Development and Application of 780N/mm² class Steel Plates for Building Structures

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Yukio Murakami
JFE Steel Corporation
Contents

1. **Outline** of High Strength Steel Plates
2. **Manufacturing** Process of High Strength Steel Plates
3. **Material Standards & Applications** of High Strength Steel Plates

High Rise Buildings (Tokyo Shiodome Area)
Annual Construction Volume per floor area in Japan

- Wooden Structure
- SRC Structure
- RC Structure
- Steel Structure
- Others

37%
History of High-rise Steel Building

1968 1978 1993

KASUMIGASEKI  Sunshine60  Landmark Tower

Height
147m(36F)  226m(60F)  296m(70F)

Frame Member
WIDE-FLANGE(column)
Width 400mm
Thickness 60mm

Steel Makers had developed TMCP steel plates, which provide higher strength, and enables reduction of member size.

Structure: Higher & Larger
Steel Member: Larger & Heavier
# “Steel strength level” and “Type of application”

<table>
<thead>
<tr>
<th>Application</th>
<th>Tensile Strength level (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>490 ～ 550</td>
</tr>
<tr>
<td>Buildings</td>
<td>HBL385</td>
</tr>
<tr>
<td>Bridges</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanks</td>
<td></td>
</tr>
<tr>
<td>Penstocks</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Ships</td>
<td></td>
</tr>
<tr>
<td>Offshore structure</td>
<td></td>
</tr>
<tr>
<td>Line pipe</td>
<td></td>
</tr>
<tr>
<td>Machinery</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td></td>
</tr>
</tbody>
</table>

* Akashi Ohashi Bridge
* Kannagawa Hydropower Plant
* Submarine (Shinkai 2000)
Built-up Column

Weld built-up box column

- Commonly adopted for high-rise building construction
- Applicable to plate thicknesses of 19~100 mm
- Extremely large welding heat input (300-1000 kJ/cm)
- Welding: Automatic electro-slag welding (ESW) and submerged arc welding (SAW)
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High Rise Buildings (Tokyo Shiodome Area)
Manufacturing Process of Steel Plate

**On-Line Accelerated Cooling**

- **Super-OLAC**
- **HOP**
- Fukuyama Works

- **Heating**
- **Rolling**
- **Hot leveller**
- **Cooling**

- **Heat treatment**
- **Quenching, Normalizing**
- **Tempering**
- **Cutting**
- **Inspection**
- **Marking**
Manufacturing Process of 780N/mm² Steel

**DQ-HOP type**

- Rolling
- Water Cooling
- Tempering

**Direct Quenching & Tempering**

**RQ-T type**

- Rolling
- RQ
- Q'
- T

**Reheated Quenching & Tempering**
Manufacturing Process of 780N/mm² Steel

DQ-HOP

Water Cooling

Online Tempering

Bainite

Bainite (tempered)

Austenite

C diffusion into austenite

M-A

RQ-T

Reheated Quenching

Tempering

Maetensite

Ferrite

Maetensite (tempered)

Maetensite (tempered)
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High Rise Buildings (Tokyo Shiodome Area)
# 780N/mm² Class Steel

<table>
<thead>
<tr>
<th>Designation</th>
<th>Plate thickness (mm)</th>
<th>YS (N/mm²)</th>
<th>TS (N/mm²)</th>
<th>YR (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-SA700</td>
<td>6~50</td>
<td>700</td>
<td>780</td>
<td>≤ 98</td>
<td>High-YR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>~ 900</td>
<td>~ 1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HBL630-L</td>
<td>12~40</td>
<td>630</td>
<td>780</td>
<td>≤ 85</td>
<td>Low-YR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>~ 750</td>
<td>~ 930</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HITEN780T</td>
<td>22~100</td>
<td>630</td>
<td>780</td>
<td>≤ 85</td>
<td>RQ-T</td>
</tr>
<tr>
<td></td>
<td></td>
<td>~ 750</td>
<td>~ 930</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Remarks:
- DQ-HOP
- RQ-T

Symbols:
- ≤

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<table>
<thead>
<tr>
<th>Designation</th>
<th>Yield Strength (N/mm²)</th>
<th>Tensile Strength (N/mm²)</th>
<th>Elongation (%)</th>
<th>Impact Energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN10025-6 S690</td>
<td>(3 ≤ t ≤ 50 mm) min.690</td>
<td>(3 ≤ t ≤ 50 mm) min.770 max.940</td>
<td>min.14 (Lo=5.65√So)</td>
<td>-20 °C 30 ≤</td>
</tr>
<tr>
<td></td>
<td>(50 &lt; t ≤ 100 mm) min.650</td>
<td>(50 &lt; t ≤ 100 mm) min.760 max.930</td>
<td></td>
<td>-40 °C 30 ≤</td>
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<tr>
<td></td>
<td>(100 &lt; t ≤ 150 mm) min.630</td>
<td>(100 &lt; t ≤ 150 mm) min.710 max.900</td>
<td></td>
<td>-60 °C 47 ≤</td>
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<tr>
<td>H-SA700 (High-YR)</td>
<td>min.700 max.900</td>
<td>min.780 max.1000</td>
<td></td>
<td>0 °C 47 ≤</td>
</tr>
<tr>
<td>(DQ-HOP)</td>
<td></td>
<td></td>
<td></td>
<td>-20 °C 47 ≤</td>
</tr>
<tr>
<td>HBL630-L (Low-YR)</td>
<td>Min.630 max.750</td>
<td>Min.780 max.930</td>
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<td>0 °C 47 ≤</td>
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<tr>
<td>(DQ-HOP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HITEN780 (Low-YR)</td>
<td>Min.630 max.750</td>
<td>Min.780 max.930</td>
<td></td>
<td>0 °C 47 ≤</td>
</tr>
<tr>
<td>(RQ-T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>
780N/mm² Class ②

<table>
<thead>
<tr>
<th>Designation</th>
<th>Chemical Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
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<tr>
<td>EN10025-6 S690</td>
<td>QL</td>
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<tr>
<td></td>
<td>QL1</td>
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<tr>
<td>H-SA700 (High-YR) (DQ-HOP)</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>B</td>
</tr>
<tr>
<td>HBL630-L (Low-YR) (DQ-HOP)</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>HITEN780 (Low-YR) (RQ-T)</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>

*Cev
Sample of S-S Curve

High-YR (≤ 98%)

Low-YR (≤ 85%)

DQ-HOP (H-SA700)

DQ-HOP (HBL630-L)

RQ-T (HITEN780T)
High-YR (DQ-HOP) Stub Column Test

Test Parameter
Cross-section type
Width-Thickness ratio (B/t)

Examination item
- Local buckling behavior
- B/t - Stress increase
- B/t - ductility

BOX    RHS    H-shape    Pipe
High-YR (DQ-HOP)  Stub Column Test

![Graphs showing stress-strain behavior and ductility comparison between different materials and structures.](image)

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Examination item

- Bending behavior in compression-side
- Behavior of plastic deformation

High-YR (DQ-HOP) Cyclic Loading Test

Test specimen

Jack

Jack

Test specimen
High-YR (DQ-HOP)  Cyclic Loading Test

Ductility vs. Non-dimensional B/t

- **Stub Column**
- **Cyclic Bending**

Graphs showing the relationship between ductility and non-dimensional B/t for different loading conditions.
**High-YR (DQ-HOP) Full-scale Test**

- **Floor area**: 98.0m²  
  (14.0m × 7.0m)
- **Height**: 16.0m
- **Story**: 4F/8F

- **Inter-story drift**: ⇒ 1/75
- **Columns, Beams, Floors**: ⇒ No damage

No damage
Low-YR (DQ-HOP)

☆Chemical Composition

<table>
<thead>
<tr>
<th>Design.</th>
<th>Thick. mm</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Ceq</th>
<th>PCM</th>
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</thead>
<tbody>
<tr>
<td>HBL630-L</td>
<td>25</td>
<td>0.06</td>
<td>0.18</td>
<td>1.99</td>
<td>0.011</td>
<td>0.002</td>
<td>0.54</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>0.06</td>
<td>0.19</td>
<td>1.99</td>
<td>0.011</td>
<td>0.002</td>
<td>0.55</td>
<td>0.24</td>
</tr>
</tbody>
</table>

☆Charpy Impact Test

☆Tensile Test

<table>
<thead>
<tr>
<th>Design.</th>
<th>Thick. mm</th>
<th>Yield Str. N/mm²</th>
<th>Tensile Str. N/mm²</th>
<th>Yield ratio %</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBL630-L</td>
<td>25</td>
<td>733</td>
<td>900</td>
<td>81</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>675</td>
<td>830</td>
<td>81</td>
<td>45</td>
</tr>
</tbody>
</table>

◎Lowering Carbon & Cev content

Improving Weldability: hardenability & cold-crack-susceptibility & HAZ toughness
Low-YR (DQ-HOP) Welding Joint GMAW

<table>
<thead>
<tr>
<th>Process</th>
<th>Groove Shape</th>
<th>Macro Etch</th>
<th>Weld Condition</th>
<th>Tensile Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2W</td>
<td>![Groove Shape Diagram]</td>
<td>![Macro Etch Image]</td>
<td>Weld-wire: MG-80, Heat-input: 21kJ/cm, Preheat: N.A, Inter-pass: max.150°C</td>
<td>804N/mm², 806N/mm²</td>
</tr>
</tbody>
</table>

Impact Energy @0°C

Charpy impact Test

Vickers Hardness Test

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Low-YR (DQ-HOP) Bending Test

[Objective]
Evaluating Plastic Deformation Capacity of Welded-Box Section column

[Loading schedule]
Plastic Rotation Angle $\theta_p$
$\times 1, \times 2, \times 3, \ldots$
(two cycles each)
Low-YR (DQ-HOP)  Bending Test

Moment [kN・m]  fracture

-5000 -4000 -3000 -2000 -1000 0 1000 2000 3000 4000 5000

Rotation [rad]

M2 test spec.
400x25
Inner-diaphragm

Ductility Factor 3.0

Loading jig

Ductility Factor 3.0

column
Application of High Strength Steel

View from our office (Tokyo)

Tokyo Station

Imperial Palace

Hibiya Park

Tokyo Sky Tree
I thank you for your kind attention.