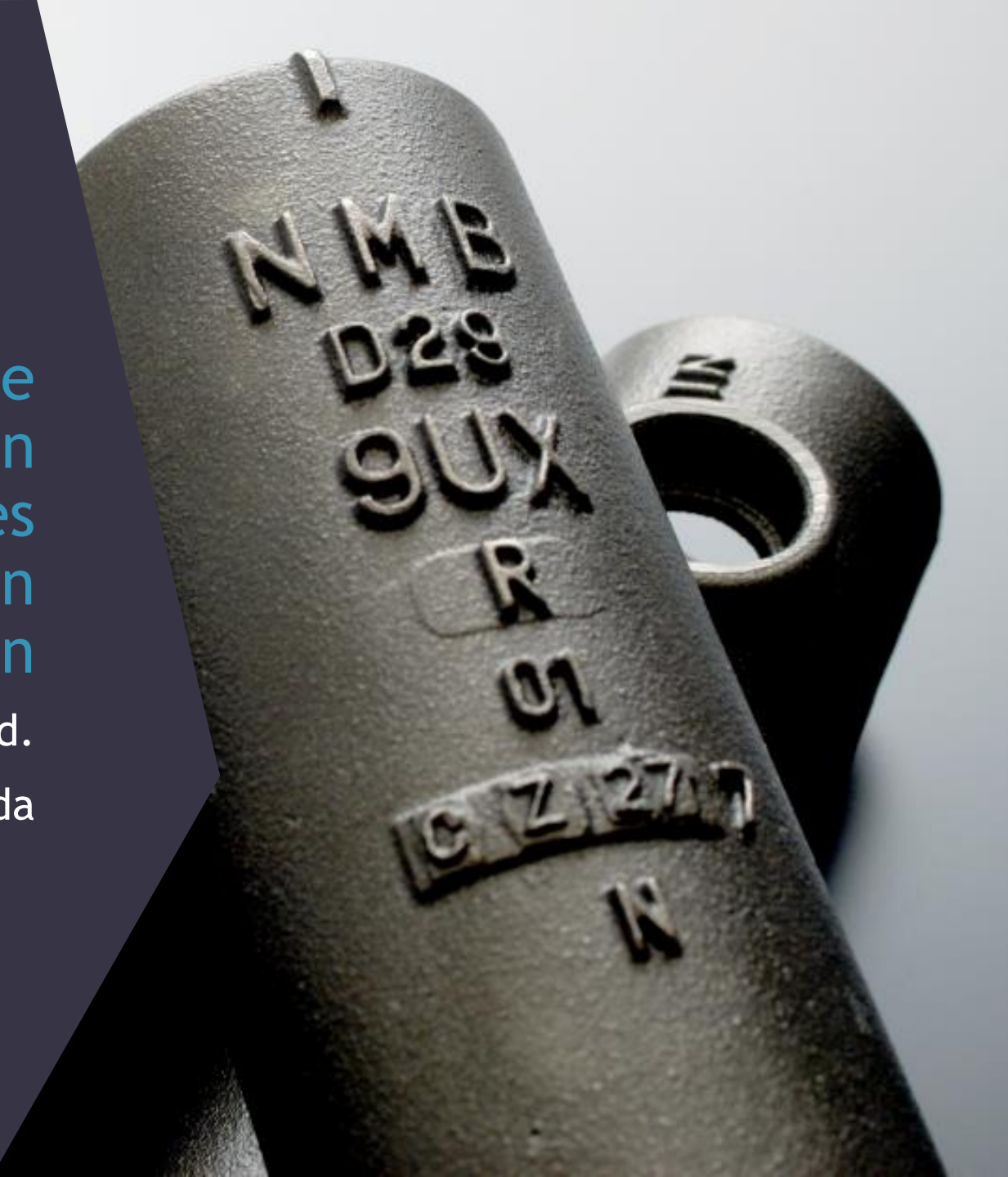
Precast concrete connections in seismic zones grout splices in Japan

Splice Sleeve Japan, Ltd.

Asao Sakuda



I ♥ PRECAST

NMB SPLICE SLEEVE SYSTEM

Agenda

- What are grout splices?
- Japanese requirements for mechanical splices
- Application examples of grout splices

Agenda

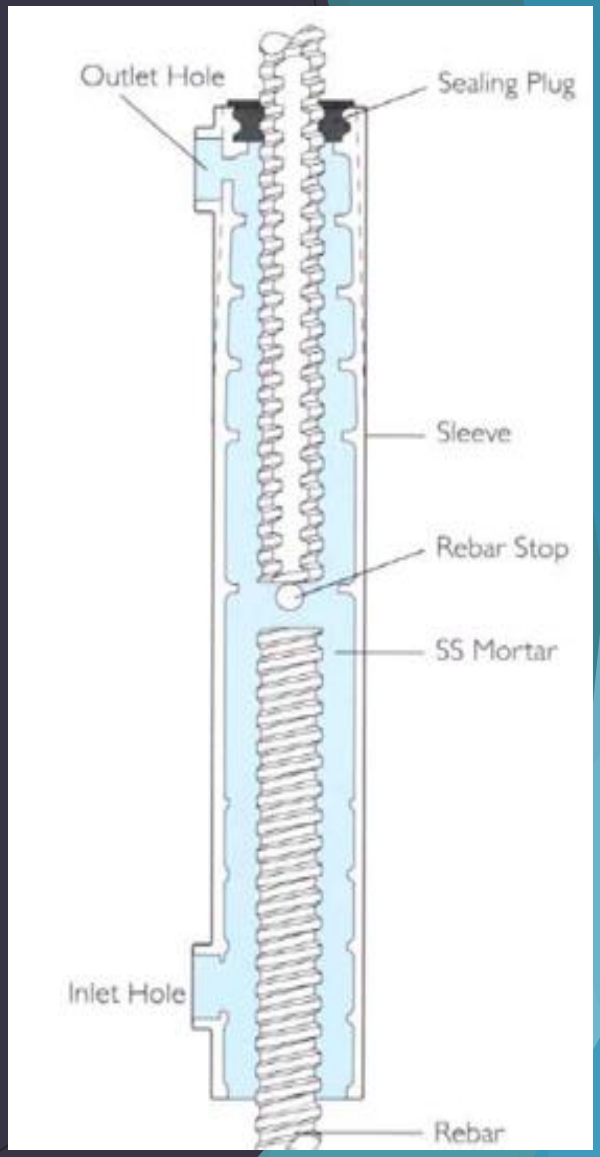
- What are grout splices?
- Japanese requirements for mechanical splices
- Application examples

What are grout splices?

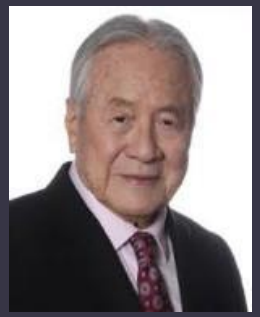
A grout splice consists of a cylindrical shaped coupler made of metal and a Portland cement based non-shrink, high-early-strength grout material.

NMB Splice Sleeve

Filling grout

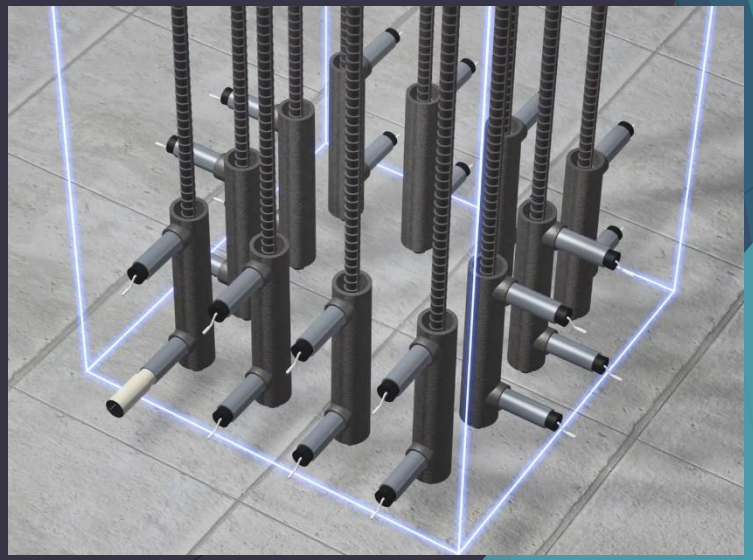


What are grout splices?

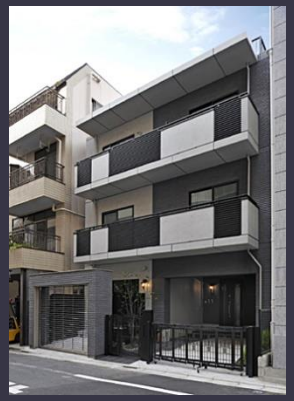
- Grout splices are reinforcing bar splices specially designed for the connection of structural precast concrete units.
- 
  They were invented by an American structure engineer, Dr. Alfred A. Yee in Hawaii in the early 1970's.
- Grout splices were used for the first time in the construction of a 38-story precast concrete building, the Ala Moana Hotel in Honolulu, Hawaii.

PCI Journal Volume 18, No.3 May-June 1973

What are grout splices?



What are grout splices?













Agenda

- What are grout splices?
- Japanese requirements for mechanical splices
- Application example

Mechanical splices requirements

Rebar Joint Performance Evaluation Standard（1982）updated in 2000, The Building Center of Japan

Class SA: The strength, rigidity and ductility are almost equivalent to those of the rebars to joint.

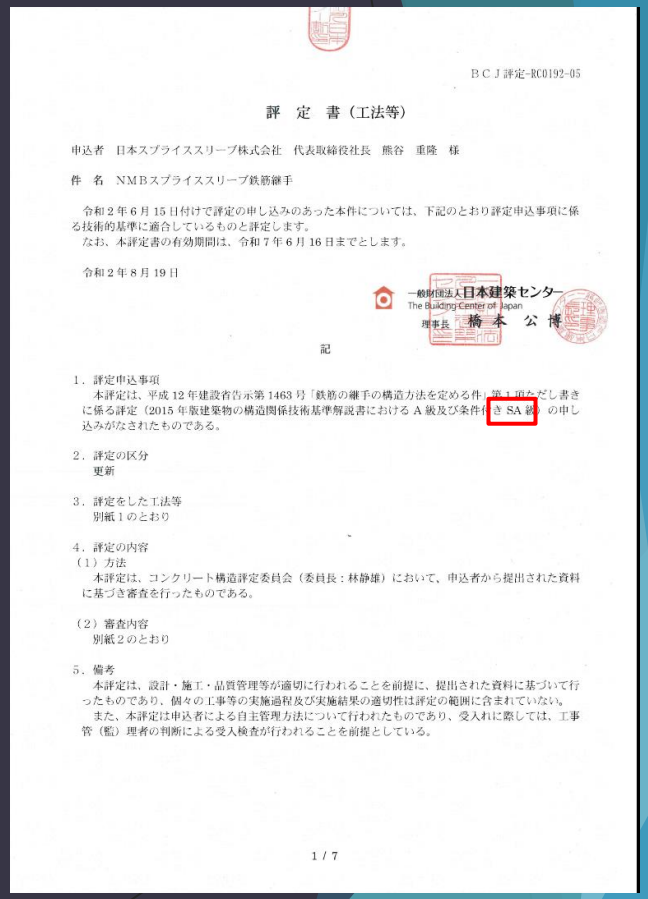
Class A: The strength and rigidity are almost equivalent, but the ductility is slightly inferior to the rebars to connect.

Class B; The strength and rigidity are almost equivalent, but other characteristics are inferior to the rebars to connect

Class C; The strength, rigidity etc. are inferior to the rebars to connect

Mechanical splices requirements

- Grout splices are the only mechanical splices qualified as class SA splices in Japan



BCJ評定-RC0192-05

評　定　書（工法等）

申込者　日本スプライススリーブ株式会社　代表取締役社長　熊谷　重隆　様

件　名　NMBスプライススリーブ鉄筋継手

令和２年６月15日付けで評定の申し込みのあった本件については、下記のとおり評定申込事項に係る技術的基準に適合しているものと評定します。
なお、本評定書の有効期間は、令和７年６月16日までとします。

令和２年８月19日

一般財団法人日本建築センター
The Building Center of Japan
理事長　橋本　公博

記

１．評定申込事項
本評定は、平成12年建設省告示第1463号「鉄筋の継手の構造方法を定める件」第１項ただし書きに係る評定（2015年版建築物の構造関係技術基準解説書における A 級及び条件付き SA 級）の申し込みがなされたものである。

２．評定の区分
更新

３．評定をした工法等
別紙１のとおり

４．評定の内容
（１）方法
本評定は、コンクリート構造評定委員会（委員長：林静雄）において、申込者から提出された資料に基づき審査を行ったものである。

（２）審査内容
別紙２のとおり

５．備考
本評定は、設計・施工・品質管理等が適切に行われることを前提に、提出された資料に基づいて行ったものであり、個々の工事等の実施過程及び実施結果の適切性は評定の範囲に含まれていない。
また、本評定は申込者による自主管理方法について行われたものであり、受入れに際しては、工事管（監）理者の判断による受入検査が行われることを前提としている。

1 / 7

Mechanical splices requirements

Requirements for class SA splices
1- high performance

(1) Monotonic tensile test $0 \rightarrow \sigma_{y0} \rightarrow$ failure

(2) Repeated tensile test $0 \rightarrow (0.02\sigma_{y0} \leftrightarrow 0.95\sigma_{y0}) \rightarrow$ failure
↑30 times

(3) Elastic cyclic test $0 \rightarrow (0.95\sigma_{y0} \leftrightarrow -0.5\sigma_{y0}) \rightarrow$ failure
↑20 times

(4) Plastic cyclic test $0 \rightarrow (2\varepsilon_y \leftrightarrow -0.5\sigma_0) \rightarrow (5\varepsilon_y \leftrightarrow -0.5\sigma_0) \rightarrow$ failure
↑4times ↑4times

σ_{y0}: specified yield strength of the rebar
ε_y: yield strain of the grout splice assembly at yield stress

Mechanical splices requirements

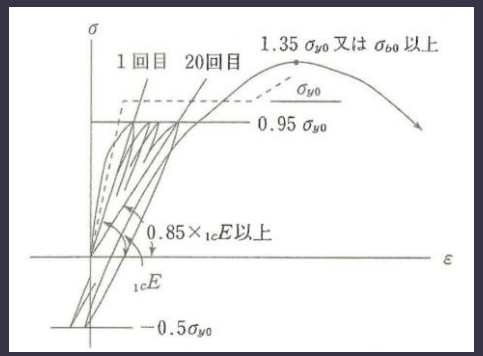
Requirements for class SA splices
1- high performance

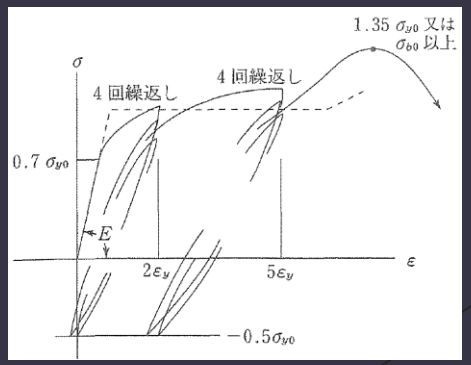
(3) Elastic cyclic test $0 \rightarrow (0.95\sigma y0 \leftrightarrow -0.5\sigma y0) \rightarrow$ failure
↑20 times

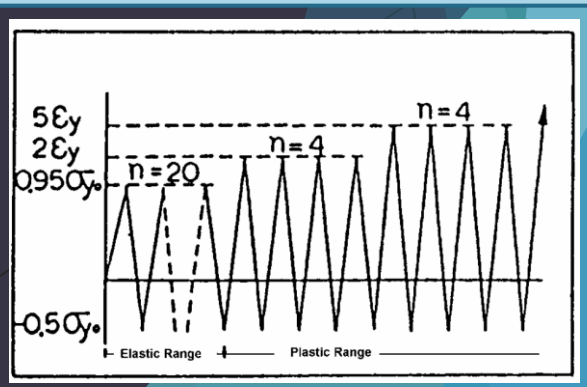
(4) Plastic cyclic test $0 \rightarrow (2\varepsilon y \leftrightarrow -0.5\sigma 0) \rightarrow (5\varepsilon y \leftrightarrow -0.5\sigma 0) \rightarrow$ failure
↑4times ↑4times

required tensile strength	$\sigma b > 1.35\sigma y0$ or $\sigma b > \sigma b0$
residual slip	elastic area 20c $\delta s \leqq 0.3$mm
	plastic area 4c $\delta s \leqq 0.3$mm and δs 8c $\leqq$ 0.9mm
failure mode	bar break

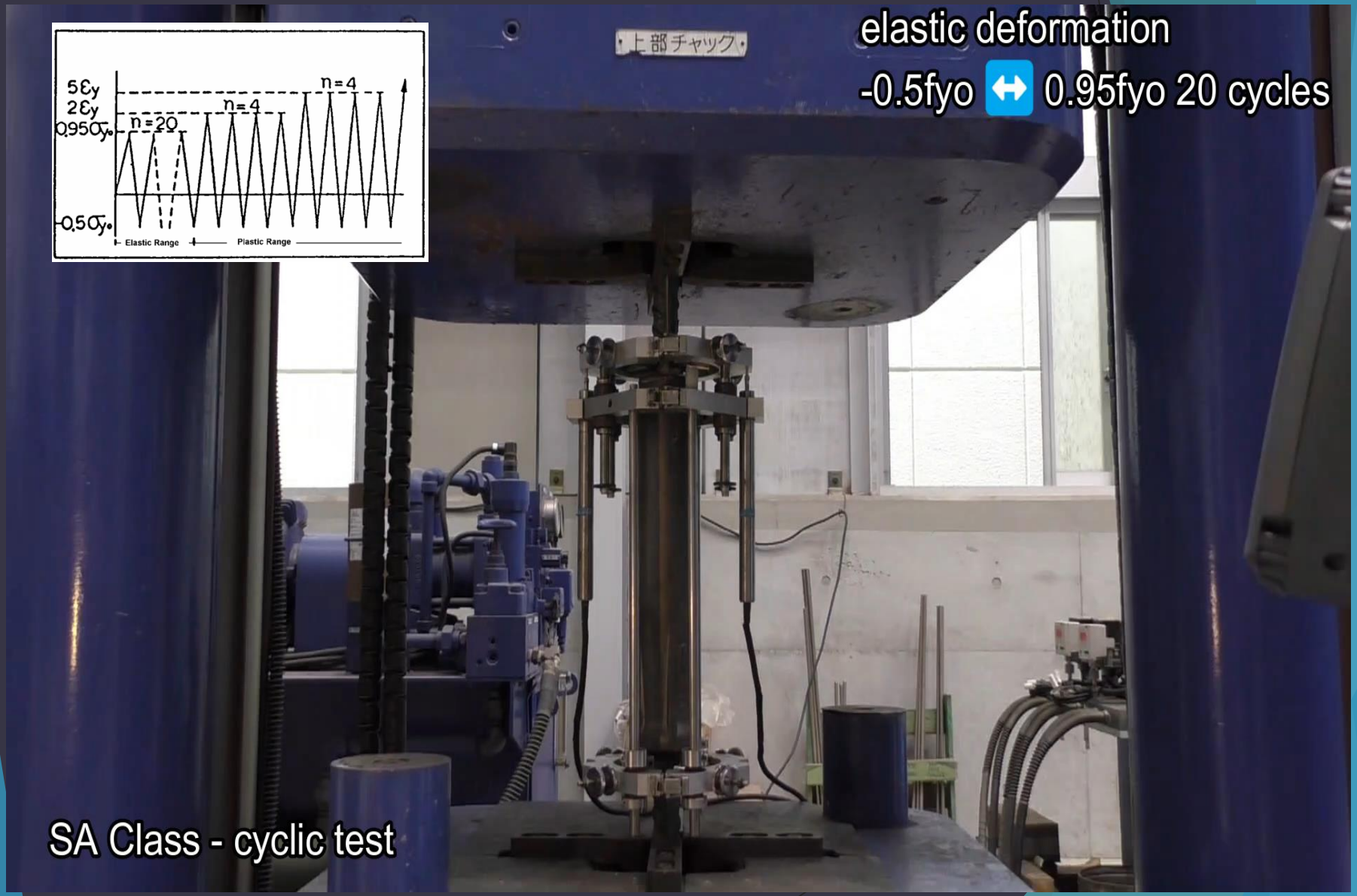
σy0:specified yield strength of the rebar
εy: yield strain of the grout splice assembly at yield stress
20c δs, 4c δs 8c δs: residual slip after 20 or 4 or 8 load cycles







Mechanical splices requirements



Mechanical splices requirements

Requirements for class SA splices
2 - submission of performance mock-up tests results to prove high resistance during earthquakes

Conduction of performance mock-up test
- minimum 1/3 scale mock-up test
- shall use actual mechanical splices
- applied load shall be as an emulation of an earthquake

NMB Splice Sleeve mock-up results evaluated for class SA recognition columns 58 pieces, beams 12 pieces, walls 82 pieces total of 152 precast concrete units

Mechanical splices requirements

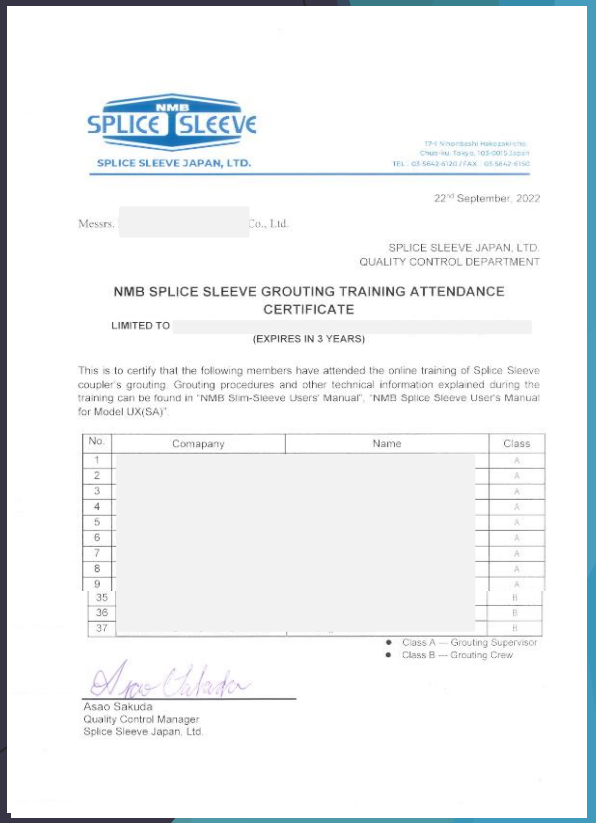
Requirements for SA class splices
3 – Design Guidelines
4 – Grouting Procedure's Instruction Manual

Design Guidelines contents
- Scope of application of grout splices
- List of existing standards to follow
- Additional information necessary to consider during design
- Rebars, grout splices, grout's scope of specifications

Grouting Procedure's Instruction Manual contents
- Quality control system
- Recommend tool and equipment
- Quality control check lists
- Quality control test criteria
- Training sessions for grouting work team members and leaders

Mechanical splices requirements

Requirements for SA class splices
3 - Design Guidelines
4 - Grouting Procedure's Instructions



SPLICE SLEEVE JAPAN, LTD.

22nd September, 2022

Messrs. Co., Ltd.

SPLICE SLEEVE JAPAN, LTD.
QUALITY CONTROL DEPARTMENT

NMB SPLICE SLEEVE GROUTING TRAINING ATTENDANCE CERTIFICATE

LIMITED TO

(EXPIRES IN 3 YEARS)

This is to certify that the following members have attended the online training of Splice Sleeve coupler's grouting. Grouting procedures and other technical information explained during the training can be found in "NMB Slim-Sleeve Users' Manual", "NMB Splice Sleeve User's Manual for Model UX(SA)".

No.	Comapany	Name	Class
1			A
2			A
3			A
4			A
5			A
6			A
7			A
8			A
9			A
35			B
36			B
37			B

- Class A — Grouting Supervisor
- Class B — Grouting Crew

Asao Sakuda
Quality Control Manager
Splice Sleeve Japan, Ltd.

Agenda

- What are grout splices?
- Japanese requirements for mechanical splices
- Application example

RC-full PCa building construction example

- Project name: new development in Tokyo area（multistory condominium, private project）
- Total period: September 2010～July 2012
- Structure:　RC & S　23 stories, 1 underground story
  1 penthouse　condominium（201 flats）
  B1～2F：cast in place
  2F～23F・PH：precast

Building area: 3,000 m^2

Total floor space: 20,000 m^2

RC-full PCa building construction example

Splice Sleeve Japan, Ltd.

Splice Sleeve Japan, Ltd.

RC-full PCa building construction example

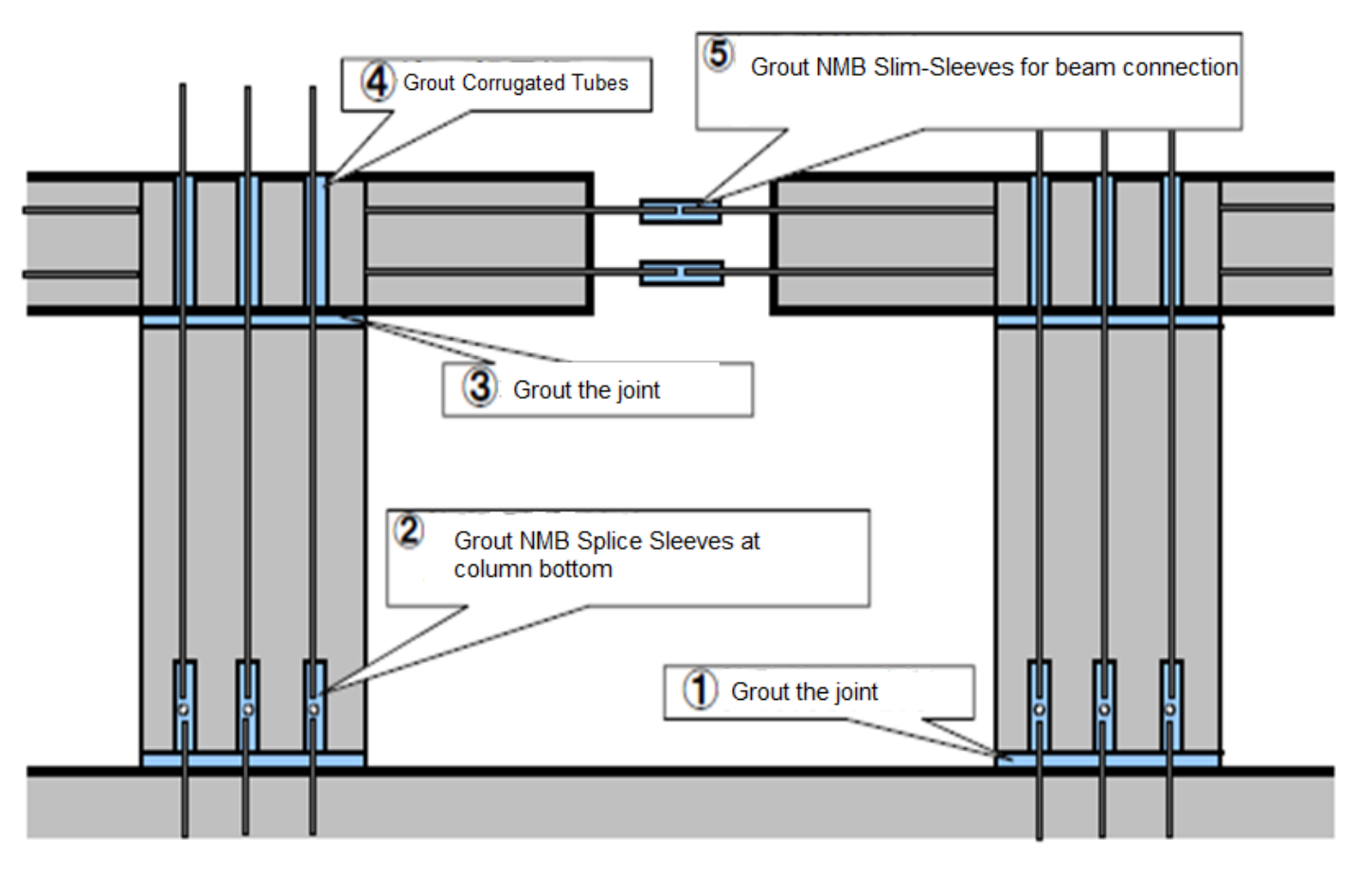
Precast concrete units

RC-full PCa building construction example

Precast concrete units

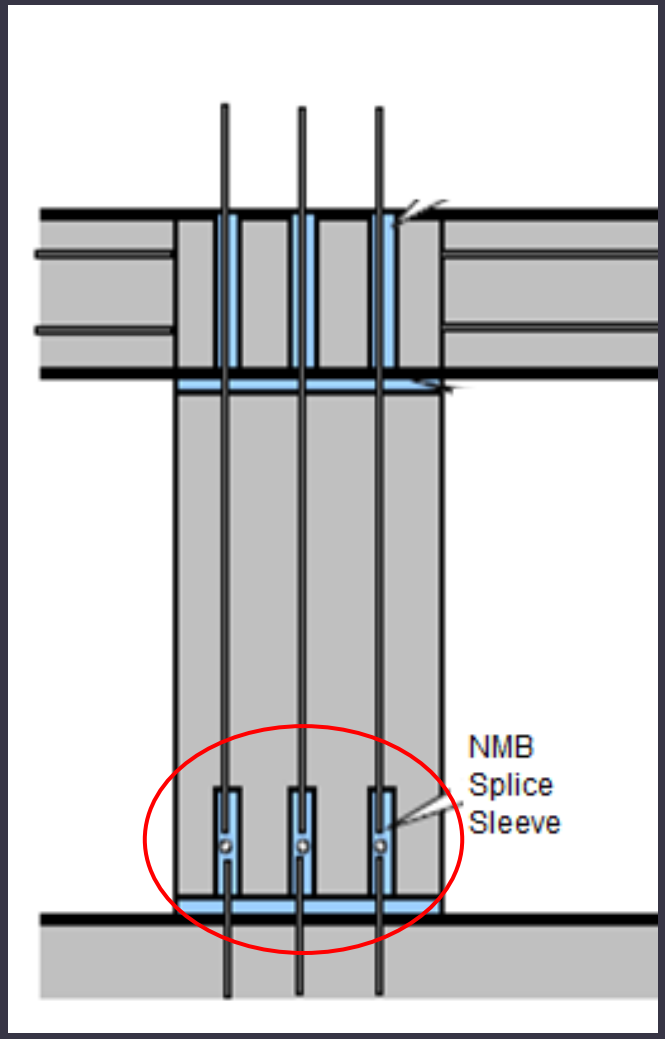
RC-full PCa building construction example

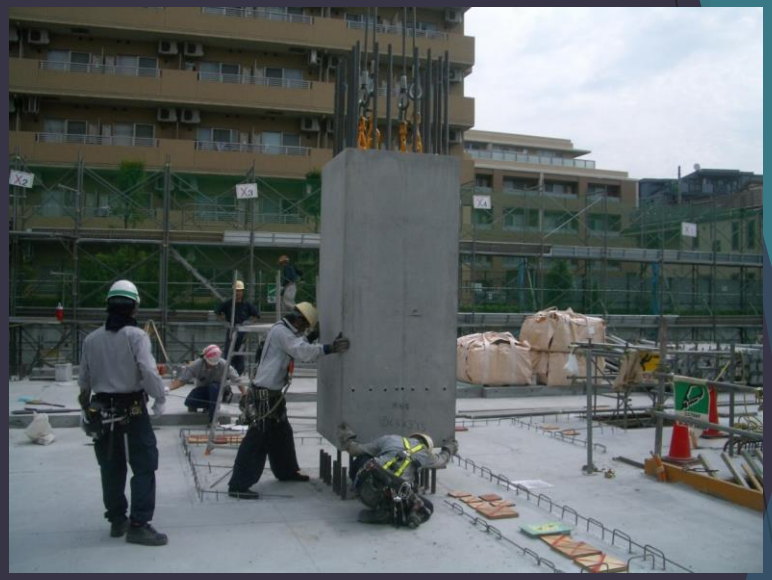
Precast concrete units



RC-full PCa building construction example

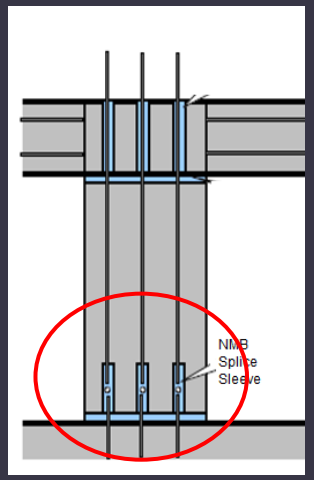
Precast column's erection

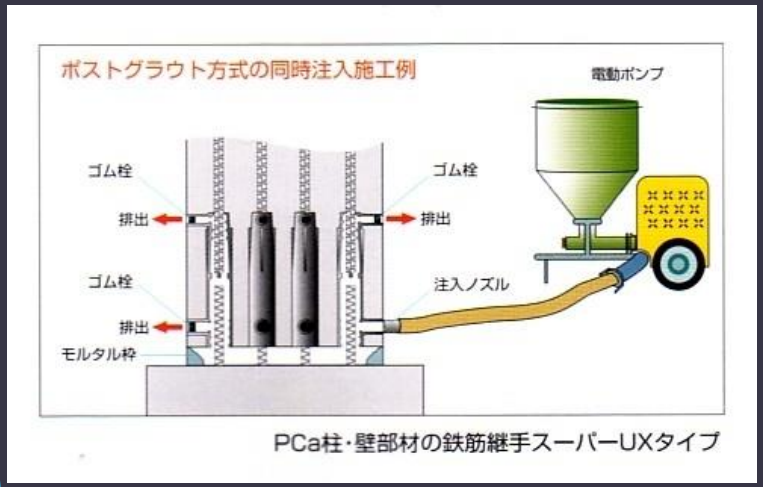




RC-full PCa building construction example

Precast column / column connections



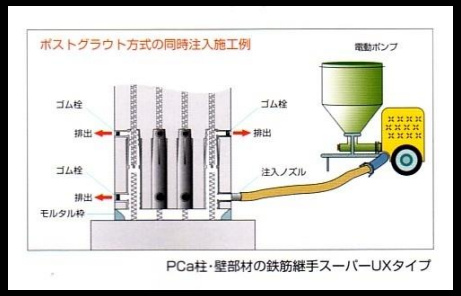


column/column joint sealing

（sealing method: high strength low-flowable grout, grouting Sleeve schedule to be conducted the next day）

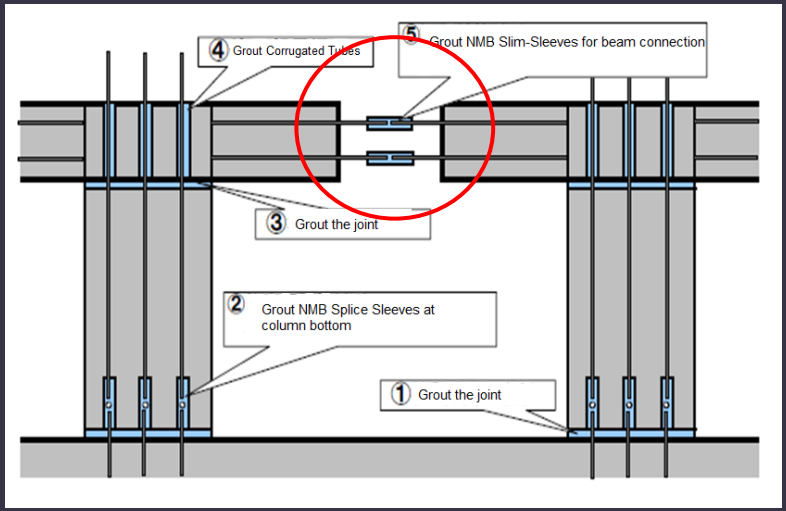
RC-full PCa building construction example

Precast column / column connections



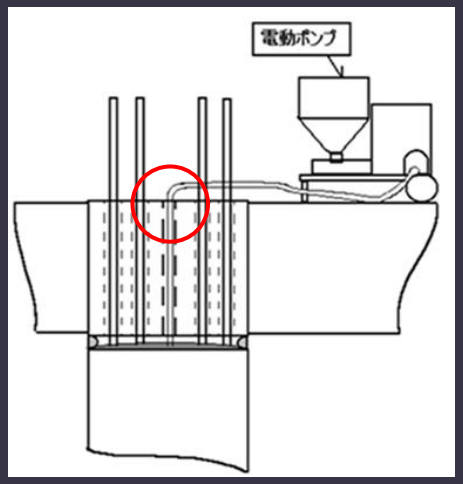
RC-full PCa building construction example

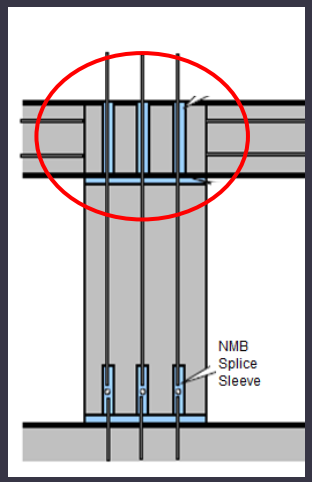
Beam / beam connection's location

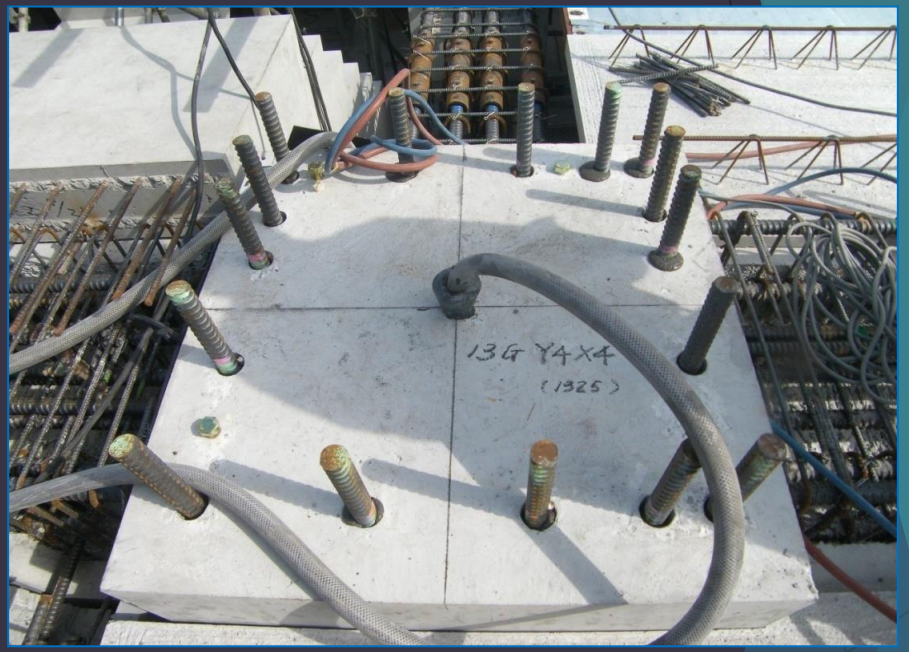


RC-full PCa building construction example

Precast column/beam connection grouting







High-rise buildings

High rise building
56 stories, Tokyo

High rise building
53 stories, Tokyo

High rise building
100 stories, Australia

ig. 1. Ala Moana Hotel in Honolulu, Hawaii, neari

- “The new vertical support technique was designed to overcome a difficulty in joining precast units. Designers and builders are continually working on new joinery for structural precast units that will provide continuity at minimum cost. This new technique appears to be a promising one. ”

PCI Journal Volume 18, No3
May-June 1973

Thank you for your attention

arigato gozaimashita

ありがとうございました

www.splice.co.jp

Middle-rise buildings

[Taisei U-Lec Co., Ltd. web site]

[Taisei U-Lec Co., Ltd. web site]

Railways projects

PCa viaducts

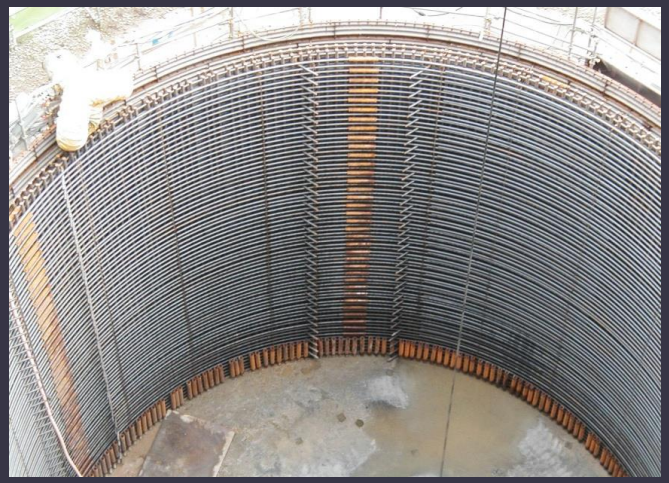
PCa sound walls

CIP piles

socket connections

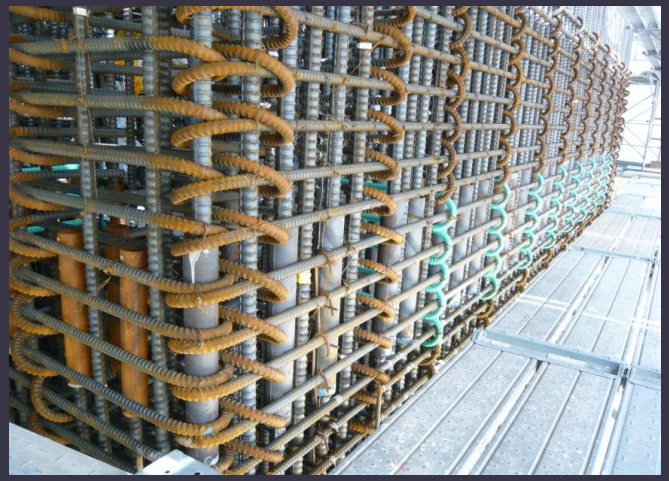
PCa columns

Bridges



CIP foundations

Epoxy couted Splice Sleeves



CIP piers

CIP upper sttructures

Others

PCa box calvarts

PCa arch calvarts

Electric power plants

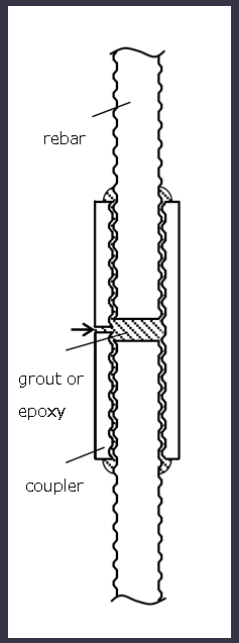
Nuclear power plants

Agenda

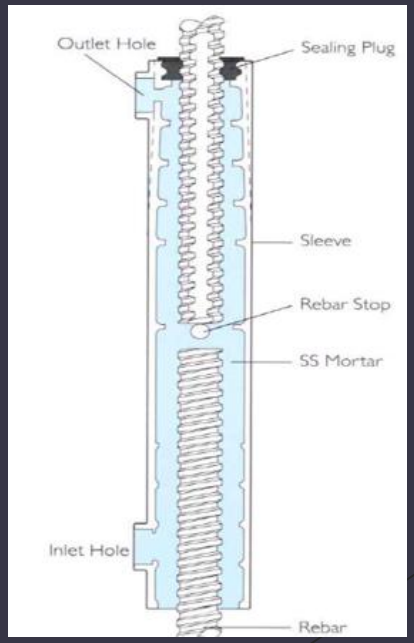
- Japan - characteristics as a seismic country
- Mechanical splices in Japan
- Japanese requirements for mechanical splices
- What are grout splices?
- Application examples

Mechanical splices in Japan

Gas pressure welding

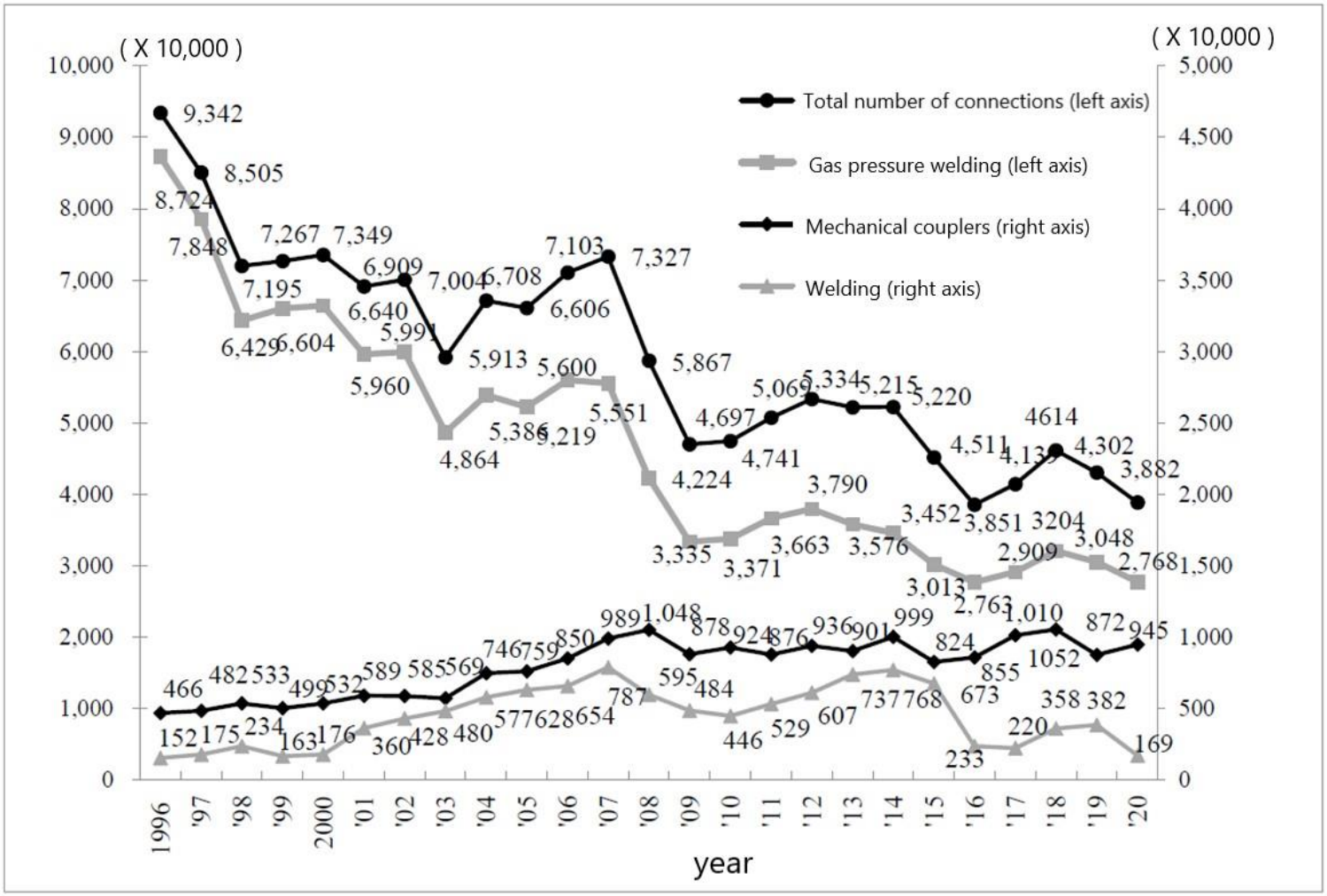


Threaded rebar's splices



Grout splices

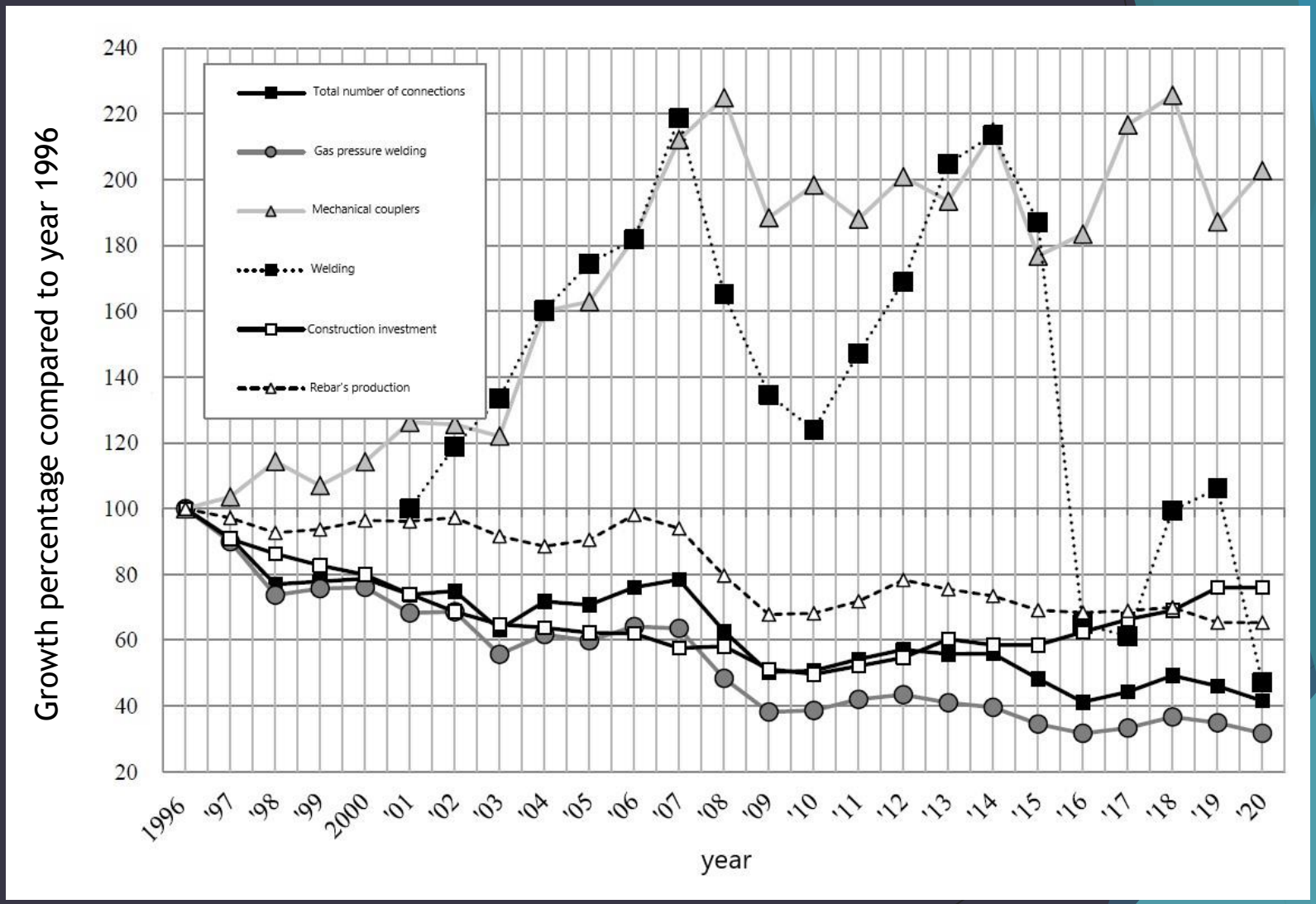
Mechanical splices in Japan



Trend of number of rebar connections per year/ per connection method

公益社団法人　鉄筋継手協会　鉄筋継手統計調査報告書（1996～2020）
Japan Reinforcing Bar Joint Institute Survey Report (1996-2020) with translations into English

Mechanical splices in Japan



公益社団法人　鉄筋継手協会　鉄筋継手統計調査報告書（1996～2020）
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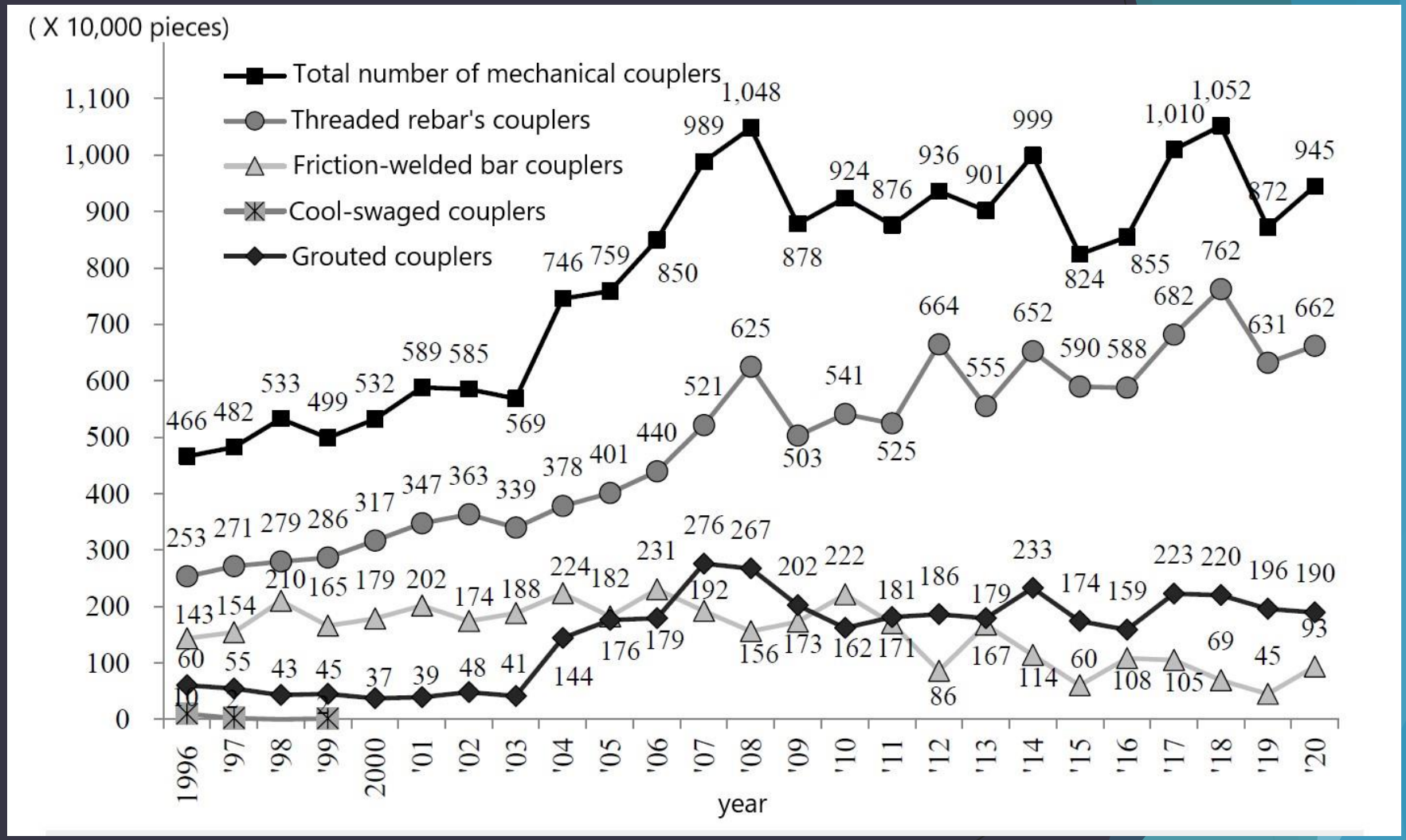
Mechanical splices in Japan



公益社団法人　鉄筋継手協会　鉄筋継手統計調査報告書（1996～2020）
Japan Reinforcing Bar Joint Institute Survey Report (1996-2020) with translations into English

- Issues about mechanical splices that were discussed at early times 1960's – 1980%s

- Is there a risk of adverse effects on the performance of the splices or the precast units by the residual stress in the splices when the concrete units are installed ?

- Is there a risk of system-specific failure of the splice in the vicinity of the splices ?

- Effects of mechanical splices installed close to the concrete unit's joint surfaces, especially on the behavior of column-beam joints

- What about the behavior of a joint within a column-beam connection ?

- Can shear forces be transferred between units at the joints ?

- Should be there limits on the diameter of splices that can be used in relation to the diameter of the concrete units, allowances for diameter differences in rebar diameters, and whether unit reinforcement is required ?

-What is the allowable limit of splice's length relative to concrete unit's dimensions ?

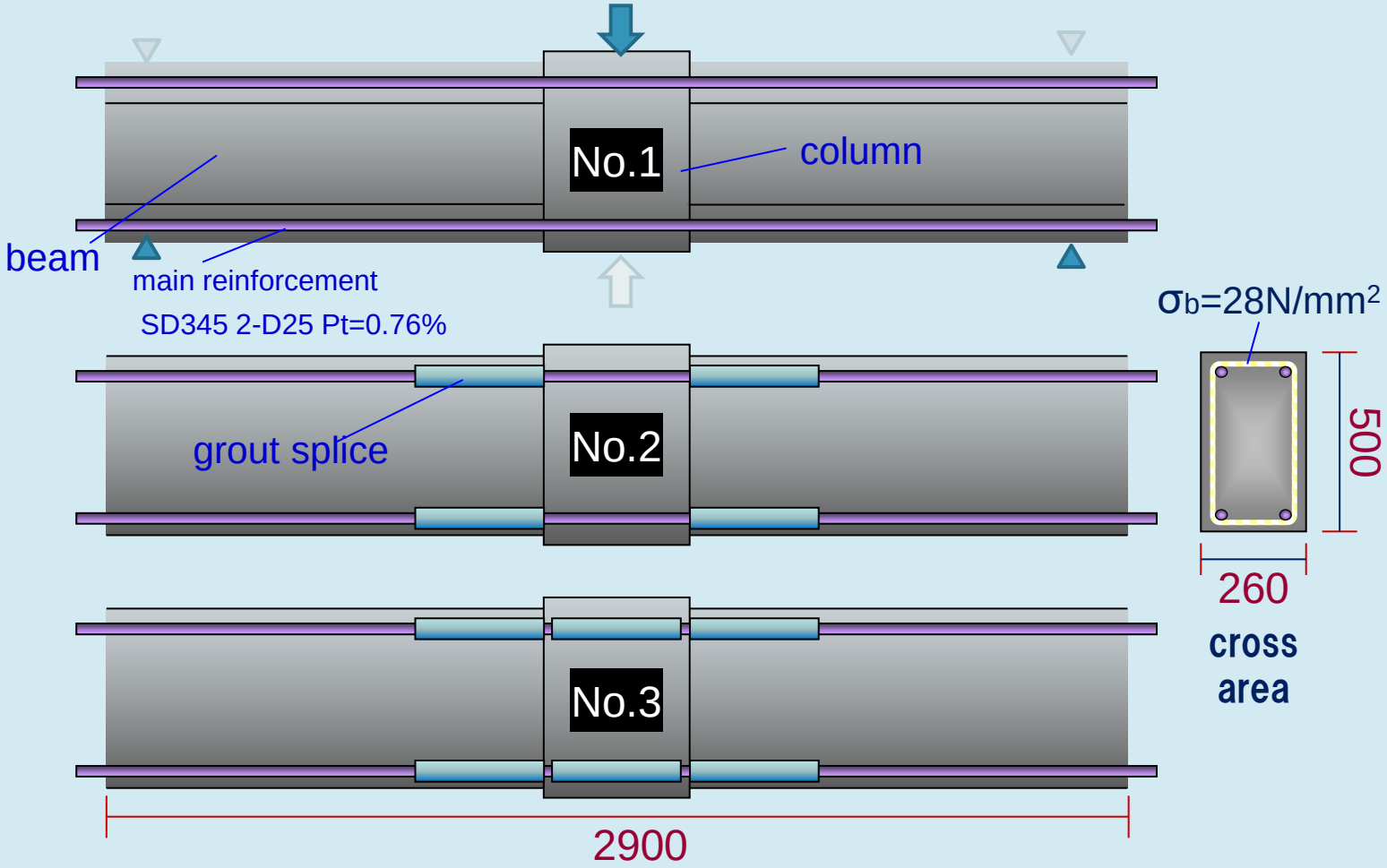
What are grout splices?

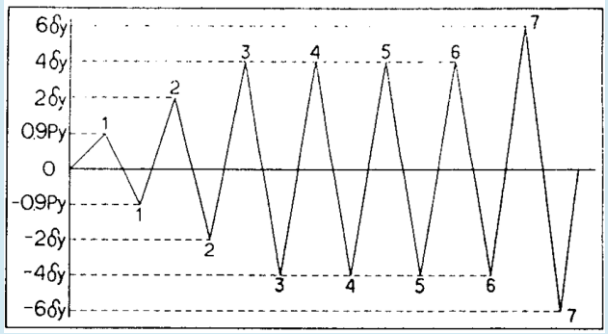
Requirements for SA class splices

- Evaluation of the splice system shall be done on the splice's single performance and by mock-up tests
- While the application of a splice system is for PIP construction, generally, mock-up tests are also required.
- Tests required for splice's single performance evaluation are monotonic tensile test, repeated tensile test, elastic cyclic test and plastic cyclic test. Fracture of the connected rebars must occur in the rebar.

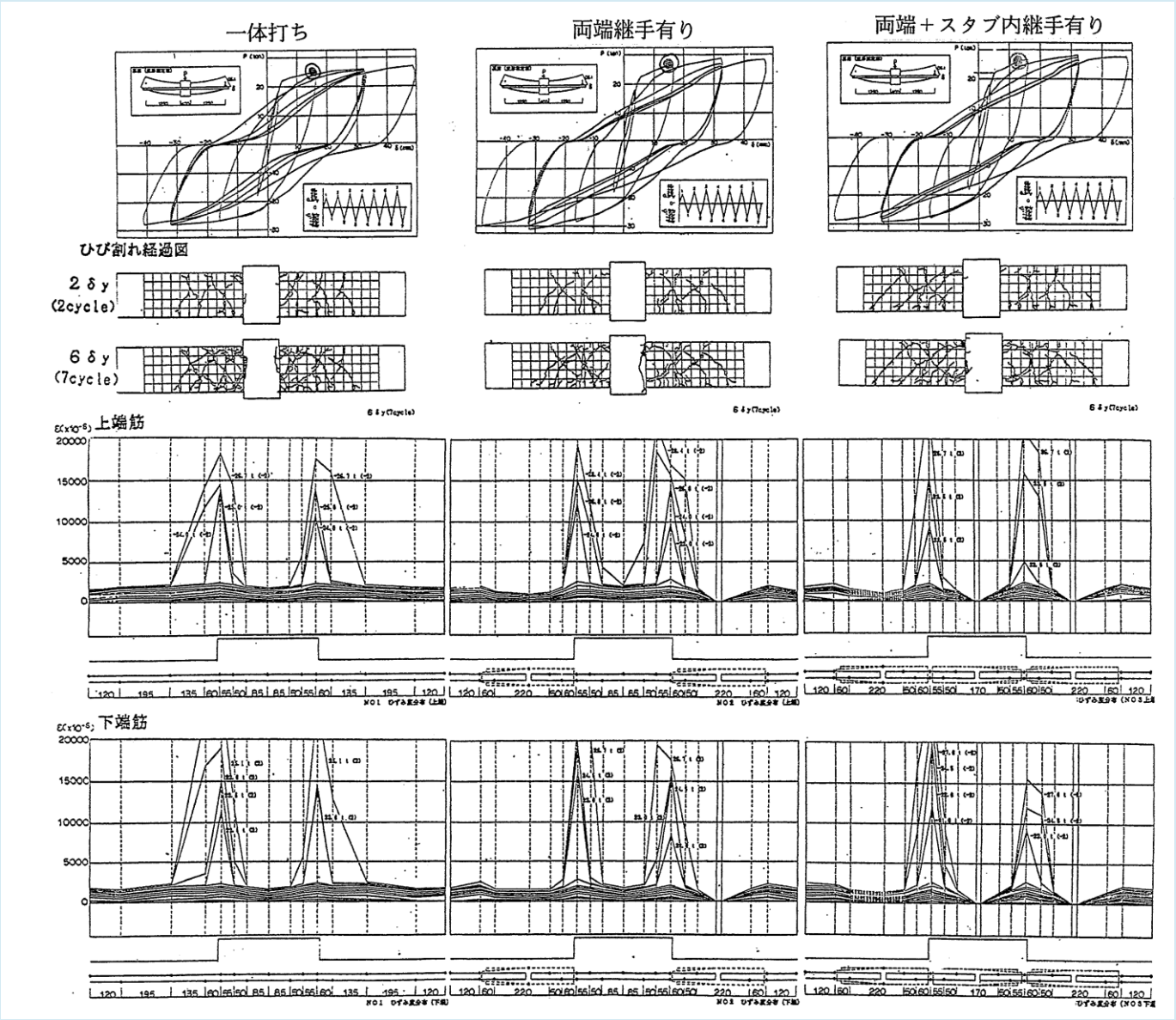
Mock-up test result example 2 (beam to column connection)

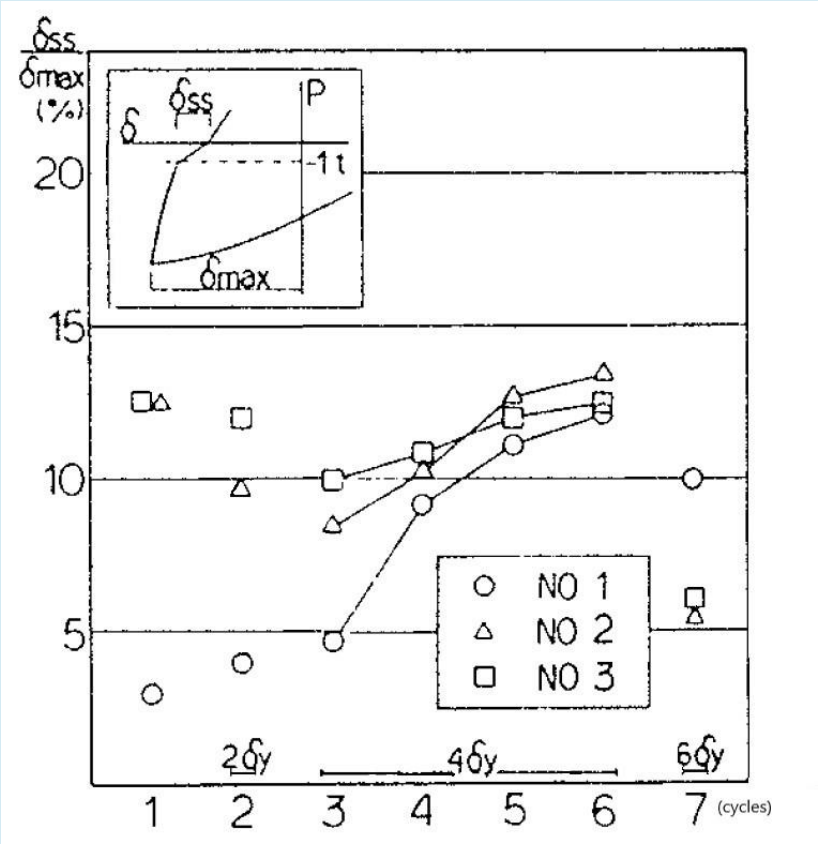
日本建築学会大会 学術講演会 1987、 p147-p148

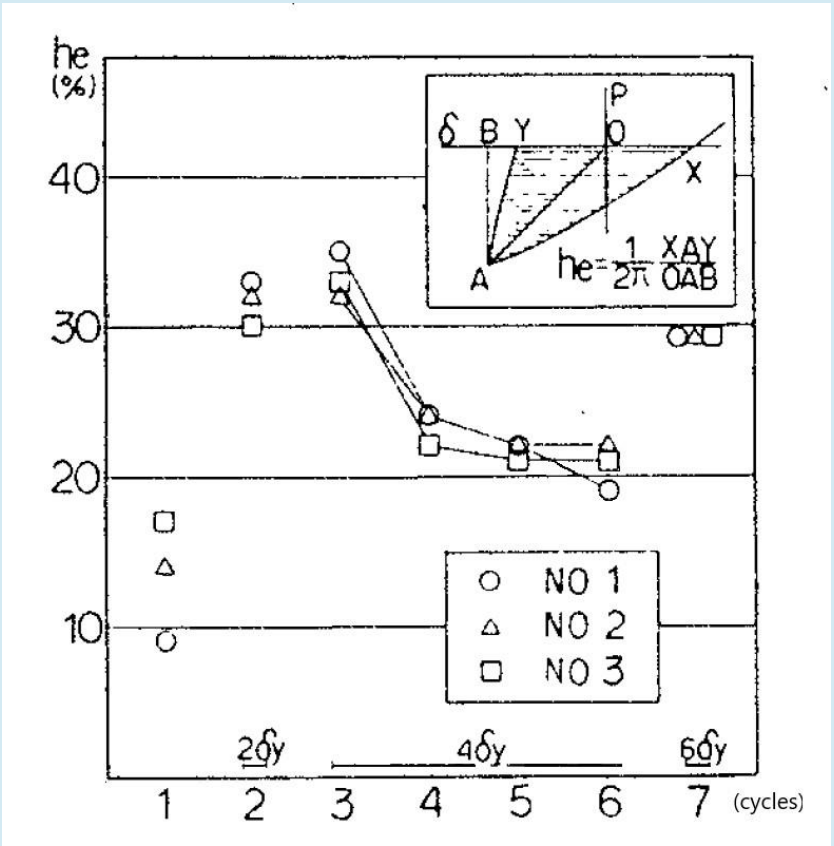


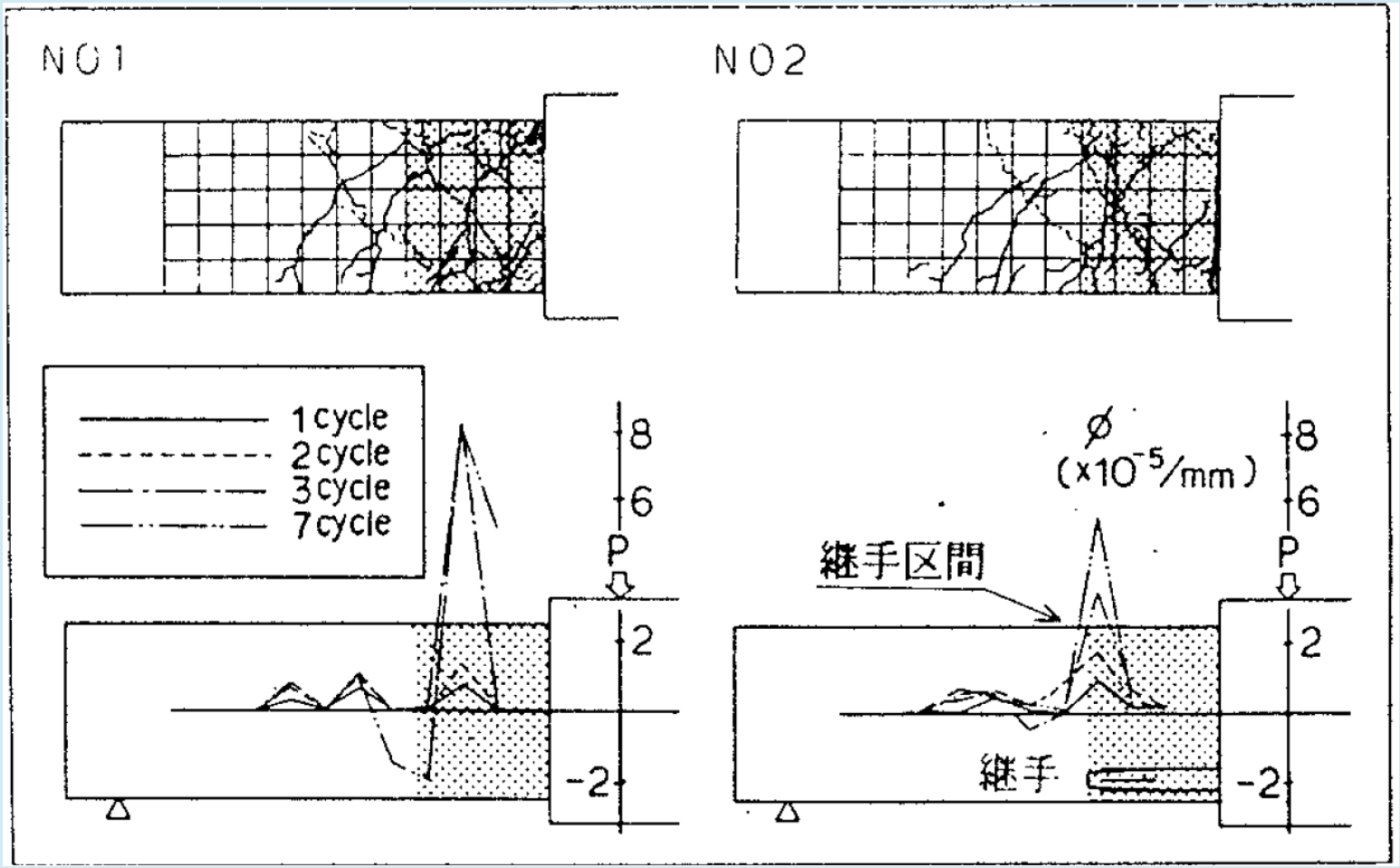


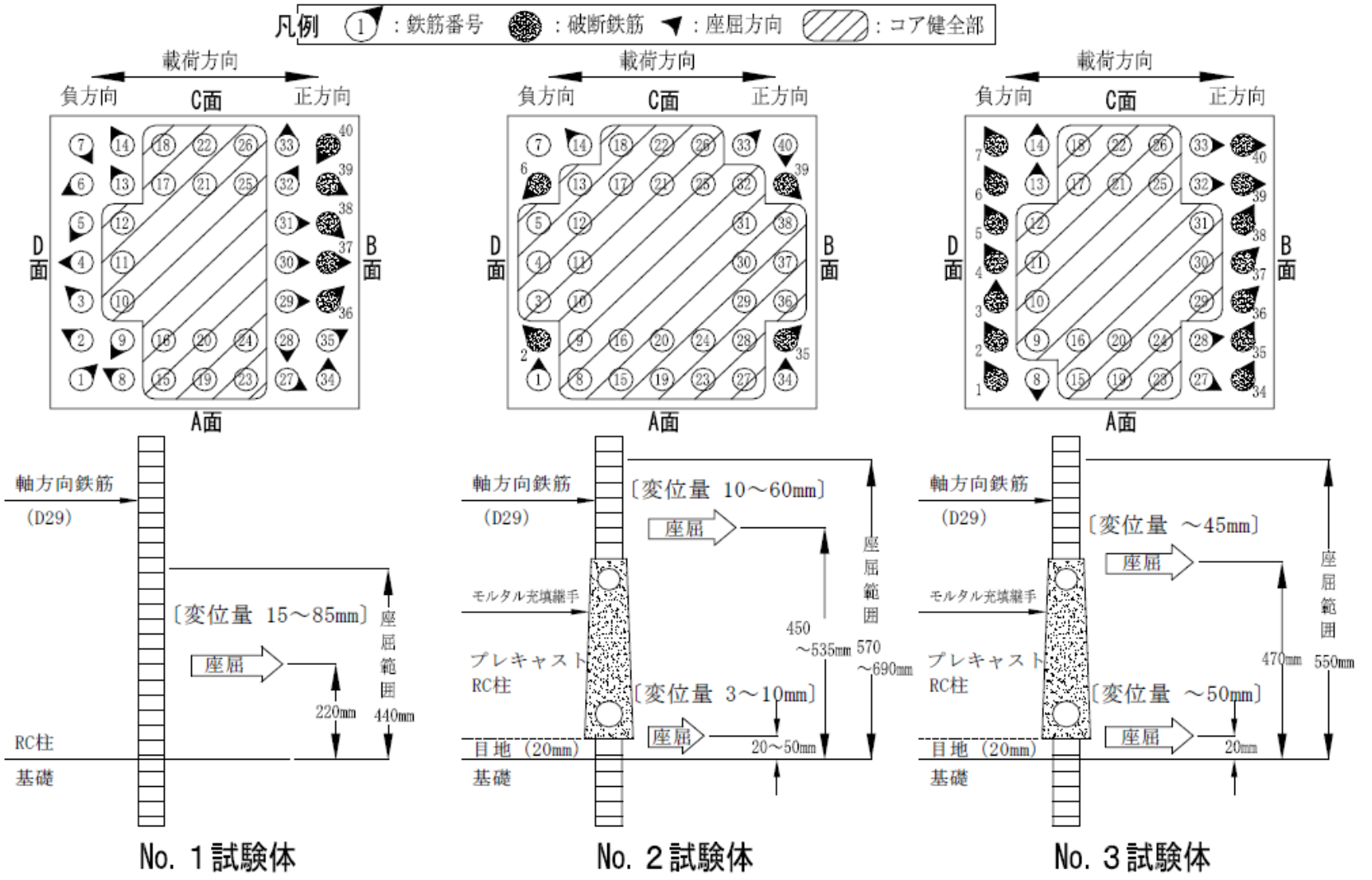
Specimen No		Test results ()number of cycles				Test /calculation results	
		flexural cracks ePc(tons)	shear cracks ePsc(tons)	flexural yield strength ePy(tons)	maximum capacity ePu(tons)	flexural yield strength ePy/cPy	ultimate bending capacity ePu/cPu
No1	+	6.5	----	22.0	26.8(7)	1.04	1.17
	—	4.0	11.0(3)	23.0	27.8(7)	1.09	1.22
No2	+	6.0	26.3(3)	21.6	28.7(3)	1.02	1.25
	—	4.5	28.6(7)	20.0	31.2(3)	0.95	1.36
No3	+	6.5	17.0	22.0	28.2(3)	1.04	1.23
	—	5.5	21.5(7)	21.0	29.3(3)	0.99	1.28
cPy = ±21.12 (tons) e function method cPu = ±22.88(tons) e function method (at concrete margin strain 0.35%)							


一体打ち
両端継手有り
両端＋スタブ内継手有り
ひび割れ経過図
2δy
(2cycle)
6δy
(7cycle)
上端筋
下端筋


δss
δmax
(%)
δ
δss
P
1 t
δmax
20
15
10
5
NO 1
NO 2
NO 3
2δy
4δy
6δy
1
2
3
4
5
6
7
(cycles)

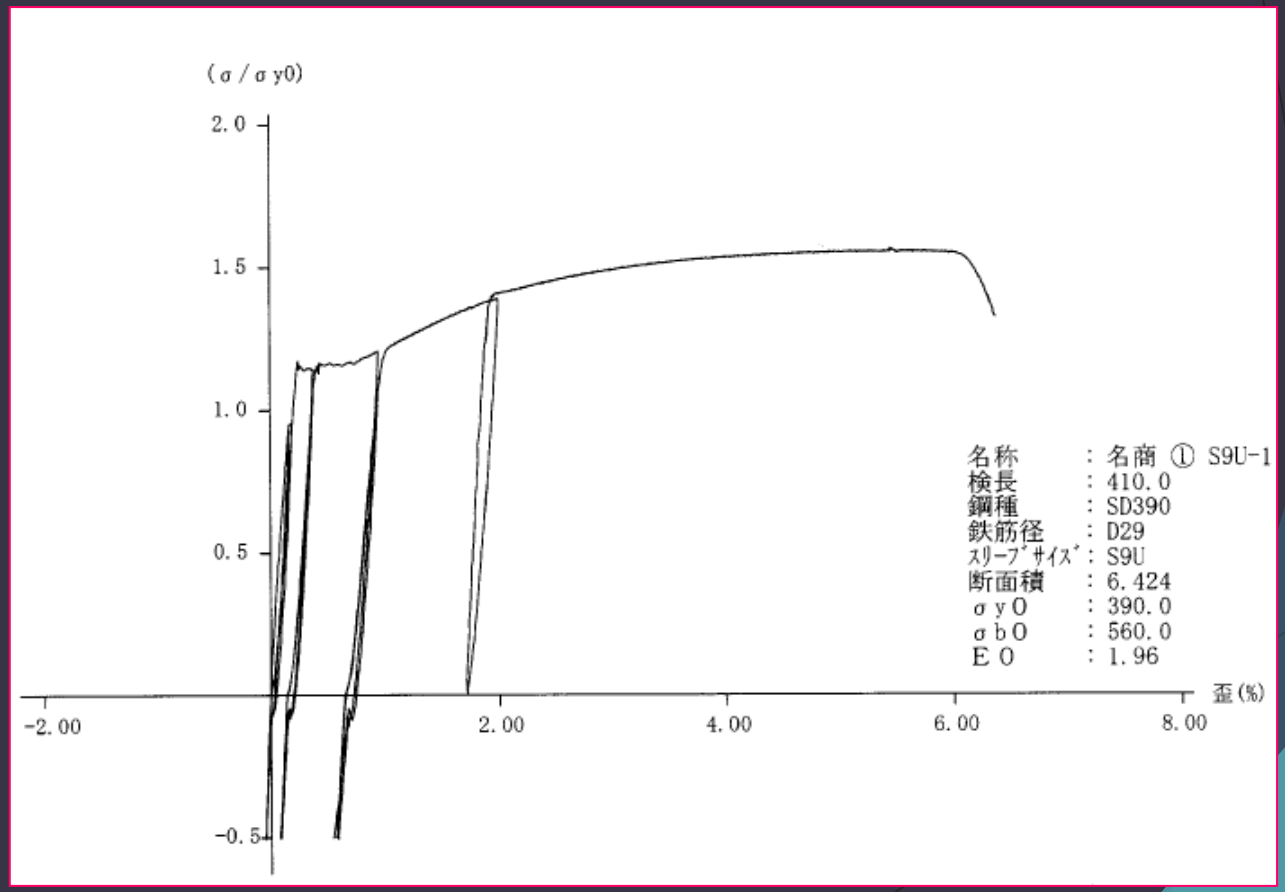

he
(%)
δ
B
Y
P
0
X
A
he = 1/2π XAY/OAB
40
30
20
10
NO 1
NO 2
NO 3
2δy
4δy
6δy
1
2
3
4
5
6
7
(cycles)


NO1
NO2
1 cycle
2 cycle
3 cycle
7 cycle
8
6
P
2
-2
ø
(x10⁻⁵/mm)
継手区間
継手


凡例
：鉄筋番号
：破断鉄筋
：座屈方向
：コア健全部
載荷方向
負方向
C面
正方向
D面
B面
A面
軸方向鉄筋
(D29)
〔変位量 15～85mm〕
座屈
座屈範囲
440mm
220mm
RC柱
基礎
モルタル充填継手
プレキャスト
RC柱
〔変位量 10～60mm〕
〔変位量 3～10mm〕
450
～535mm
570
～690mm
20～50mm
目地 (20mm)
〔変位量 ～45mm〕
〔変位量 ～50mm〕
470mm
550mm
20mm
No. 1試験体
No. 2試験体
No. 3試験体

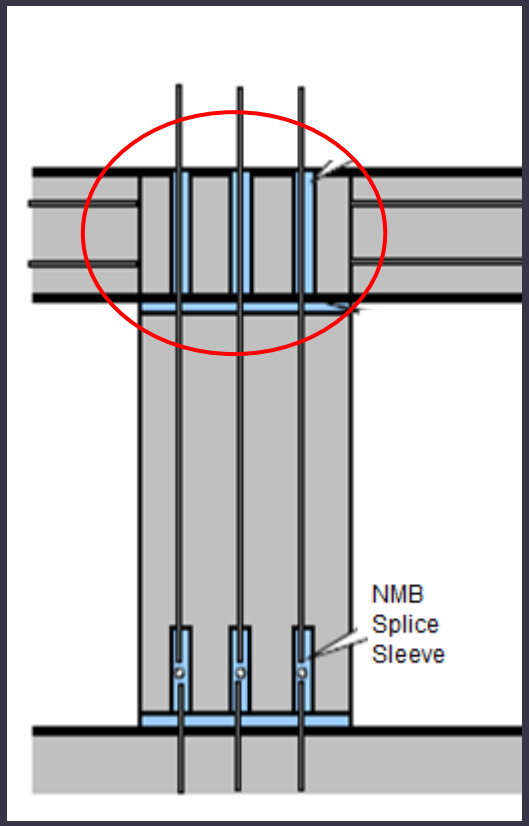
Mechanical splices requirements

Class SA: The strength, rigidity and ductility are almost equivalent to those of the rebars to splice.

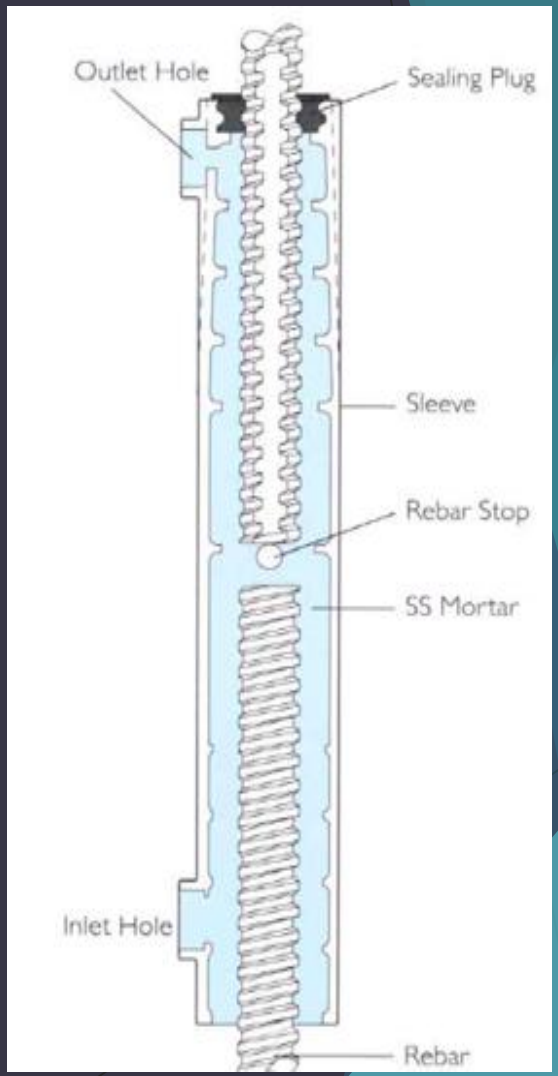


Typical R-PC building construction example

Column / beam joint area and locations



What are grout splices?



Mechanical splices requirements

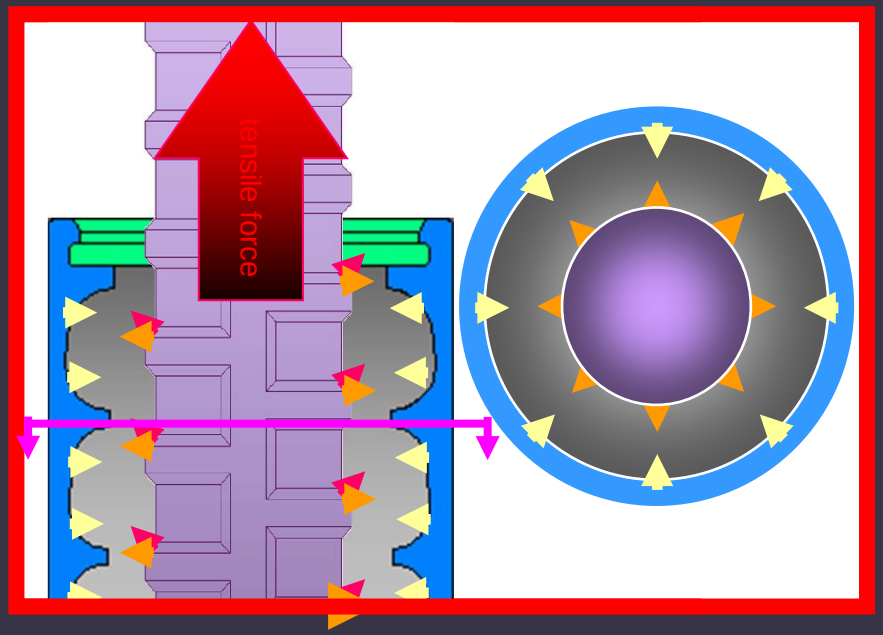
Class SA: The strength, rigidity and ductility are almost equivalent to those of the rebars to splice.

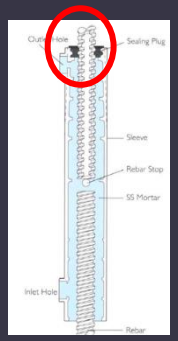
Required tension strength	**Static tension test** $\sigma_b > 1.35\sigma_{y0}$ or $\sigma_b > \sigma_{b0}$ **Repeated tension test** $\sigma_b > 1.35\sigma_{y0}$ or $\sigma_b > \sigma_{b0}$ **Cyclic tension and compression test** $\sigma_b > 1.35\sigma_{y0}$ or $\sigma_b > \sigma_{b0}$ **Static Compression test** (not required) σ_b : actual strength σ_{b0} : specified tensile strength σy_0 : rebar's specified yield strength
Required rigidity	**Static tension test** $0.7\sigma_{yo}E \geqq E_0$ $0.95\sigma_{yo}E \geqq 0.9E_0$ **Repeated tension test** ${}_{30c}E \geqq 0.85\,{}_{1c}E$ E_0 : rebar's Young's modulus E : rebar's secant modulus ${}_{1c}E$, ${}_{30c}E$: rebar's secant modulus at stresses of $0.95\sigma_{y0}$ at 1st or 30th loading. σ_{y0} : rebar's specified yield strength

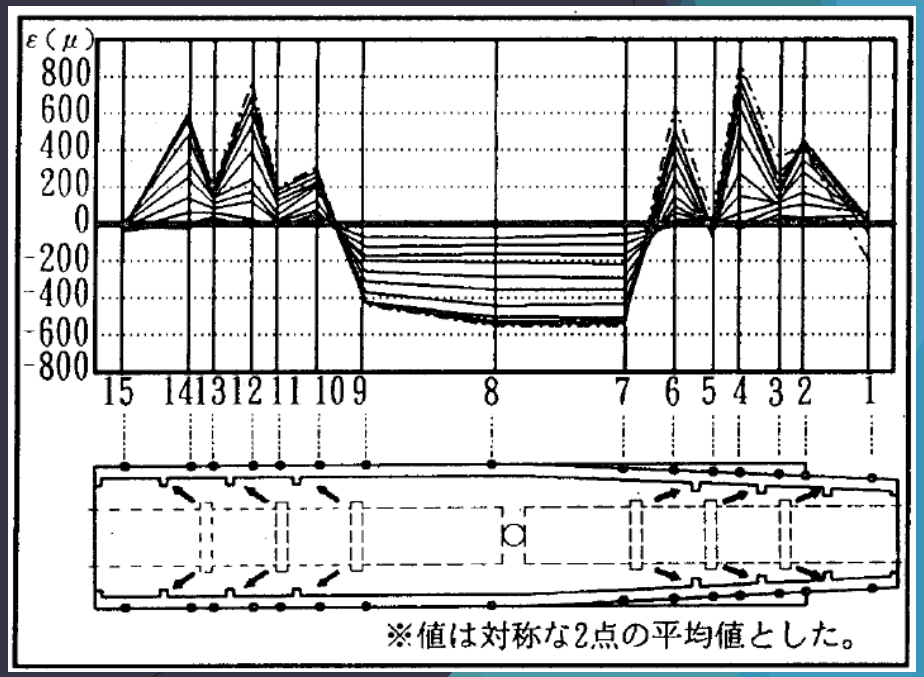
Required ductility	**Static tension test** $\varepsilon_u > 20\varepsilon_y$ **Repeated tension test** $\varepsilon_u > 20\varepsilon_y$ & $\varepsilon_u > 0.04$ ε_u : rebar's ultimate strain ε_y : rebar's strain at actual yield stress
Required elongation	**Static tension test** $\delta_s < 0.3$mm at $0.95\sigma y_0$ **Repeated tension test** ${}_{30c}\delta_s < 0.3$mm **Cyclic tension and compression test** ${}_{4c}\varepsilon_s < 0.5\varepsilon_y$ & ${}_{4c}\delta_s < 0.3$mm & ${}_{8c}\varepsilon_s < 1.5\varepsilon_y$ & ${}_{8c}\delta_s < 0.9$mm ε_s : rebar's slipping strain ε_y : rebar's strain at actual yield stress δ_s : rebar's elongation σy_0 : rebar's specified yield strength

What are grout splices?

Load transfer mechanism



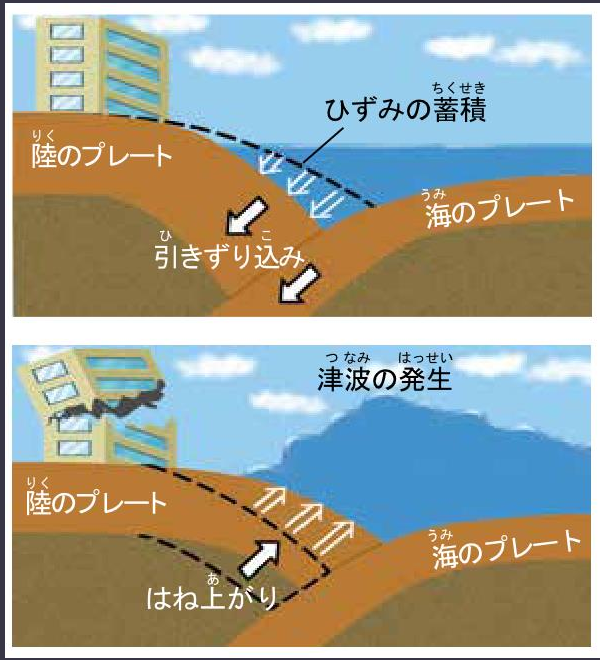




Agenda

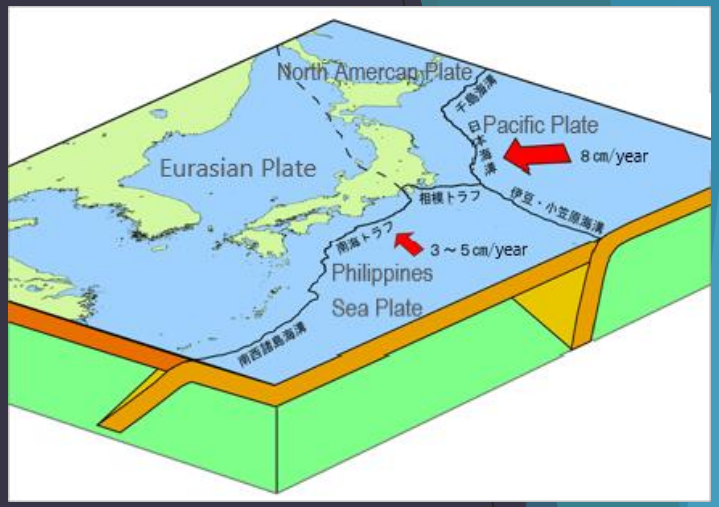
- Japan - characteristics as a seismic country
- Japanese requirements for mechanical splices
- What are grout splices?
- Application examples

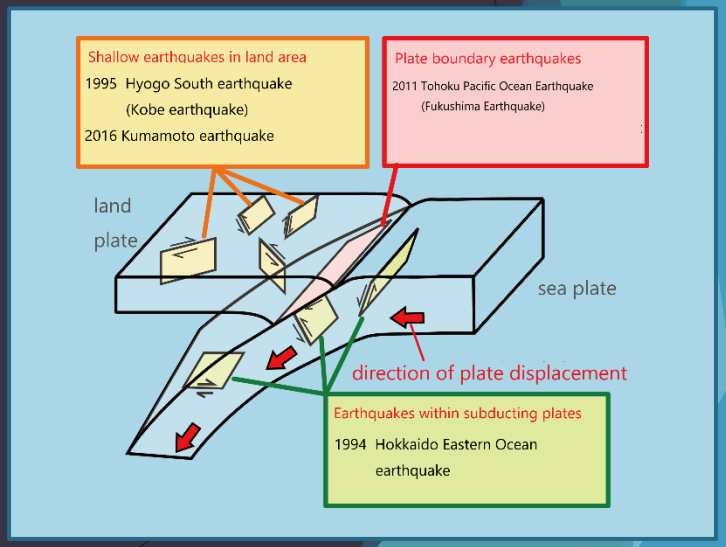
Seismic country - Japan



Ministry of Education, Culture, Sports, Science and Technology's web site,
Brochure for children [地震を知ろう]

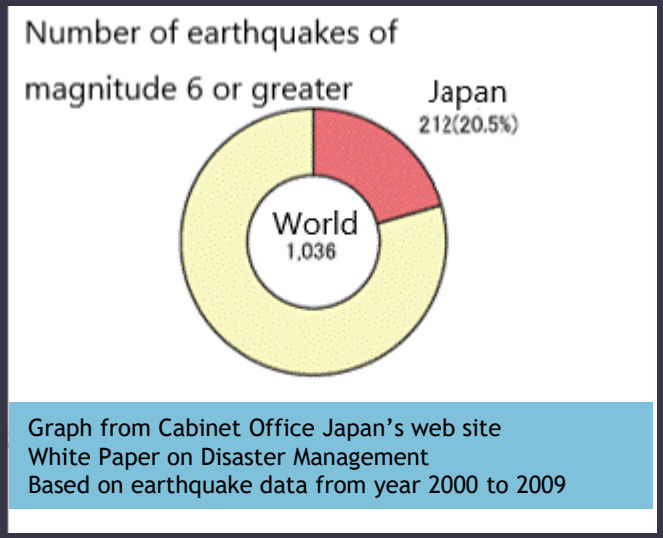
Around Japan, when the oceanic plate subducts, it drags the land plate underground. When the land plate can no longer withstand the drag, the plate boundary earthquakes occur as if it were being bounced up.



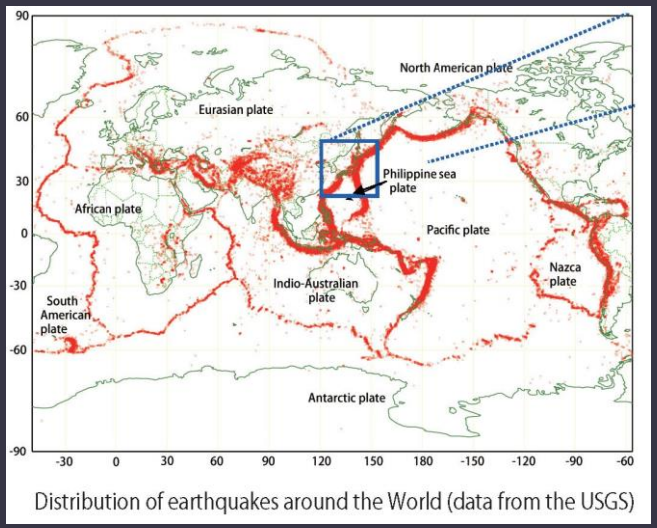


Japan Meteorological Agency web site [地震の仕組み]
with translations into English

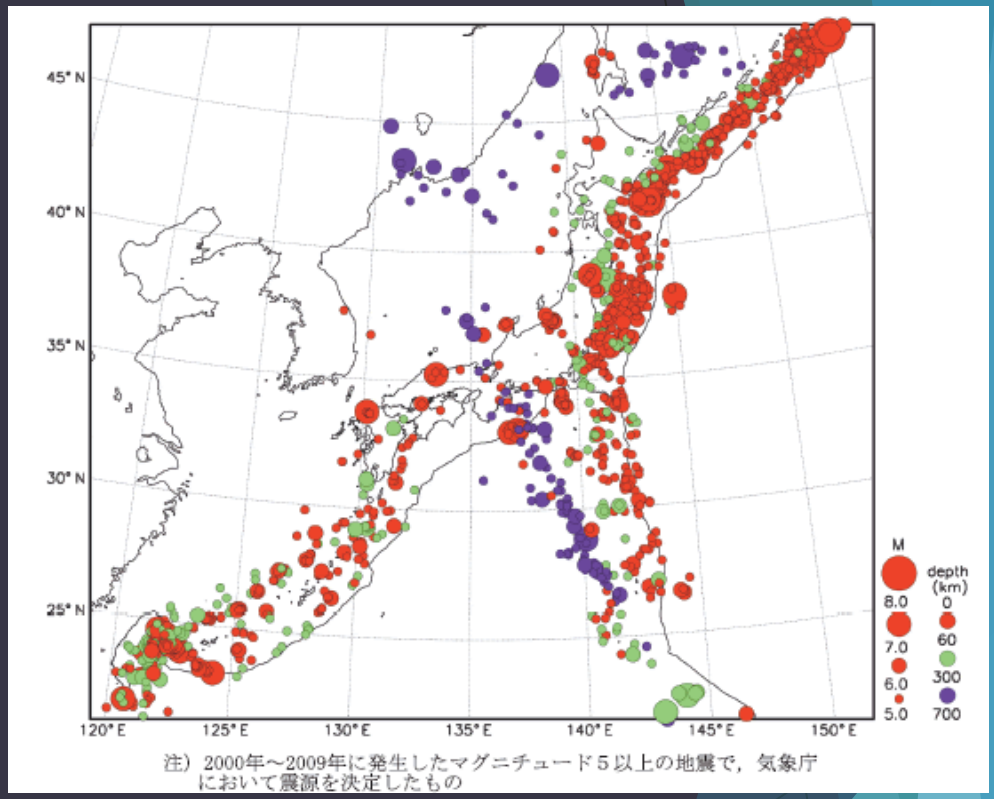
Seismic country - Japan



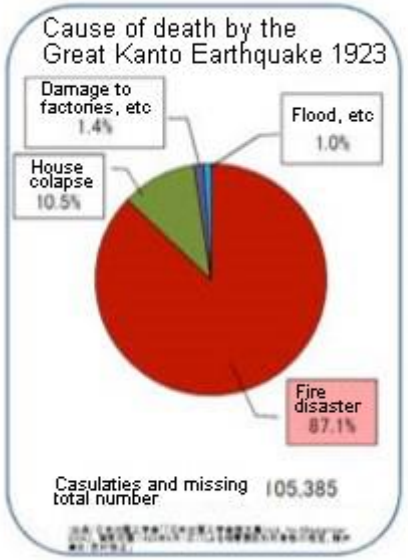
Graph from Cabinet Office Japan's web site
White Paper on Disaster Management
Based on earthquake data from year 2000 to 2009

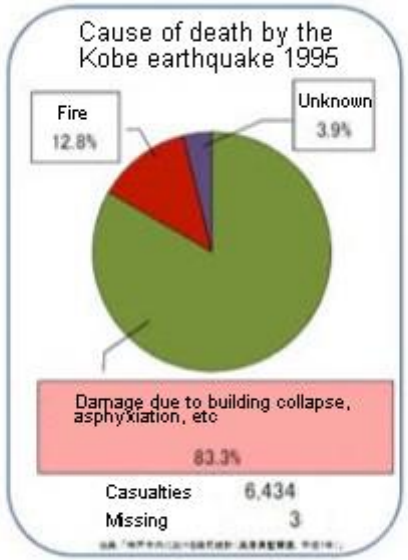


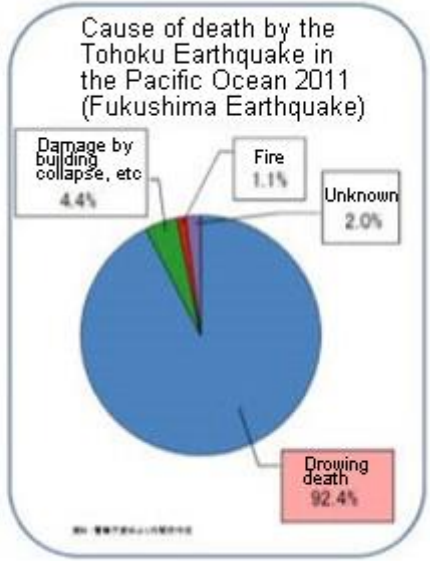
Distribution of earthquakes around the World (data from the USGS)



Cabinet office of Japan's web site
White Paper on Disaster Management year 2010







	Great Kanto Earthquake	Kobe Earthquake	Fukushima Earthquake
Date	September 1, 1923	January 17, 1995	Mach 11, 2011
Epicenter	Prefecture of Kanagawa, North-East of Sagamihara golf	North of Awaji Island	130 km east-south of Ojika peninsula, Prefecture of Miyagi,
Areas affected	South of Kanto area	South of Prefecture of Hyogo	Tohoku area, north of Kanto area
Magnitude	7.9	7.3	9.0
Casualties	105,385	6,434	15,234
Missing		3	8,616
Injured	103,733	43,792	5,339
Houses damaged	372,659	256,312	161,665

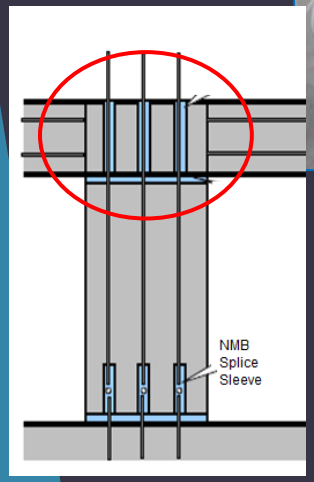
注）東日本大震災の死者・行方不明者は平成 23 年 5 月 26 日現在

（出典）中央防災会議「東北地方太平洋沖地震を教訓とした地震・津波対策に関する専門調査会」
第 1 回会合（平成 23 年 5 月 24 日）資料 3-2 より作成

Japan Institute of Country-ology and Engineering web site
「意外と知らない日本の国土→地震の多い国、日本」 with translations into English

Typical R-PC building construction example

Precast column/beam connection

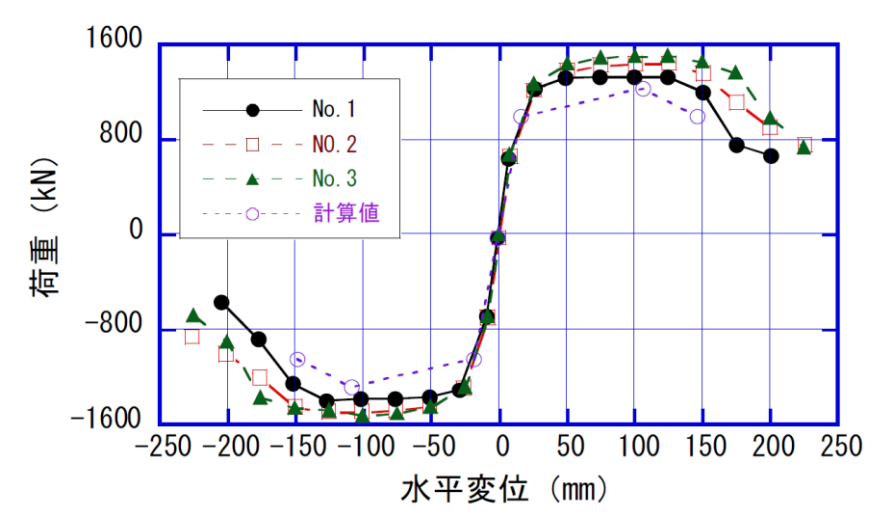


column/column

gap sealing

Grout splices – column mock-up test example

コンクリート工学年次論文集, Vol. 27, No. 2, 2005**より引用**

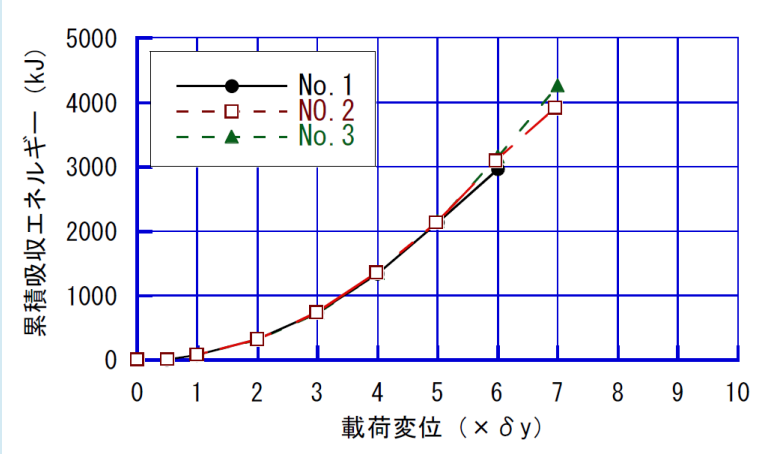


envelop curve of the load/displacement curves
the line connecting the white cycles show the calculated line

no significant difference between the 4 lines

Accumulated absorbed energy

no significant differences



Mock-up test result example (column-foundation connection)

コンクリート工学年次論文集, Vol. 27, No. 2, 2005より引用 Proceedings of the Japan Concrete Institute

Example

Performance mock-up test

Railway Technical Research Institute

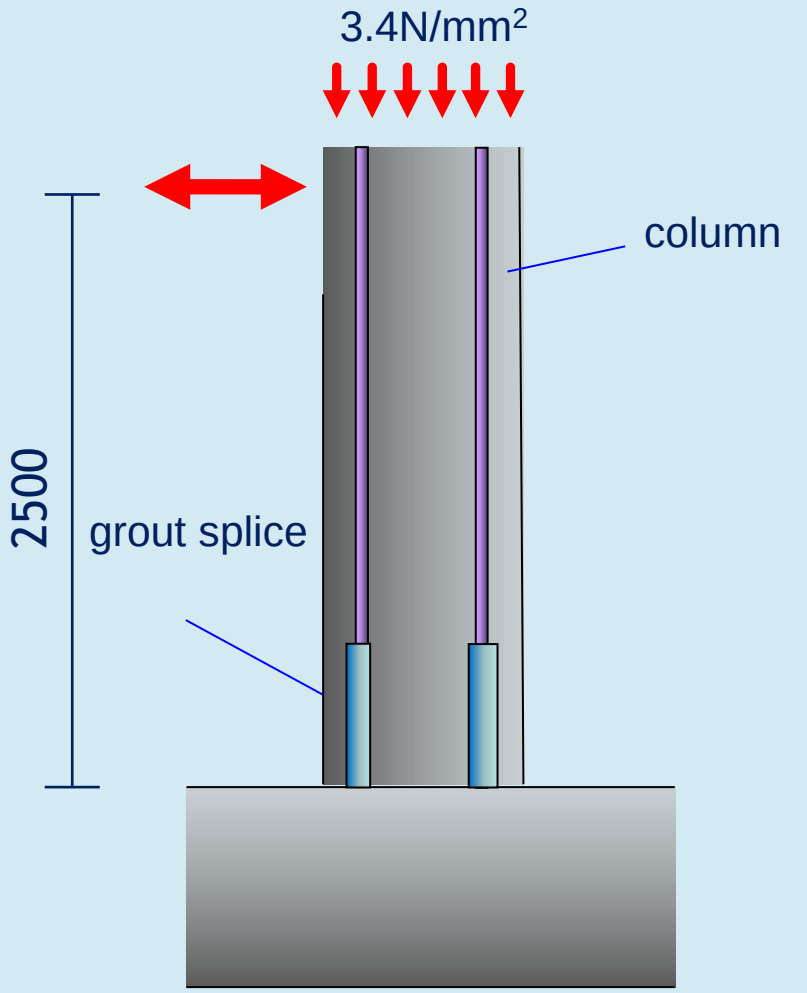
Viaduct for railways

Frame structure

Comparison between PIP and PCa + grout splices

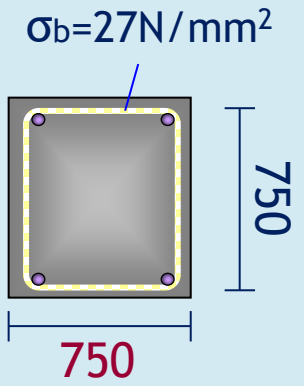
Mock-up test result example 1 (column-foundation connection)

コンクリート工学年次論文集, Vol. 27, No. 2, 2005より引用



Column vertical reinforcement ratio 4.568%

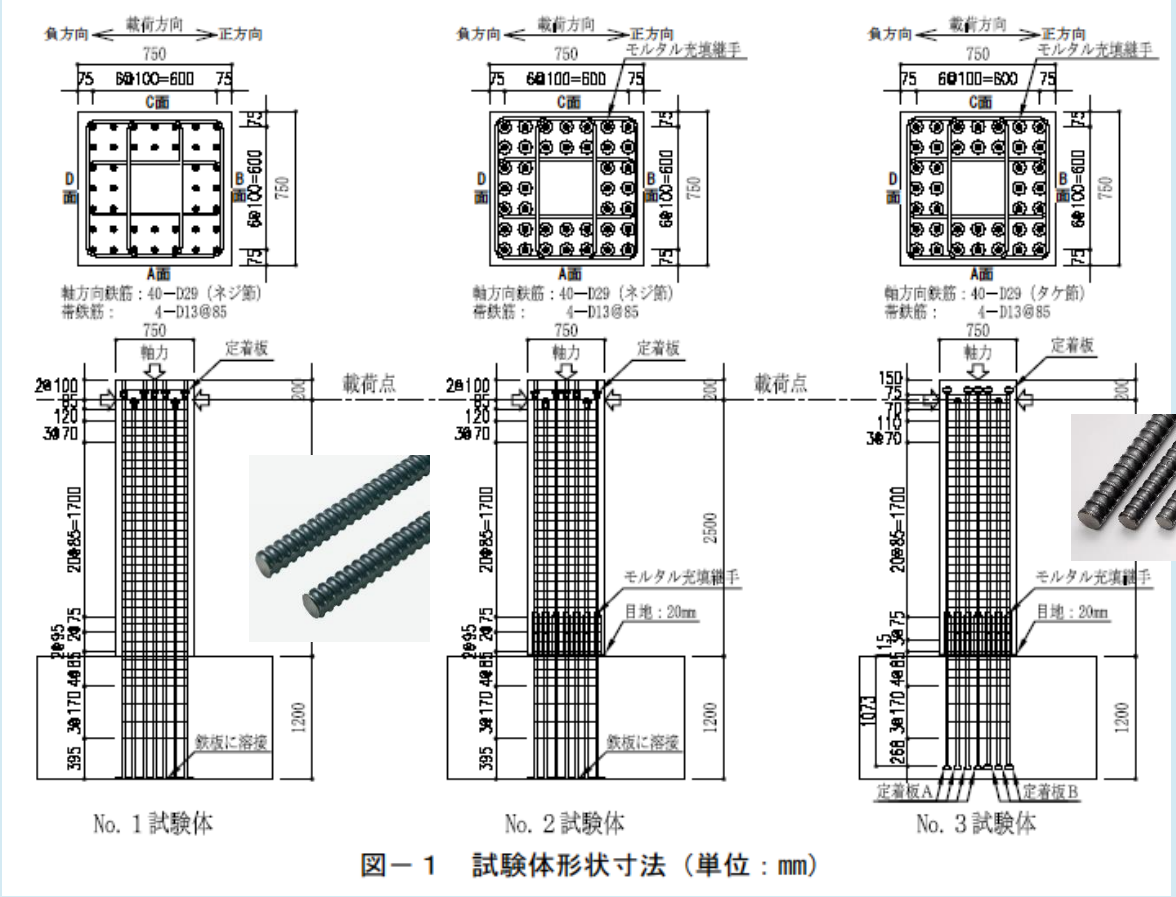
Rebar size D29



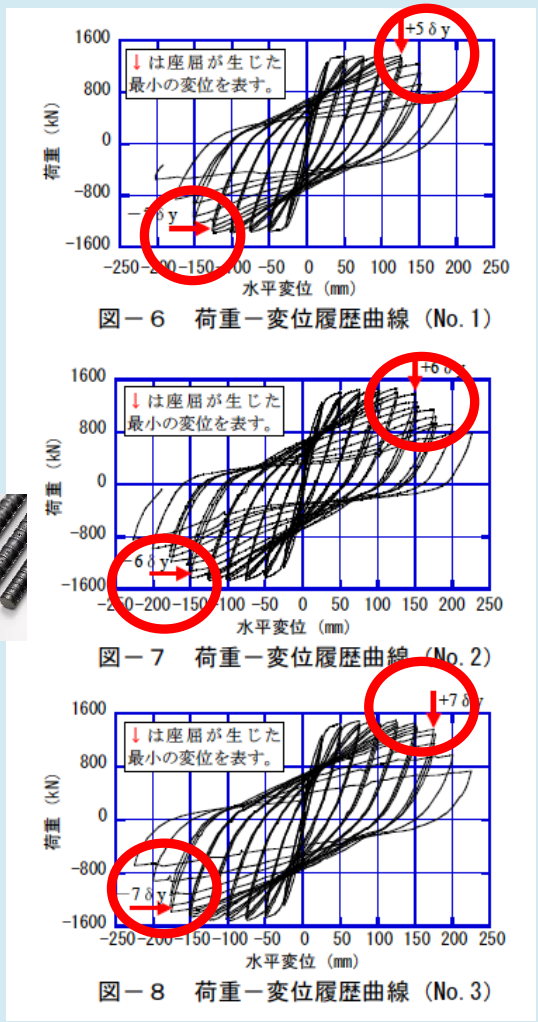
cross area

Grout splices – column mock-up test example

コンクリート工学年次論文集, Vol. 27, No. 2, 2005**より引用**



図－１　試験体形状寸法（単位：mm）



図－６　荷重－変位履歴曲線（No. 1）

図－７　荷重－変位履歴曲線（No. 2）

図－８　荷重－変位履歴曲線（No. 3）

Comparison between a CIP column and PCa column connected to the footing with grout splices