High Performance Steel Needs, Application to Bridge Structures in Japan, U.S.

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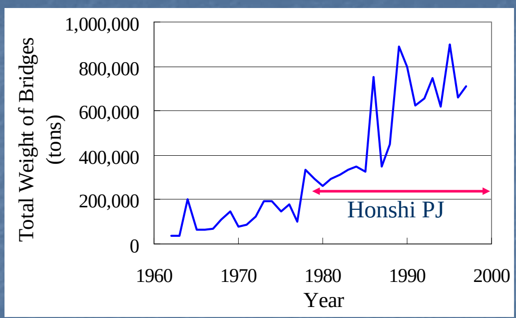
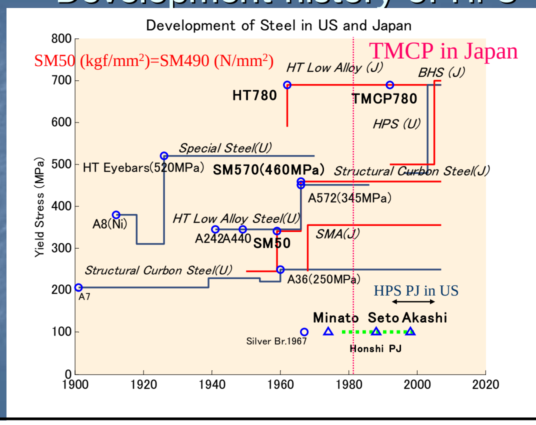
4. BHS （Bridge HPS) in Japan

History of Steel Bridge Construction in Japan

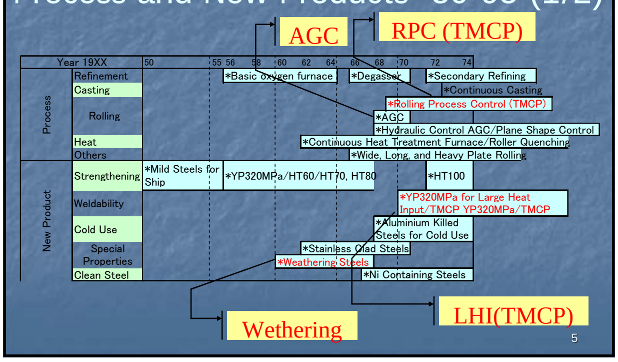


Total Weight of Constructed Bridges

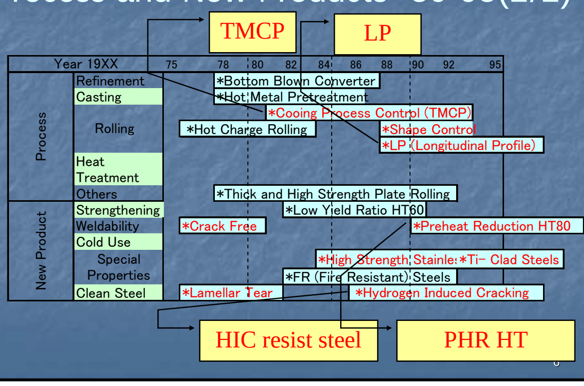
Development history of HPS

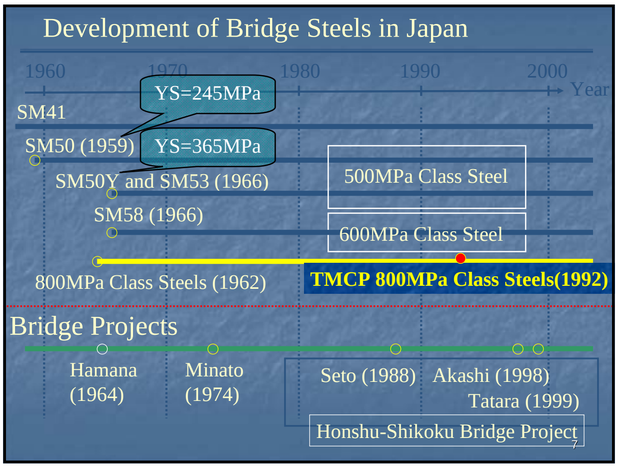


Developments of Innovative Rolling Process and New Products 50-95 (1/2)



Developments of Innovative Rolling Process and New Products 50-95(2/2)



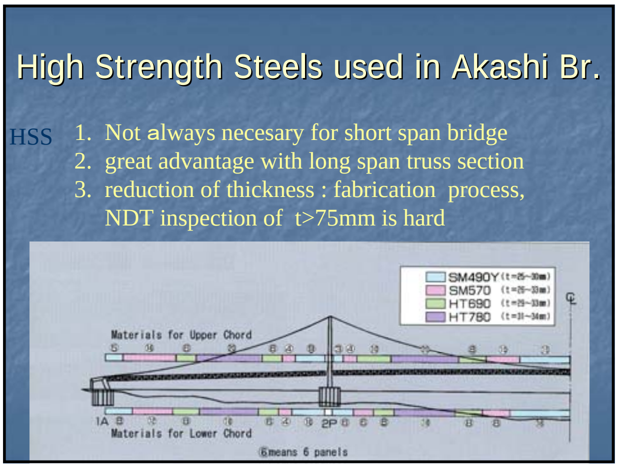

Development of Bridge Steels in Japan
1960
1970
1980
1990
2000
Year
YS=245MPa
SM41
SM50 (1959)
YS=365MPa
500MPa Class Steel
SM50Y and SM53 (1966)
SM58 (1966)
600MPa Class Steel
800MPa Class Steels (1962)
TMCP 800MPa Class Steels(1992)
Bridge Projects
Hamana
(1964)
Minato
(1974)
Seto (1988)
Akashi (1998)
Tatara (1999)
Honshu-Shikoku Bridge Project

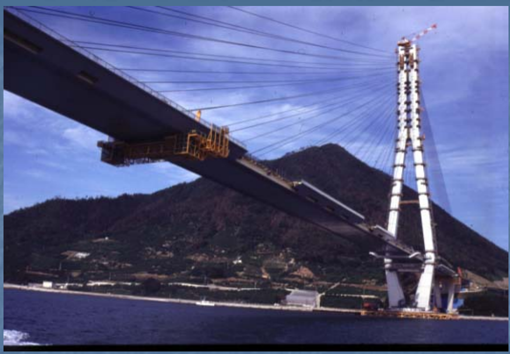

Minato Ohashi
Constructed in 1974
(235m+510m+235m)
First 800 MPa class steel was amde in Keiyo Express way in 1964
The Use of High Strength Steel
700MPa Class Steel : 1073 ton
800MPa Class Steel : 4195 ton
MEX Steel Pier


Honshu-Shikoku Bridge Project
1979-1999
SM570, HT700,800
TMCP 800 in 1992


Innoshima Br.
tatara Br.
Ikuchi Br.
O-mishima Br.
Hakata-Oshima Br.
Kurushima Br.
Tatara (1999)
890 + 320 (Cable Stayed)
Iwaguro
185 + 420 +185 (Cable Stayed)
4105


Akashi (1998) 960 + 1991 + 960 (The Longest Suspension Bridge)


High Strength Steels used in Akashi Br.
HSS
1. Not always necesary for short span bridge
2. great advantage with long span truss section
3. reduction of thickness : fabrication process, NDT inspection of t>75mm is hard
SM490Y
SM570
HT690
HT780
Materials for Upper Chord
Materials for Lower Chord
6 means 6 panels



Tatara (1999) 270 + 890 + 320
(The Longest Cable Stayed Bridge)

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Seto Ohashi
Highway+Railway combination type
Total Length 10km

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- Full scale or near scale test

⇩

- local stress in connection
- complicated force transmision in truss node
- static design and fatigue design

1/4 scale model of truss

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connection

- most important part in structure
- stress distribution in bolt splice
- true scale bolt connection tested
- slip, redistribution of force

Multi-array High Strength Bolts

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Fatigue stress assessment of complicated steel structure

long span bridge : fatigue considered in specific region

- Bearing member supports whole load
- weld detail affects 100 life year
- detail of 2nd member (Stiffenner, gusset) evaluated

Cross Frame, bearing structure of railway stringer

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Full scale Box girder section fatigue test

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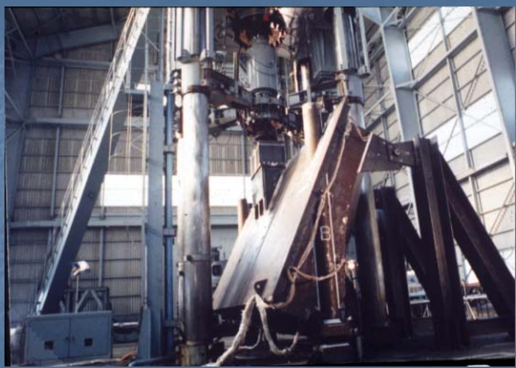

Anchoring System of Cable-Stayed Bridge

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2. Optimized Performance of BHS

1. Weldability
2. Anti-corrosion
3. Strength (tensile, fatigue)

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Optimized Performance

rationalization of bridge structure

- reducing number of small members to reduce fabrication cost
- HP material combined with advanced design, fabrication technology

New Concept of steel system → Performance to fit the purpose is required

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New Innovative Steels

Akashi

New Developed 800MPa Class Steel

Superior Weldability
- Low Preheating Temperature
120℃ ➡ 50℃

Development of TMCP (Thermo Mechanical Control Process)

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BHS : Bridge High-performance Steel

- developed to reduce bridge construction cost. following properties are accomplished with 100mm plate
- strength : Weight reduction
  - BHS500, 500W : 9-19% higher YS than SM570
  - BHS700W : same (+15 to 35 MPa)
- fabrication, Weldability : fabrication cost reduction
  - BHS500, 500W : Pcm<0.2 , no preheating
  - BHS700W : Pcm<0.30 (t<50), 0.32 (t<100), 50℃ preheating
- Other features
  - Constant YS steel
  - Weathering steel

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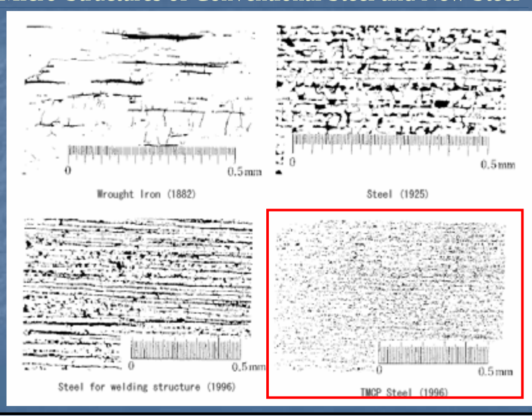
Micro-Structures of Conventional Steel and New Steel



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Weldability – C_{eq}, P_{cm}

$$C_{eq} = C + \frac{Si}{24} + \frac{Mn}{6} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{V}{14} (\%) \qquad \text{JIS}$$

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} (\%) \qquad \text{IIW}$$

Cracking Parameter of Material (used in Japan now)

$$P_{CM} = C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B$$

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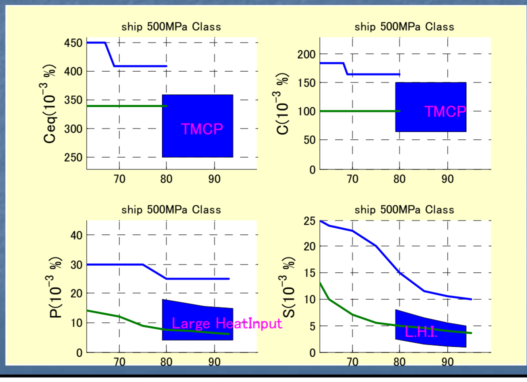
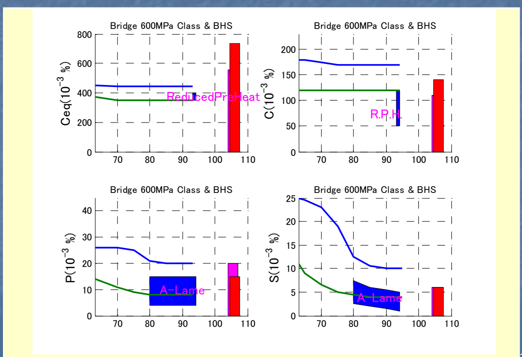
Change of Chemical composition for Ship 500MPa Class



Change of Chemical composition for Bridge 600MPa Class & BHS



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Trial Manufacturing of BHS500 and BHS500W

Thickness : 22, 50, 100mm

Chemical Composition

Steel type	No.	t (mm)	C	Si	Mn	P	S	Cu	Ni	Cr	Pcm
BHS500	required value		≦0.11	≦0.55	≦1.60	≦0.020	≦0.006	added if needed			≦0.020
	1	22	0.08	0.29	1.56	0.009	0.002				0.17
	2	50	0.08	0.29	1.56	0.009	0.002				0.17
	3	100	0.09	0.29	1.57	0.011	0.002				0.18
BHS500W	required value		≦0.11	≦0.55	≦1.60	≦0.020	≦0.006	0.30-0.50	0.05-0.30	0.45-0.75	≦0.020
	4	25	0.05	0.21	1.35	0.006	0.002	0.33	0.26	0.47	0.17
	5	60	0.05	0.21	1.35	0.006	0.002	0.33	0.26	0.47	0.17
	6	100	0.04	0.19	1.35	0.003	0.001	0.35	0.26	0.49	0.18

C≦0.11 Pcm≦0.020

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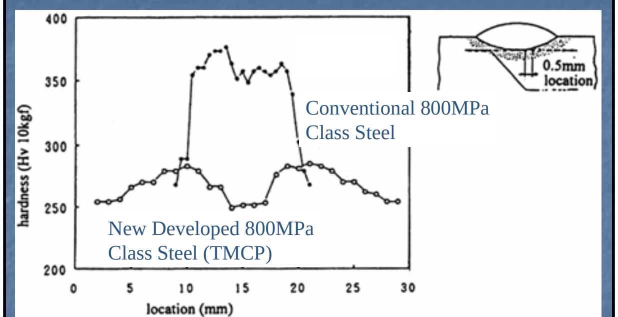
HAZ Hardness of Conventional Steel and New Steel



- Low contens of C
- Fine granular structure ⇒ Low Hardness

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Y-Groove Cracking Test

Constraint factor K (kg/mm*mm) = 70t
$P_w = P_{cm} + K/4000 + H/60$ (Ito)
$T = 1440 P_c - 392$
P_{cm} : cracking parameter of material
T: pre heating temperature

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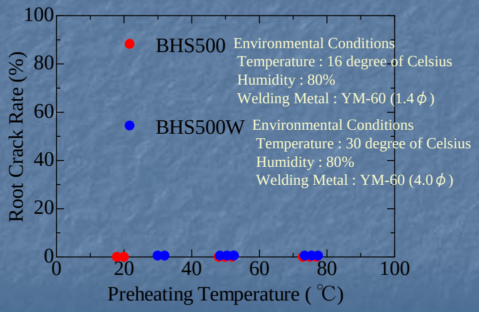
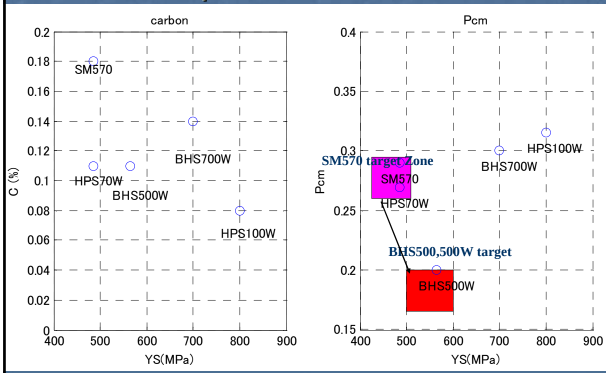
Performance Evaluation of BHS500 and BHS500W

Y-Groove Welding Cracking Test



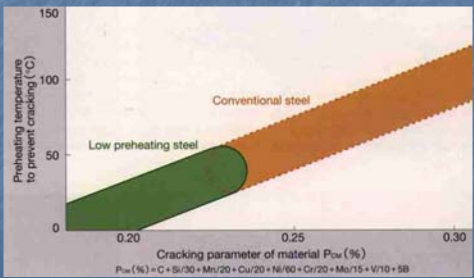
HPS : Specified Carbon & Pcm



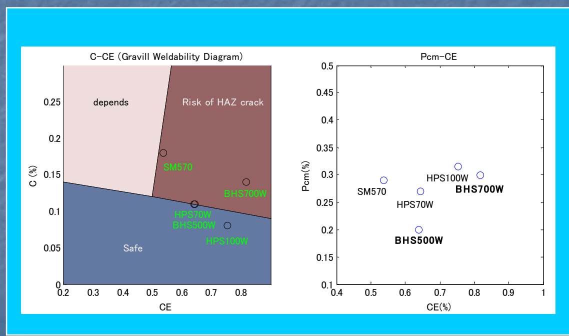
BHS, Low Preheating Steel

- Easy fabrication by eliminating/reducing preheat prior to welding.

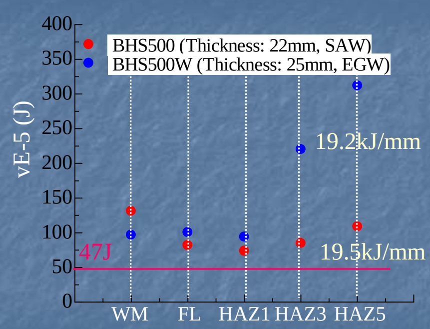
BHS500(W):No Pre-Heating required
BHS700:Pre-Heating Minimized(50℃)



CE (U.S.) , P_{cm} (Japan)



Large Heat Input Welding Proof



Required Performance
Heat Input ≧10kJ/mm, vE-5≧47J

2. Optimized High Performance

1. Welding
2. Anti-corrosion
3. Strength (tensile, fatigue)

Weathering Steel (JIS-SMA) History

1960 | 1970 | 1980 | 1990 | 2000 | Year

SM41

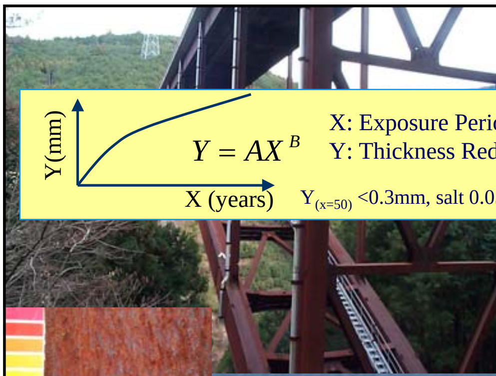
SM50 (1959)

SM50Y and SM53 (1966)

SM58 (1966)

SMA41,50,58 (1968)

Application to Bridges



$Y = AX^{B}$

Y (mm)

X (years)

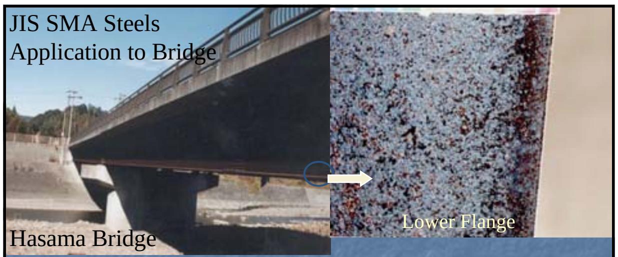
X: Exposure Period

Y: Thickness Reduction

$Y_{(x=50)}$ <0.3mm, salt 0.05ddm in JIS

JIS SMA Steels
Application to Bridge

JIS SMA Steels
Application to Bridge



Hasama Bridge

Unwilling results
Miss use of weathering steel

no rational methods to evaluate weathering performance with respect to environmental severeness

espesially with the exstence of Cl^{-}

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weathering performance index

- In US, Weathering Index
  - based on alloy conposition
  - environmental effects not considered
  - not appricable to Ni rich steel
- In Japan, JIS thickness reduction Eq
  1. Ni rich steel is preferable to salty environment
  2. Exposure test to determine coefficients of Eq
  3. Proposal of the new performance evaluation index
  4. Acceleration test

new formula

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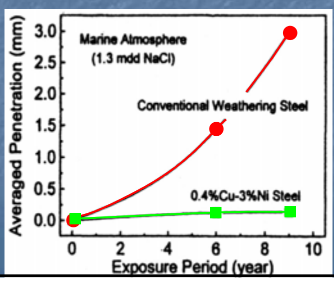
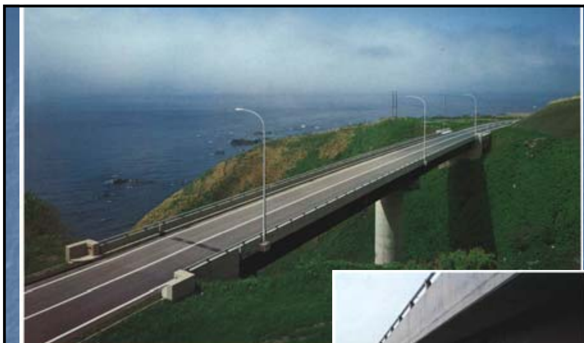
1) New Developed Weathering Steels

Steel	C	Si	Mn	P	S	Cu	Ni	V	Cr	Pcm
SMA-490W-mod	0.10	0.20	0.61	0.006	0.002	0.40	3.07	-	0.02	0.21
SMA-570QW-mod	0.09	0.19	1.33	0.004	0.002	0.38	2.97	0.02	0.02	0.33



Marine weathering steel
3% Ni steel

Results of
9 year exposure test
(at Kimitsu, Japan)



Yatate Bridge (Hokkaido)

2. Exposure Test Project : TIT – Kasetsart (Thailand)

in Kasetsart Univ.

Steels
- Conventional Steel : 1 Type
- Conventional Weathering Steel : 1 Type
- New Developed Weathering Steel : 3 Types (K1, K2, N)

Exposure Period 0.5 year, 1 year, 3 years

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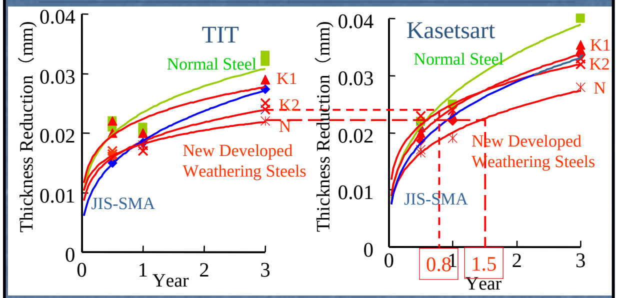
Relationship between Exposure Period and Thickness Reduction



Thickness Reduction Rate in Kasesart Univ.
2-4 times higher than the rate in TIT

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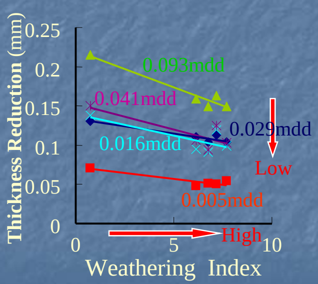
Performance Evaluation by Weathering Index

Exposure Test Results at 41 places in Japan



Low Salt Atmosphere (0.005-0.093mdd)

Weathering Index could Evaluate the Performance Properly

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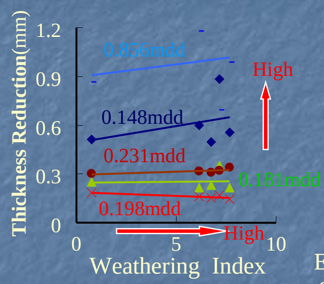
Performance Evaluation by Weathering Index



High Salt Atmosphere (0.148-0.856mdd)

Weathering Index could not evaluate the Performance

Environmental Conditions Should be included in the index

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3. Proposal of New Performance Evaluation Index

Chemical Composition : V
- V: New Weathering Alloy Index
- Exposure Test Results in 41 Places in Japan

Environment : Z
- Z: Weathering Environment Index (NaCl etc)

New Performance Evaluation Index

$$Y = A(V,Z)X^{B(V,Z)}$$

New Performance Evaluation Index

$$Y = AX^{B} = G_A(V)\cdot F_A(Z)\cdot X^{G_B(V)\cdot F_B(Z)}$$

$G_A(V)$,$G_B(V)$: function of alloy contents, $F_A(Z)$,$F_B(Z)$: function of environment
V : Weathering alloy index
Z: Weathering Environmental index

V=1/U
U=(1.0-0.16[C])·(1.05-0.05[Si])·(1.04-0.016[Mn])·(1.0-.5[P])·(1.0+1.9[S])·(1.0-0.10[Cu])·(1.0-0.12[Ni])·(1.0-0.3[Mo])·(1.0-1.7[Ti])
where 0.4≤U≤1.1

category
- A : protective rust layer is formed in 3 years
- B : in 10 years
- C : in 20 years
- D : more than 20 years.

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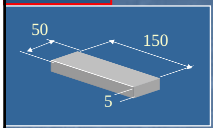
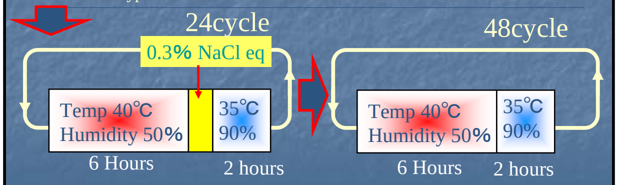
Acceleration Tests

Specimen

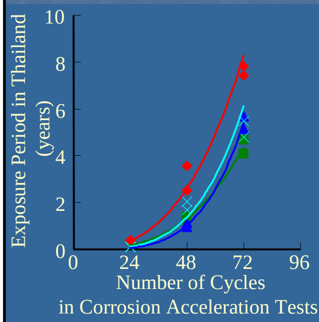


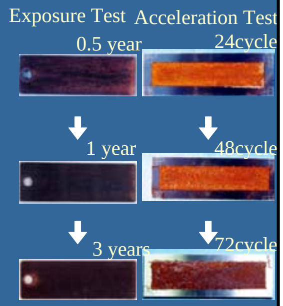
New Developed Weathering Steel 8 Types



Combined Cyclic Process

Comparison between Exposure Test Results in Thailand and Acceleration Test Results





Corrosion Acceleration Tests: 48 cycles ⇨ 1-3 years; 72 cycles ⇨ 5-8 years — Exposure Tests in Thailand

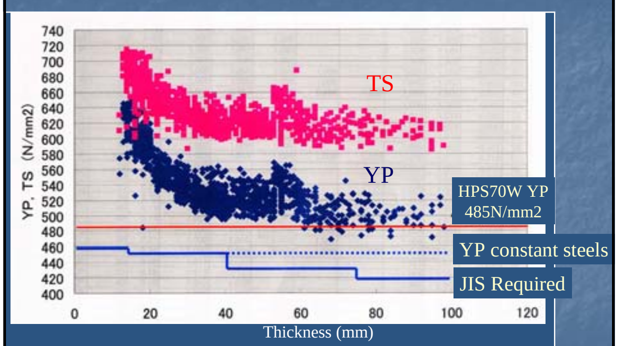
2. Needs for High Performance

1. Welding
2. Anti-corrosion
3. Strength (tensile, fatigue, fracture toughness)

Strength of Steel

		A.S.	Y.S.	T.S.	CVN
		MPa	MPa	MPa	
Conventional Steel in Japan	SM400	140	245	400	
	SM490Y	210	365	520	
	SM570	260	460	570	47
High Strength Steel in Japan	HT690		590	690	
	HT780		690	780	
	HT880		830	880	
HPS in U.S.	HPS50W		345	485	41@-12℃
	HPS70W		485	585-760	48@-23℃
	HPS100W		800		150@-30F
BHS in Japan	BHS500W		500	600	100J(0℃)
	BHS700W		700	800	100J(0℃)

Manufacturing Results of TMCP 500MPa Class Steel



YP, TS – Thickness Relationship

Trial Manufacturing of BHS500 and BHS500W

Mechanical Properties

Steel type	No.	Thickness (mm)	Test position	YP (N/mm2)	TS (N/mm2)	EL (%)		vE-5 (J)
required value(lower limit)				500	-	t≦16	19	100
						16＜t	26	
						20＜t	20	
BHS500	1	22		560	645	30		324
	2	50	1/4t	504	609	32		317
	3	100		534	624	27		291
BHS500W	4	25		566	646	38		324
	5	60	1/4t	564	638	26		175
	6	100		517	608	27		174

YP≧500MPa   vE-5≧100J

Required Performances of Steels for Bridges

Required Level of Yield Point

Steel Bridge Design Simulation (Konishi et al 2000)

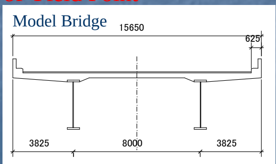
LRFD (AASHTO)

Service Limit State : Deflection
Fatigue Limit State : Fatigue Design Specification
Ultimate Limit State : Buckling, yielding

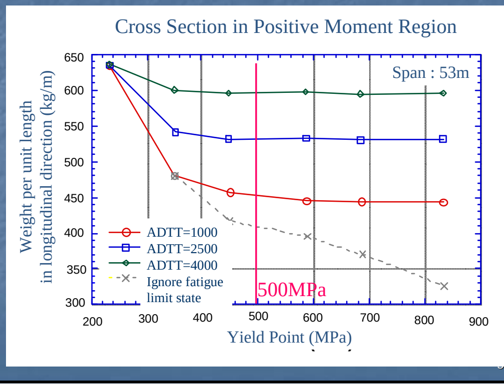
For Each Level of Yield Point

Optimized Cross Section

Bridge Weights

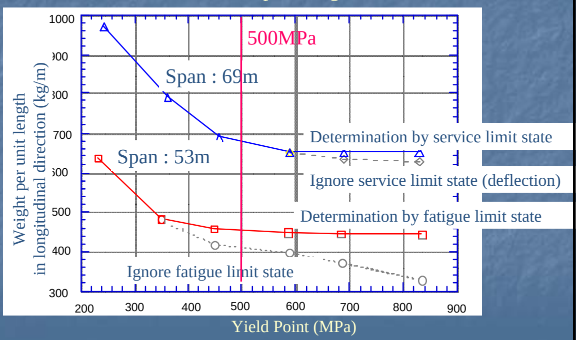


Relationship of Bridge Weight and Yield Point



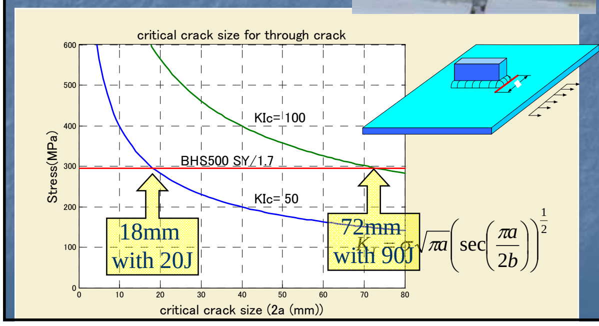
Relationship of Bridge Weight and Yield Point

Effect of Span Length



Longer Span ➡ Higher Optimized Yield Point

Fracture Toughness



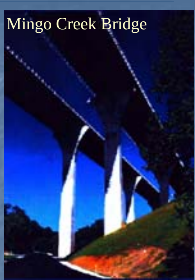
$$K = \sigma\sqrt{\pi a}\left(\sec\left(\frac{\pi a}{2b}\right)\right)^{\frac{1}{2}}$$

4. High Performance Steel for Bridges in US

In USA (1992-)

"High Performance Steel"

- Better Fracture Toughness
- Better Weldability
- Better Cold Formability
- Better Corrosion Resistance



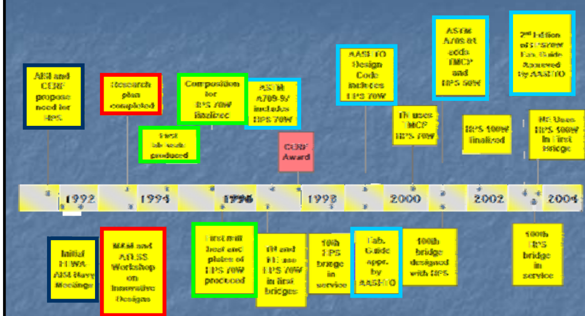
HPS Steering Committee

US-HPS (2 Types)

HPS70W (Yield Strength: 485MPa)
HPS100W

Listed in ASTM in 1997

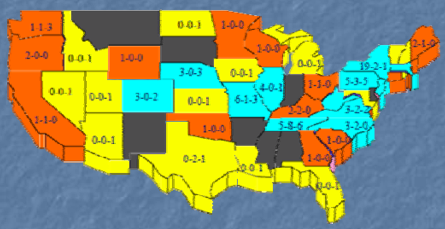
HPS Development Timeline



Application of HPS to Bridge Structures

In Service : >130bridges
Designed : >200 bridges

HPS Scoreboard (Jan.2004)



x-x-x in Service – in Construction – in Design

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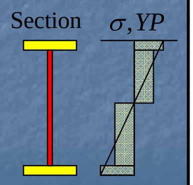
HPS Use in Bridge

- HPS50W,HPS70W used in over 200 (154 open) Bridges in 2004.
- 28% weight, 18% cost reduction (Best to date)
- Hybrid Design HPS 50W & 70W
- HPS 100W in ASME spec. (2004)



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Availability of HPS

- Thickness:

50W		up to 4” (≒102mm)
70W	Q&T	up to 4” (≒102mm)
	TMCP	up to 2” (≒ 51mm)

- Delivery time:
  approximately 6 to 10 weeks depending on market demand.
- A market demand of steel bridge fabrication:
  over 400,000 tons in 1999 and 2000
  (Based on industry information)

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High Performance Steel Designers’ guide

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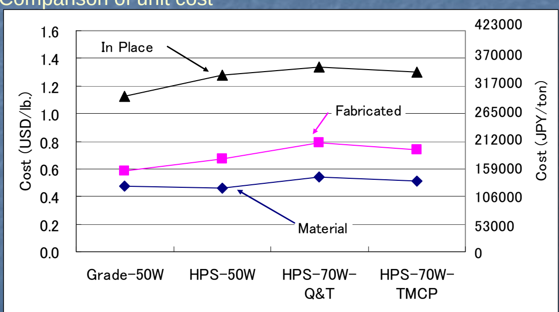
Cost of HPS

Comparison of unit cost



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HPS Bridge Project in U.S.

- Design
  - Ductility capacity of HPS70W
  - Live-Load deflection Criteria for HPS Bridge
  - Toughness of HPS (CVN)
  - Innovative Designs (colgate web, tubular truss, Box girder)
  - Seismic evaluation
- Fabrication
  - update Guide Spec. for Bridge Fabrication with HPS70W, Fabrication Guide for HPS100W
  - Optimized Weld of HPS 70W, 100W
  - Consumable for HPS

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4. Bridge High-performance Steel in Japan

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Proposal of BHS (Bridge High Performance Steel)

Strength : Yield Strength 500MPa (BHS500,500W)
700MPa (BHS700W)

Weldability : Preheating Temperature
0 (degree of Celsius) for BHS500
50 (degree of Celsius) for BHS700

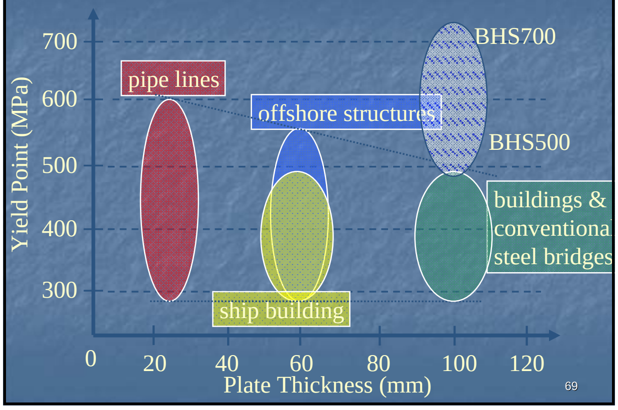
Cold Formability (Strain Aging Proof for BHS500) :
Cold Formed Corner R
greater than 7t (t: plate thickness)

Large Heat Input Proof : less than 10kJoule/mm for BHS500
less than 5kJoule/mm for BHS700

Lamellar Tearing Proof : Equivalent to Z35 Steels

Weathering Version (BHS500W, BHS700W) : Weathering Capacity

Target Strength Range of BHS



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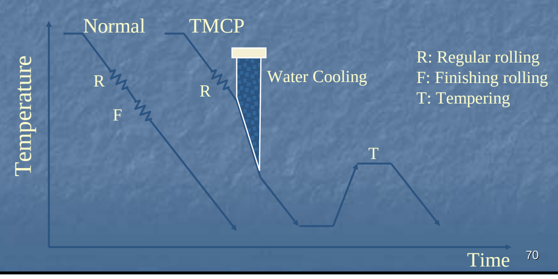
Manufacturing of BHS

Rolling Process for BHS
TMCP (Thermo Mechanical Control Process)

Required Weldability



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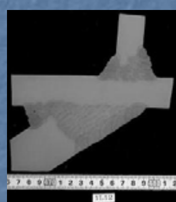
Application Plan of BHS

Tokyo Port Seaside Road (Tentative)

Center Span : 760m
(4 Truss Type Bridges)

Welding in High Constraint Region



Weld Test for the Port Seaside Bridge Truss Node

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Application of BHS

- BHS 500, 700 Just developed in Japan
- Cost performance : fabrication cost
- Welding technology
- Suitable structural systems
- Joint research works: Korea and Japan


JIS SMA Steels
Application to Bridge

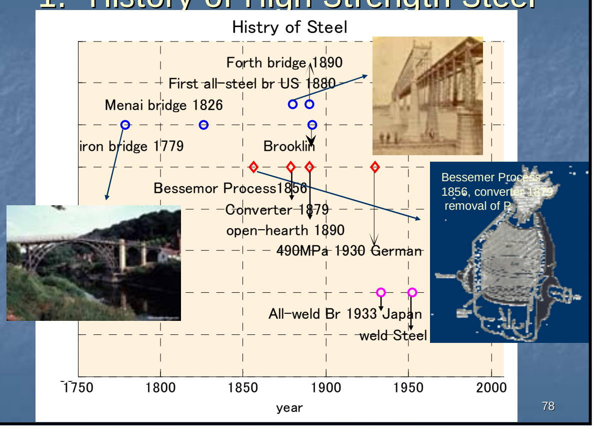
JIS SMA Steels
Application to Bridge

Application of New Weathering Steels

Maitegawa Bridge (Oita)

Thank you for listening

1. History of High Strength Steel



K_{Ic}-CVN correlation