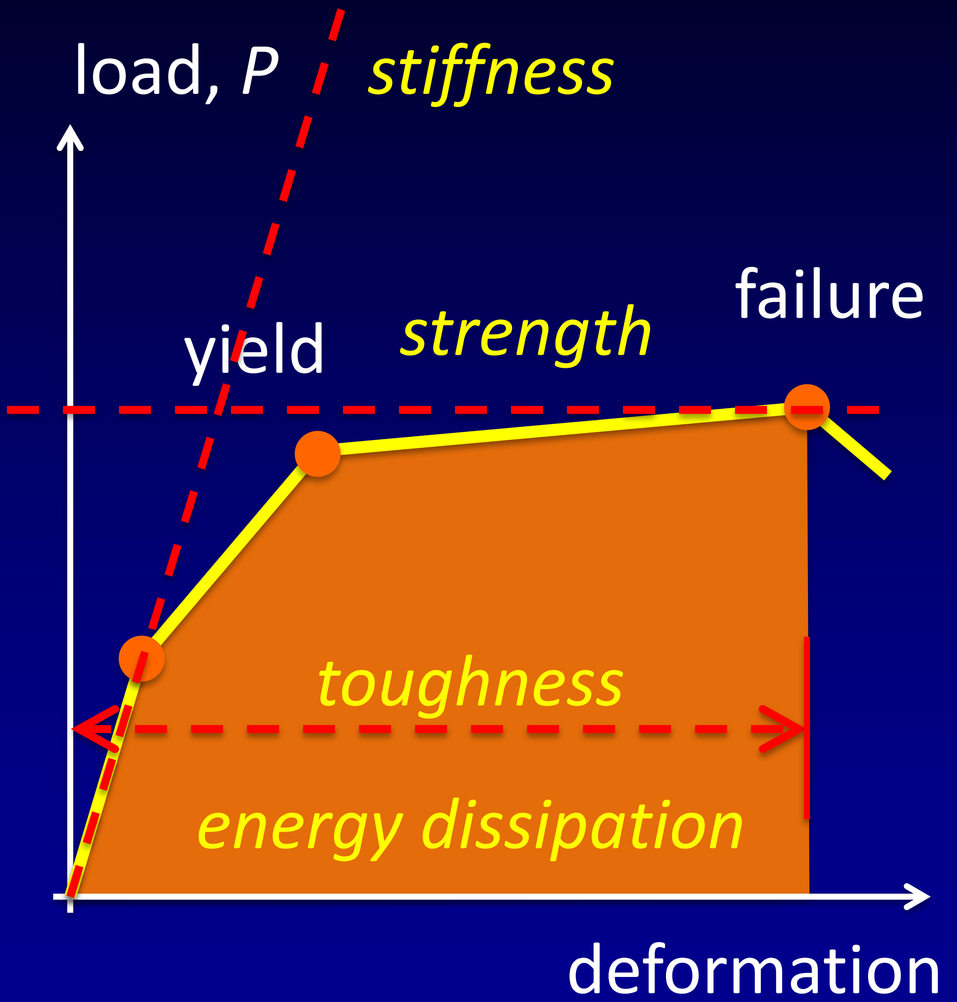
Present



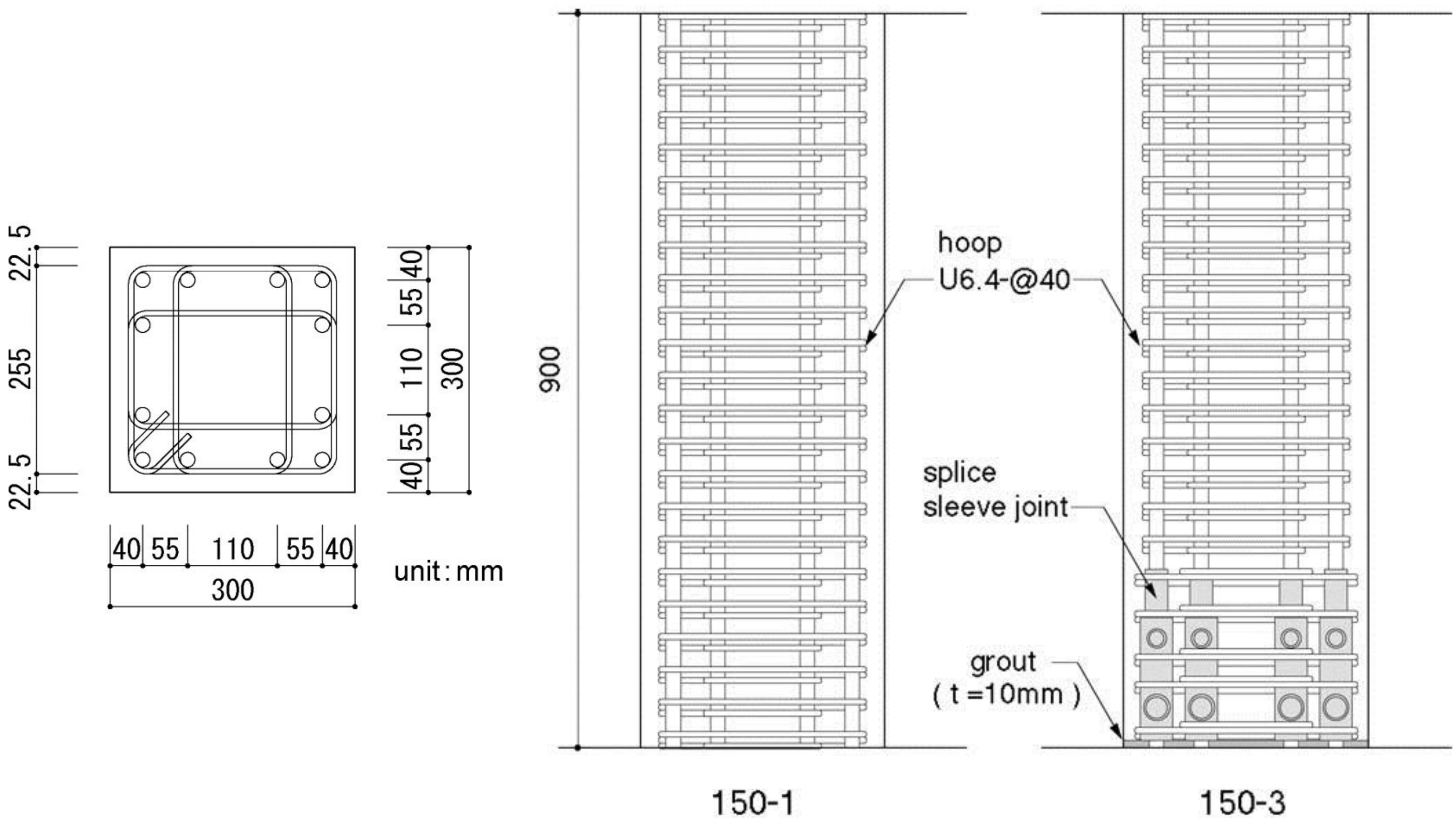


equivalence in seismic performance





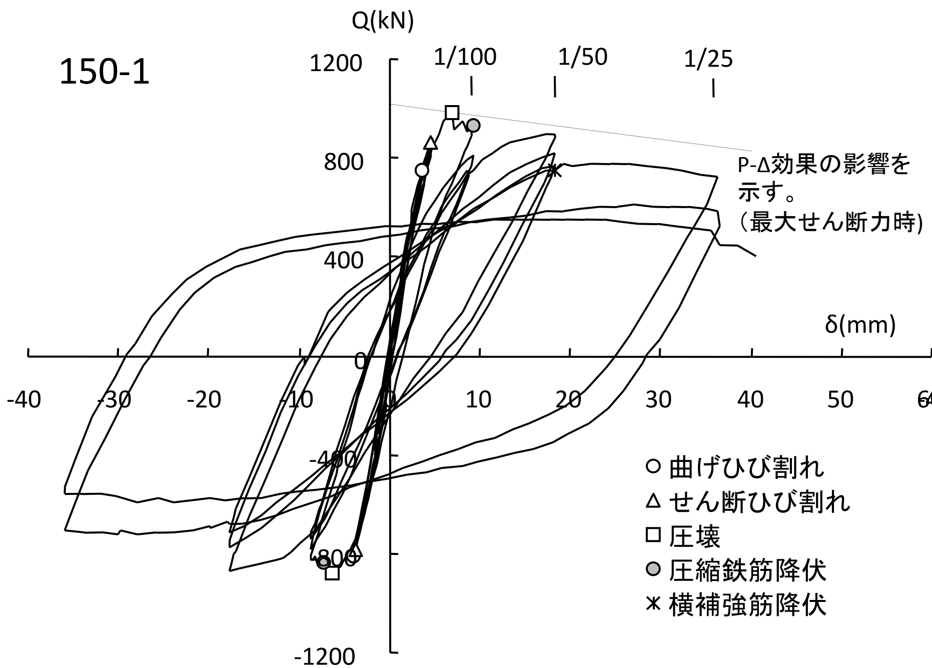
Details of column specimens



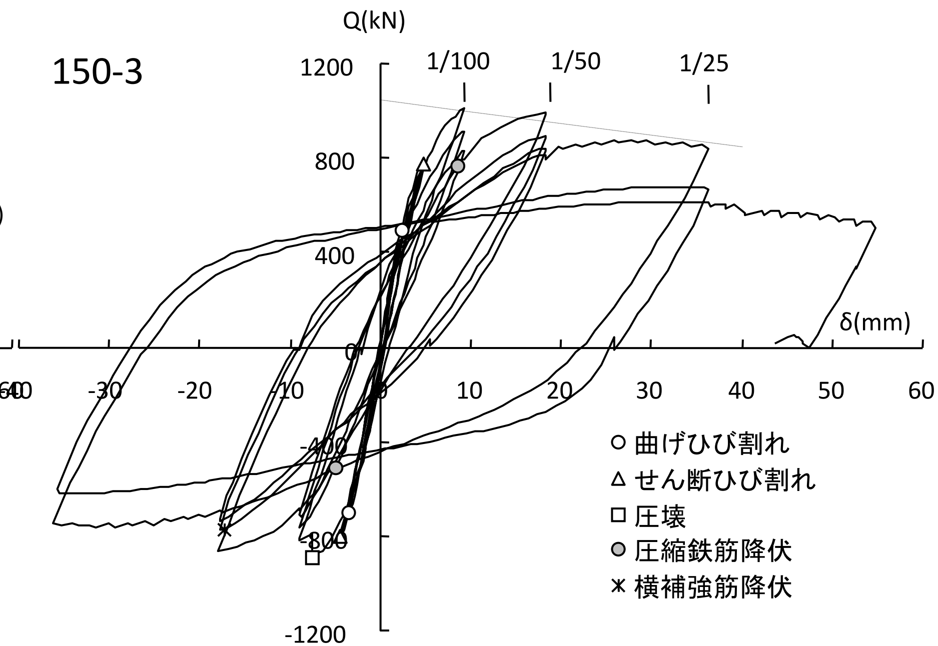
Cast-in-situ

Pre-cast

Shear force - drift angle relations



Cast-in-situ



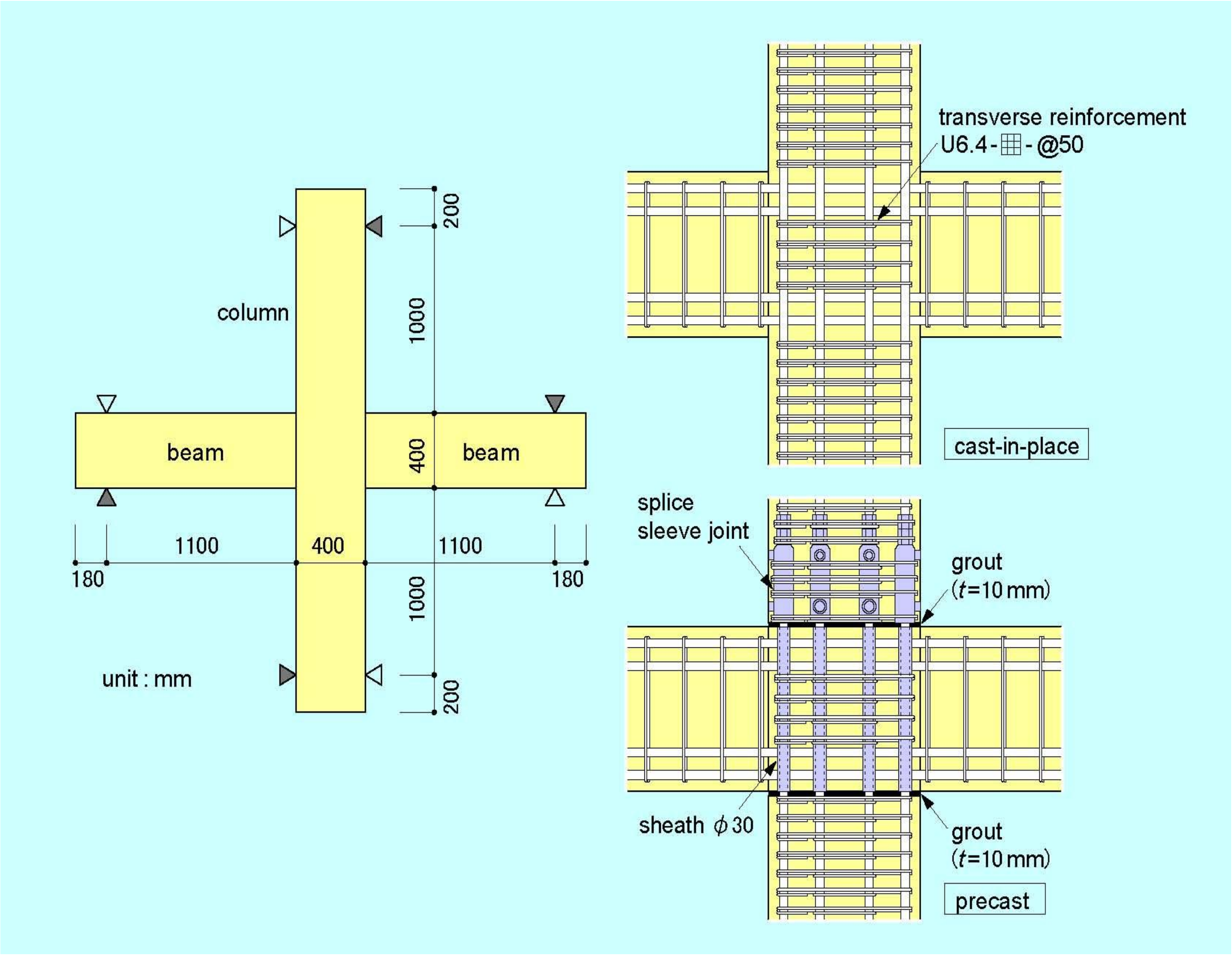
Pre-cast

Damage condition drift Angle= +1/100

150-1(Cast-in-situ)

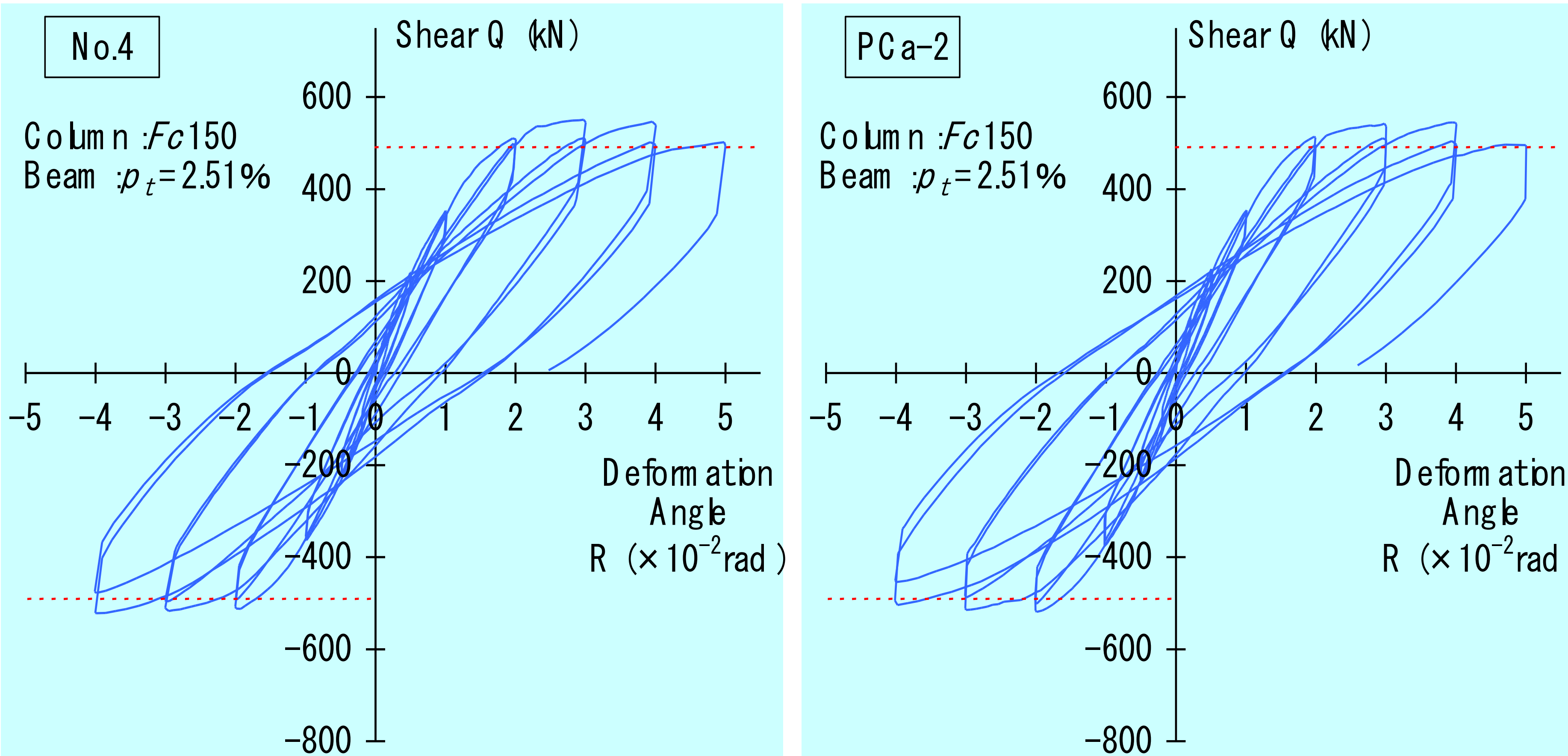
150-3(Pre-cast)

Beam-column joint test units



Shear force – interstory drift angle relation

Column, Beam-Column Joint : Fc150



Cast-in-situ

Pre-cast

outstanding precast concrete buildings in Japan

Osaka Municipal Gymnasium
JPCEA & FIP Awards for
Outstanding structure （1998）

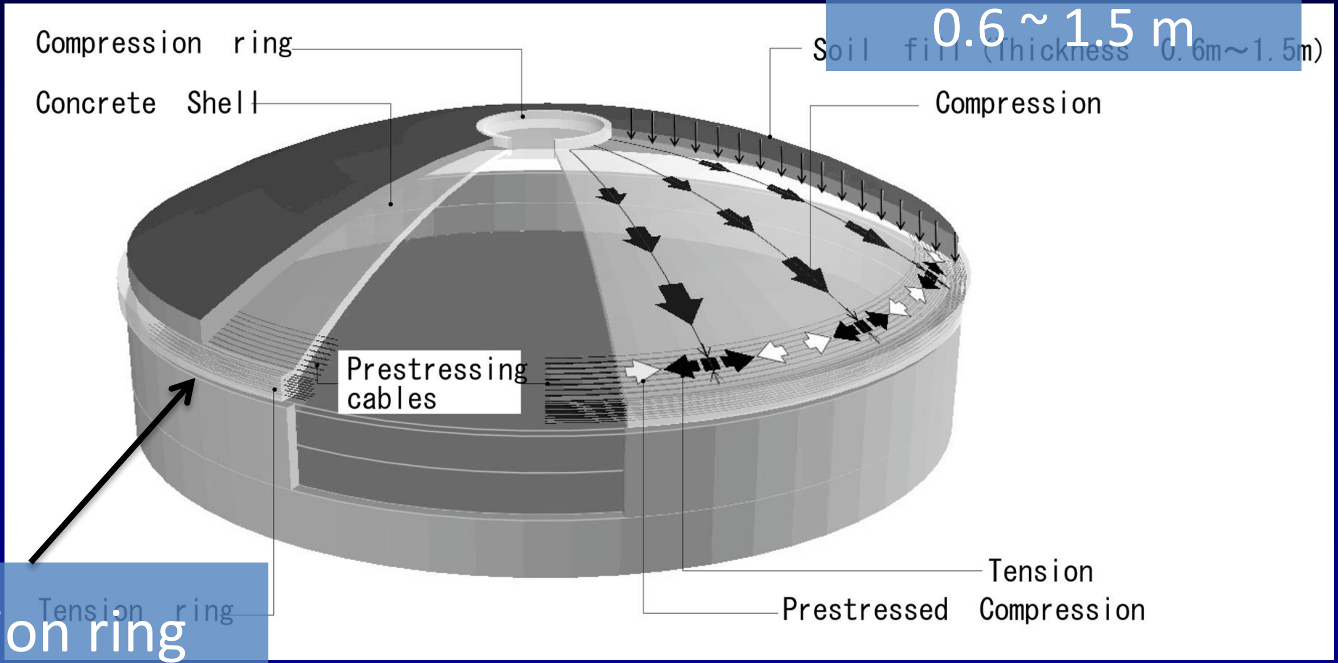
- ✓ Prestressed concrete spherical shell
- ✓ Height: Design GL+26.6m（GL+4.0m）
- ✓ Total floor area：38,425m²

- ✓ Design & supervision: Osaka city & Nikken Sekkei
- ✓ Construction: Obayashi, Nishimatsu and Asanuma
- ✓ Prestress: PS Mitsubishi and Fudo Kenken
- ✓ Construction period: June 1993 ~ May 1996

- ✓ Diameter: 110m
- ✓ Height: 30m

- ✓ Load on the roof: Total 70,000 tons, 5~6 tons/m^2)

Spherical shell

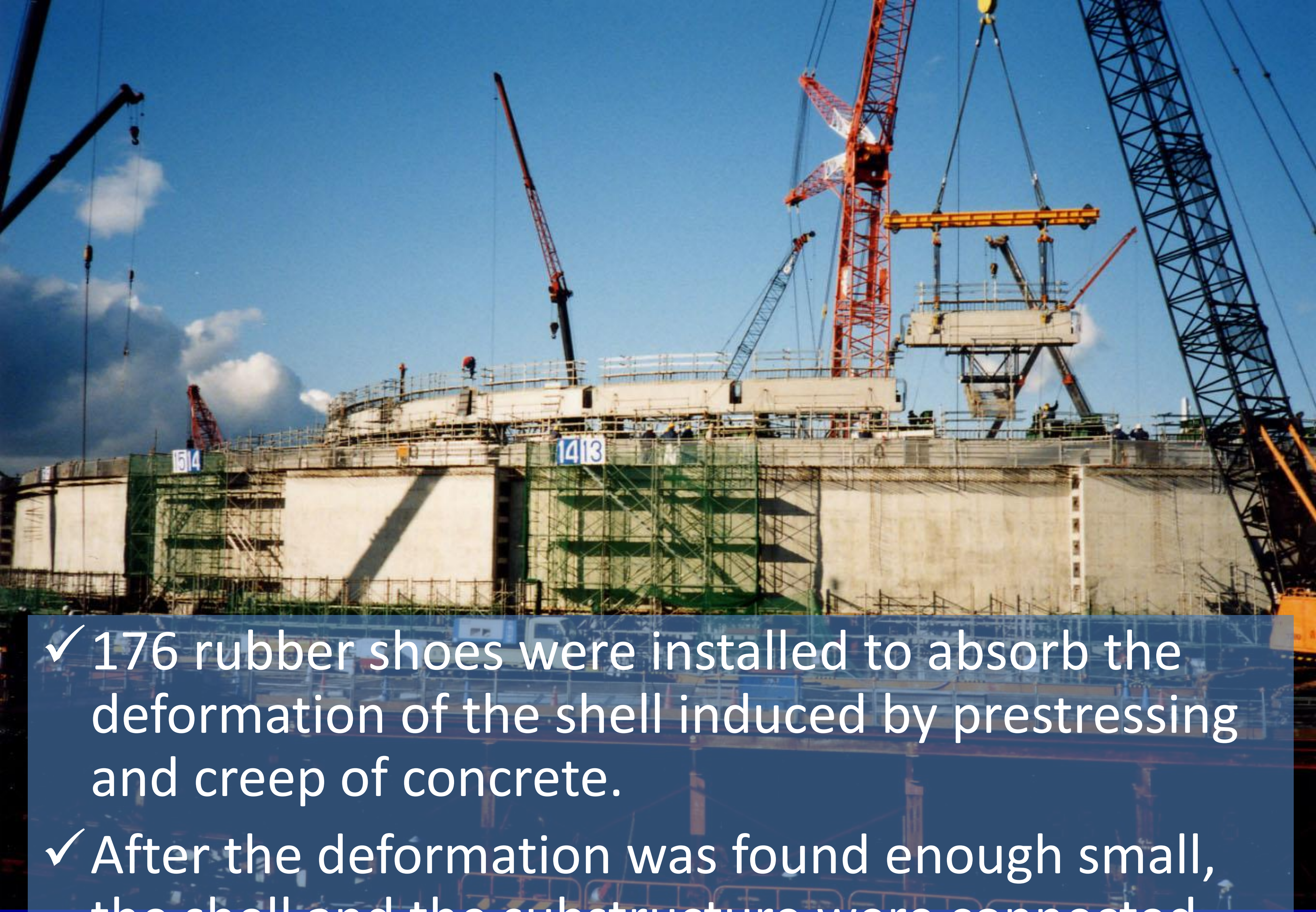


Soil thickness
0.6 ~ 1.5 m

Tension ring

✓ Prestressing force introduced to the tension ring

- Prestressing force introduced to the ring
  - 807 tons x 30 cables = 24,000 tons
  - Prestressing force was introduced in three steps depending on construction phase and load on the roof



- ✓ 176 rubber shoes were installed to absorb the deformation of the shell induced by prestressing and creep of concrete.
- ✓ After the deformation was found enough small, the shell and the substructure were connected.


95 2 3

- ✓ The shell was consisted of precast prestressed concrete beams and precast prestressed concrete floor panels covered with cast-in-situ concrete topping, which led to high constructability and economic efficiency.
- ✓ The precast members were used as a mold for concreting, which could save number of supports and simplify formwork.

Environmental issues

- ✓A building structure under the ground

⇩

- ✓Heat load to the building is extremely small.
- ✓Underground keeping temperature constant is usable.
- ✓Energy for operation can be reduced, which is resulted in an environmental-friendly building.

東大寺　正倉院
The Todaiji and Shosoin Repository

- Todaiji is one of Japan's most famous and historically significant temples and a landmark of Nara. The temple was constructed in 752 as the head temple of all provincial Buddhist temples of Japan.

正倉院　Shosoin Repository

- A “Shoso” meant a large storage of the central or regional government and temples, and the area was called “shosoin”, then it became a proper noun.
- The old wooden storage which lasted for more than 1200 years since it has been built, was registered as the World Heritage in December 1998 as a part of the Historic Monuments of Ancient Nara.

Office for Shosoin

2010 BCS (Building Contractors Society) Award
2009 JCI (Japan Concrete Institute) Award
for outstanding structure


steel columns of
200mm in diameter

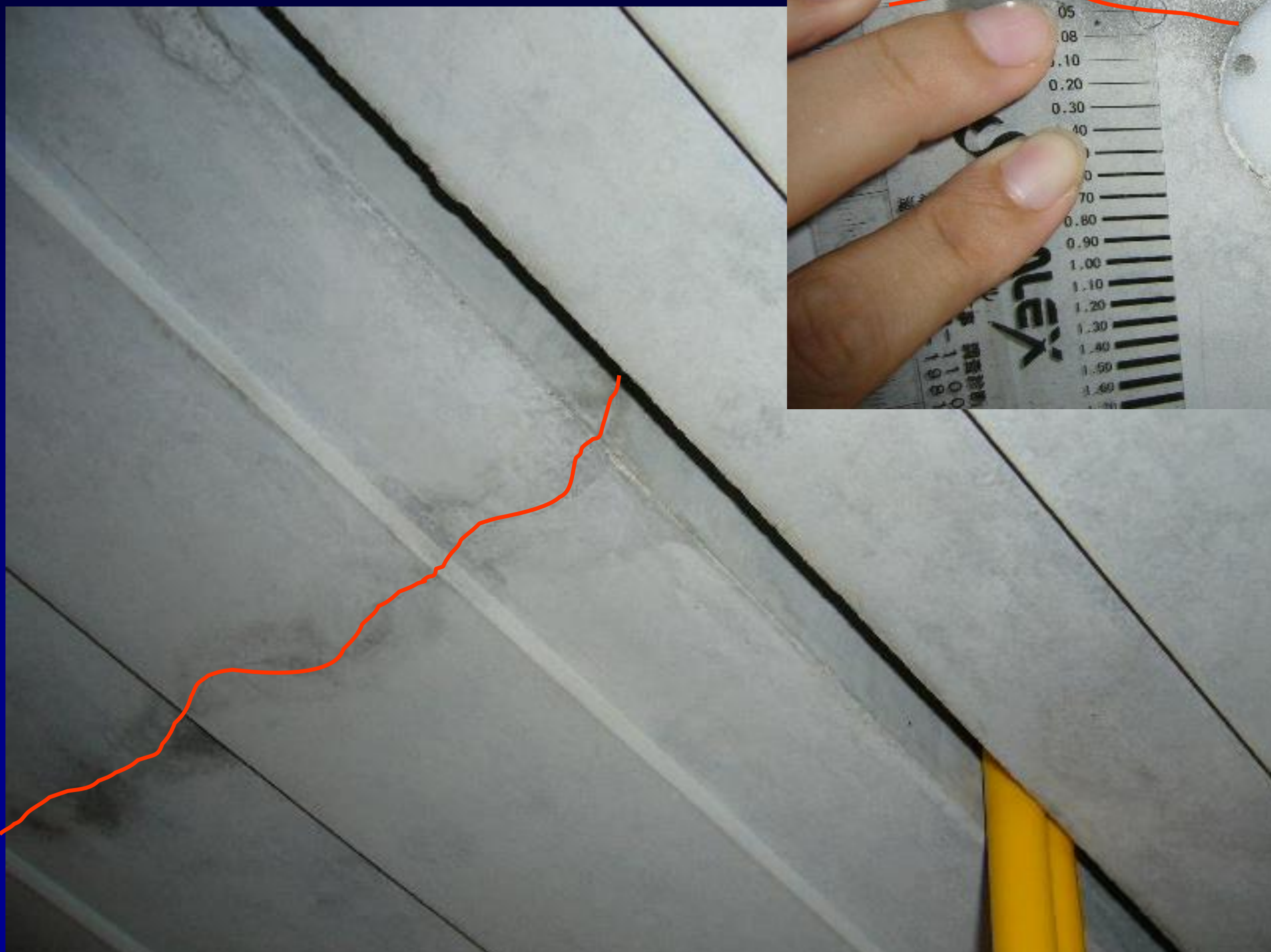

supports for roof panels

roof panel
7.2m x 2.25m

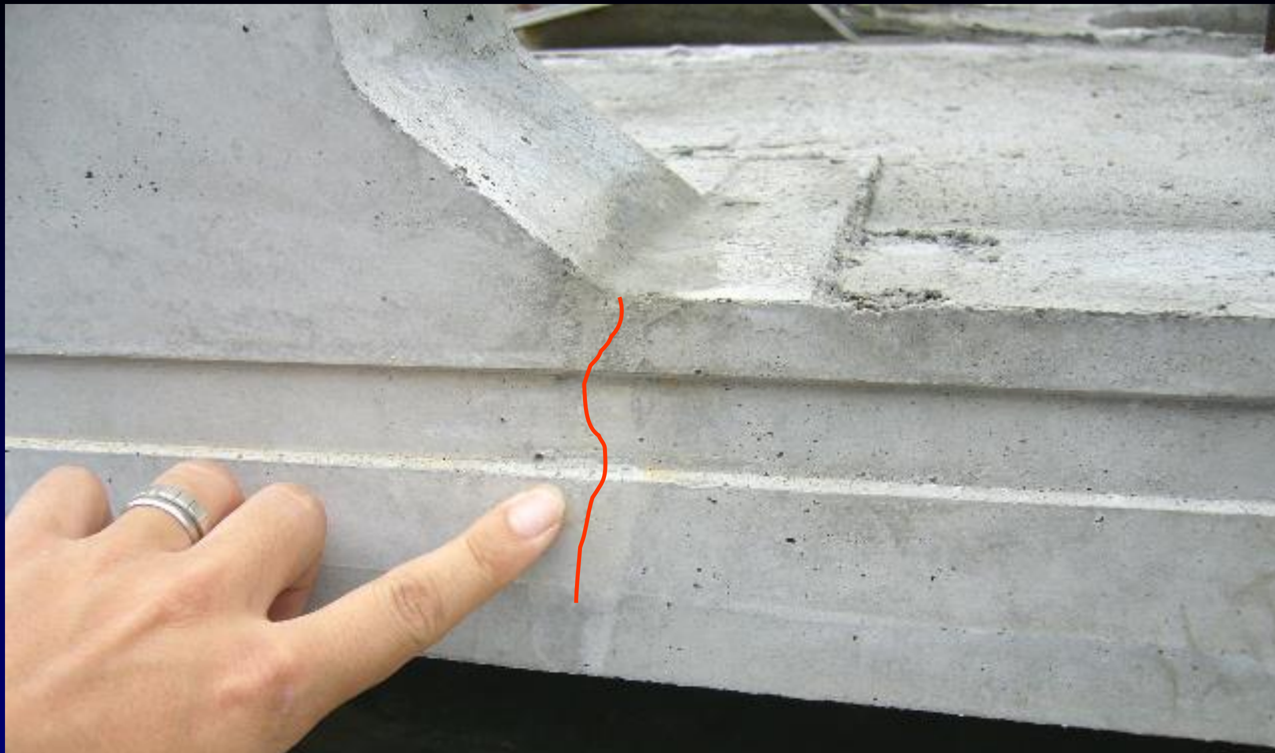

164 pieces installed


吊荷の下に入るな


SUMITOMO



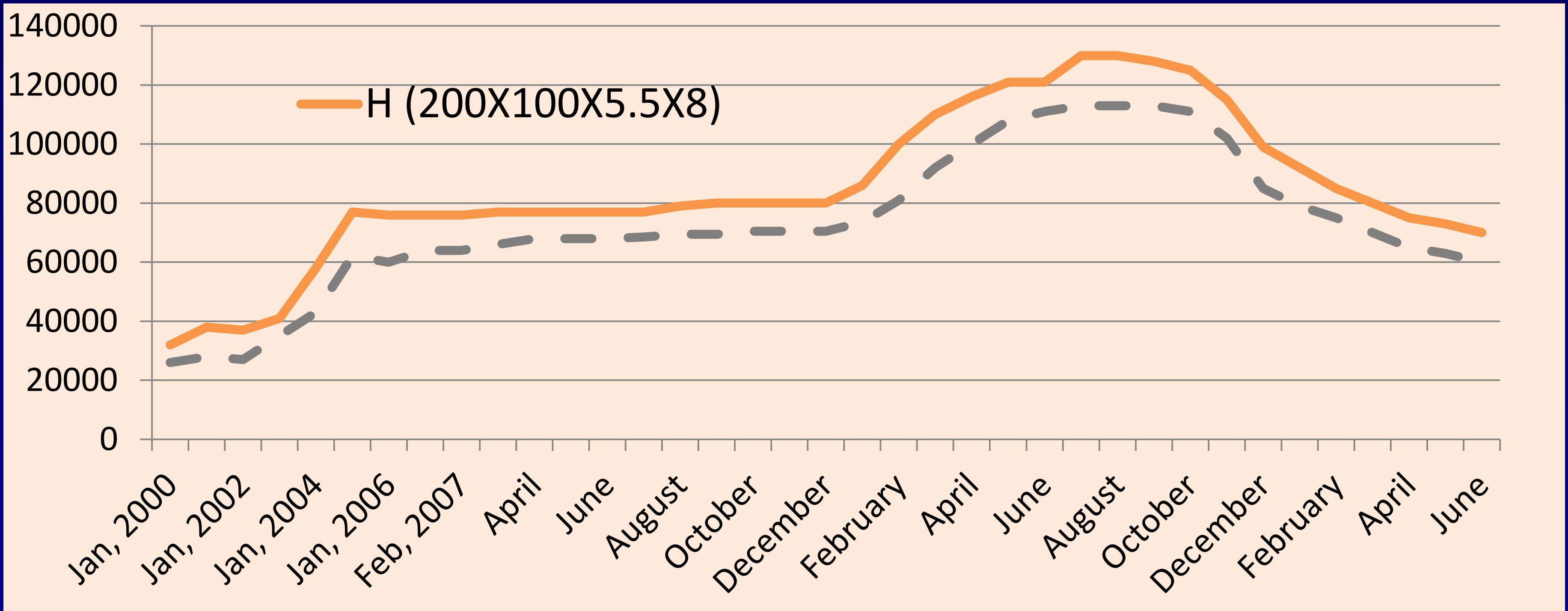

8/23 0.05
0.20
0.30
0.80
0.90
1.00
1.10
1.20
1.30
1.40
1.50




Asanuma

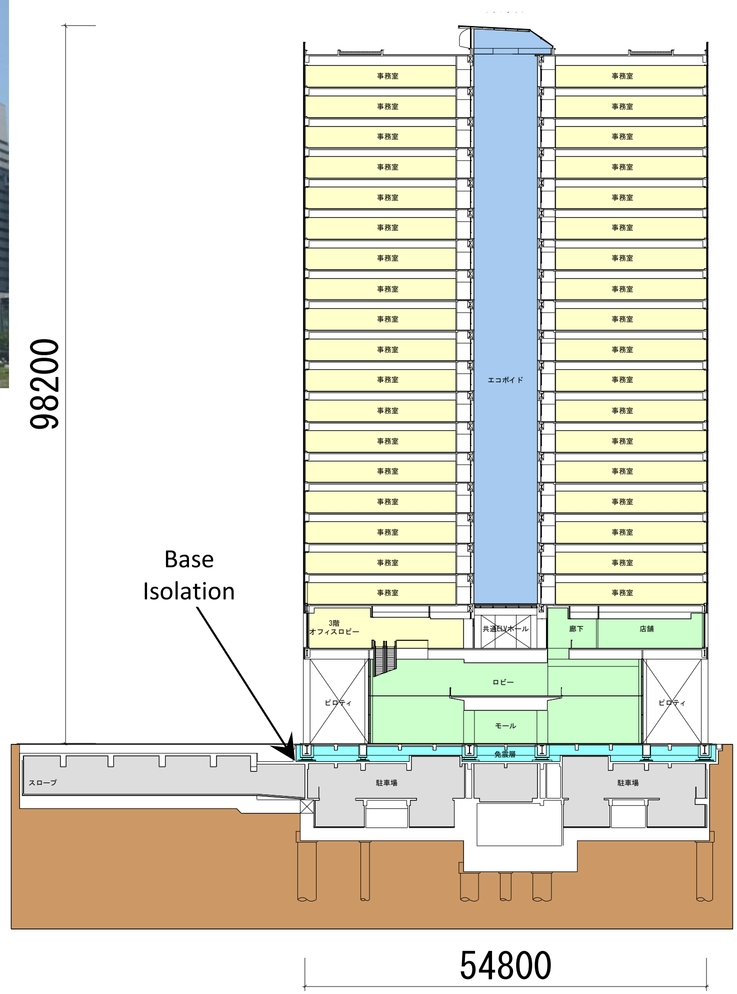
application to *office buildings*

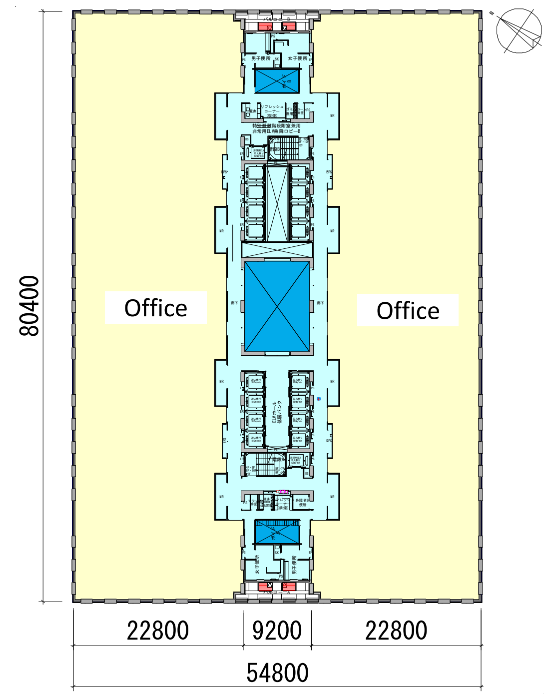
- office needs large open space
- office buildings are usually built in steel structure
- price of steel went up until summer in 2008



MM– Project 21-story Office H=98.2m

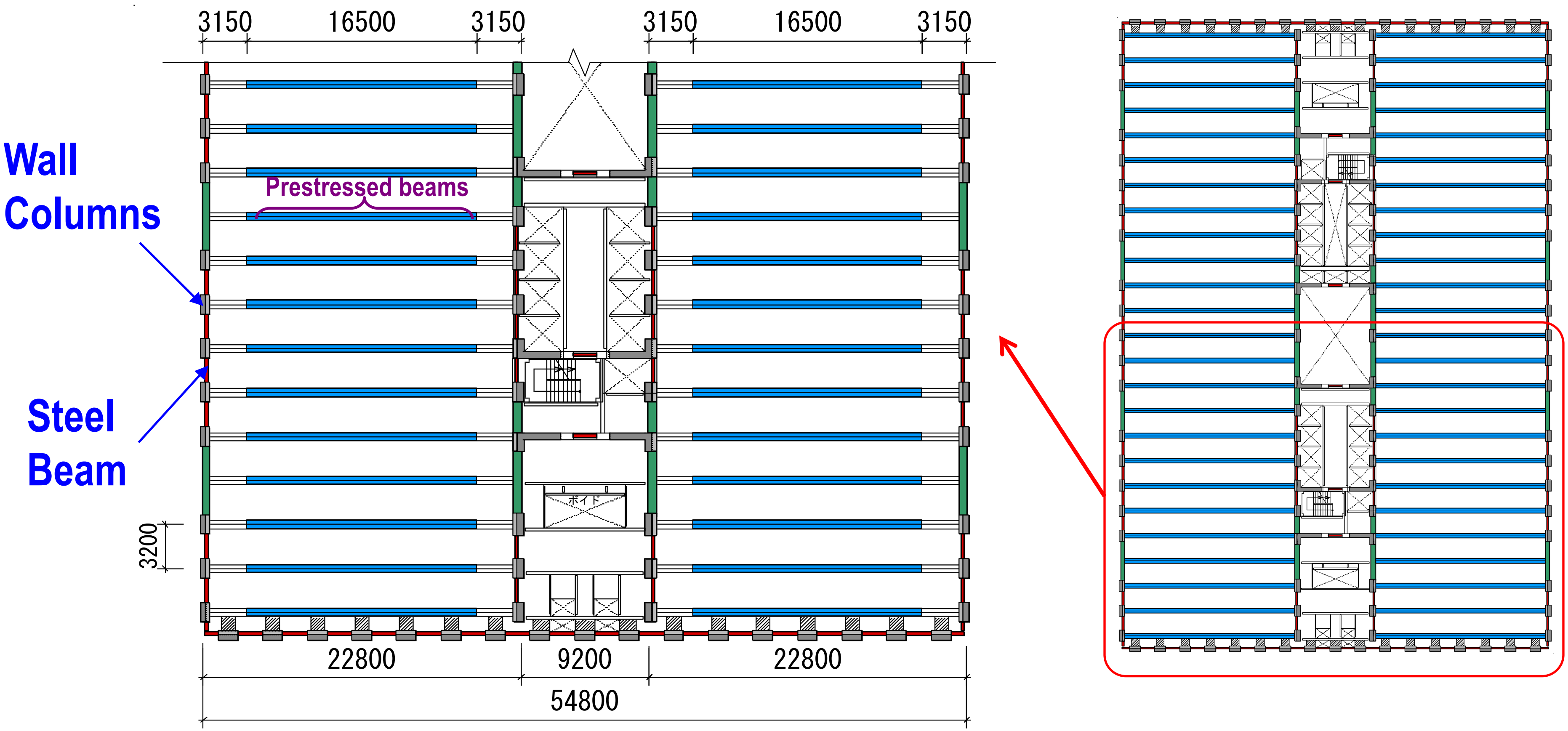
Design concrete strength : 90 (N/mm^2)

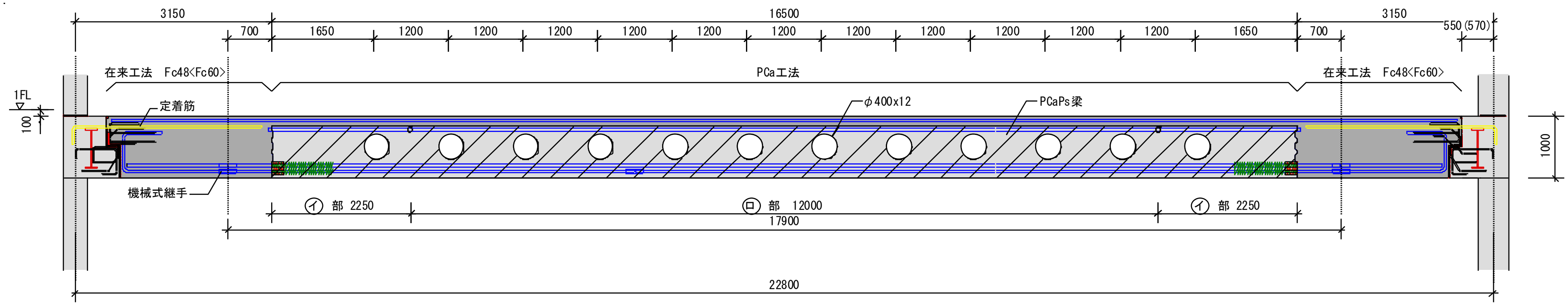


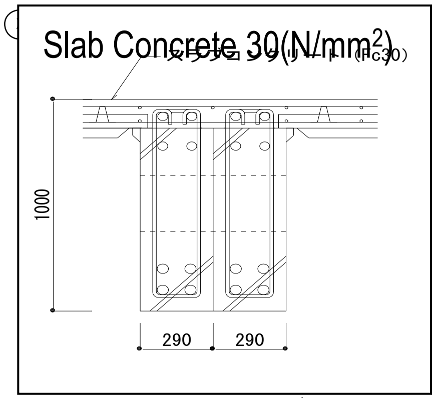


Wall Columns: 400～500mm thickness ×1,400mm wide

Prestressed beams: 580mm(290×2) wide × 1,000mm deep







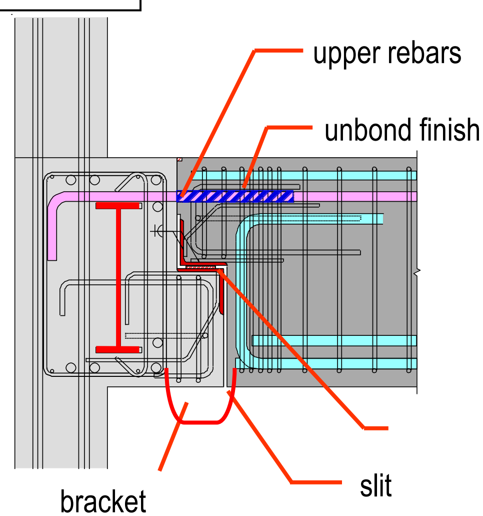
Concrete

Specified concrete strength : 80(N/mm^2)

Tendon

Yield strength of rebar : 685(N/mm^2)

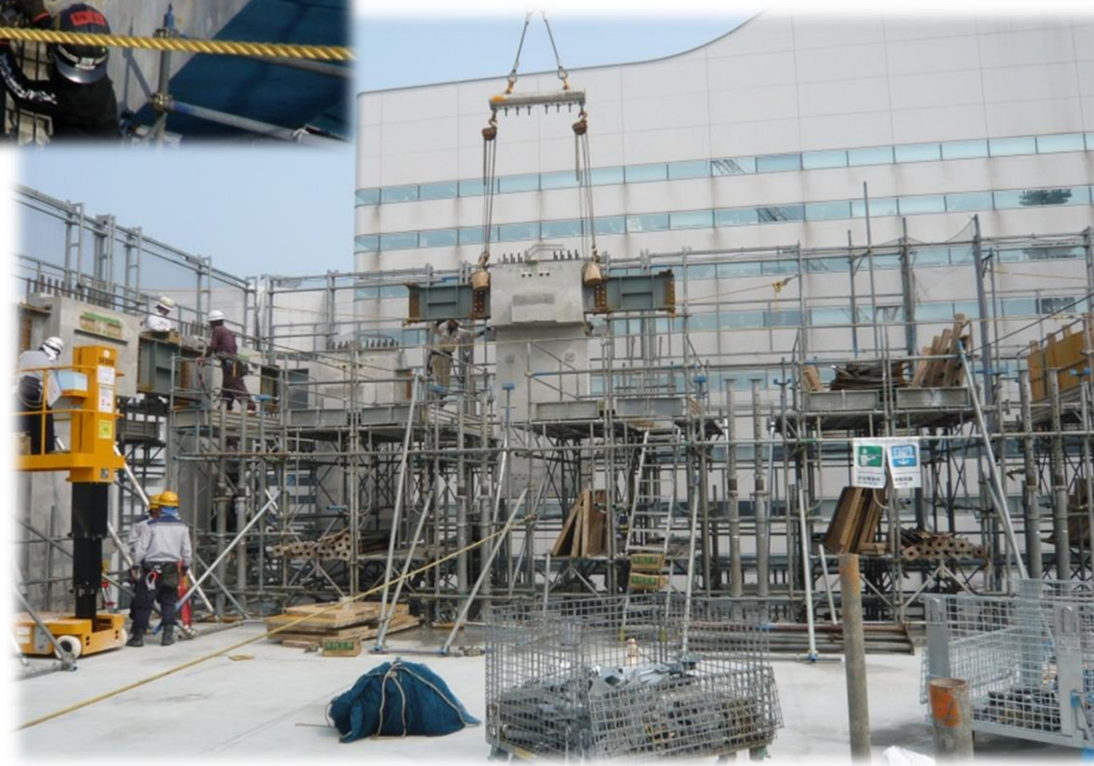
Prestressing force: 2,620 kN ×2 (σ = 575 N/mm^2)



Detail of beam end

Prestressed
concrete
beams

Wall
Columns




conclusions