Higher Grade Reinforcement in New Gen Nuclear Construction

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Bechtel Nuclear Involvement

– More than 60 Years, Started in 1948

– Engineered & Constructed More than 74,000 MW

– Performed on 88 of 104 U.S. operating facilities

– Numerous First of a Kind (FOAK)

– International presence
Japanese Tragedy

- Earthquake Magnitude = 9.0
- Tsunami exceeding 30 ft in height
- Unique and Unprecedented Combination
- Gap in regulation for a Double Punch
BWR

Secondary containment: Area of explosion at Fukushima Daiichi 1
Primary containment: Remains intact and safe

Boiling Water Reactor Design

Figure 1 Outline of PWR Power Plant
Generations of Nuclear Plants
Past, Present and Future

- Four Generations of Nuclear Plants
  - Gen 1
    - Systematic Exploration
    - Offshoot from US Navy Program (Rickover)
  - Gen 2
    - Operating Now – Providing 20% of US Electrical Power Requirements
  - Gen 3 (3+, 3++)
    - U.S. – Detailed Design in Progress
    - International – in operation / under construction
  - Gen 4
    - Conceptual
Generation III++

- Technology has significantly improved
- Multiple and Redundant Safety Systems
- Much Stringent US Regulation and Oversight – NRC an independent body

Let us put it all in context

- Largest earthquake combined with largest tsunami
- Gen II nuclear technology – lot has changed since
- Great tragedy but also learning opportunity
  - Evaluate – Correct - Improve
REALITY - Energy Forecast

- Increase in Electrical Power Demand
  - 30-40% projected increase in US
  - 40-60% projected international need
Sources of Emission-Free Electricity 2008

Solar, Wind & Geothermal 6.1%
Hydro 21.7%
Nuclear 72.3%
US Position

“The American people should have full confidence that the United States has rigorous safety regulations in place to ensure that our nuclear power is generated safely and responsibly,"

Steven Chu, Energy Secretary.

US Position

“To meet our energy needs, the administration believes we must rely on a diverse set of energy sources including renewables like wind and solar, natural gas, clean coal and nuclear power,“

$36 billion loan-guarantee to kick start the new construction
Rebar Estimates

• 24% more electricity needed by 2035

• 30 nuclear plants were originally expected in US

• Rebar = 300 – 500 pounds/cubic yard

• Recent project estimates – 90,000 T for NI and Turbine alone

WTP Concrete
Why is High Strength Reinforcement Important?

• To help reduce the significant rebar congestion expected in new gen nuclear construction
  
  – Higher design basis event loads
  – Conservative codes/licensing requirements
  – Analysis/design process
Steam Generator Replacement

What we do not want is....
Solution

1. Remove unnecessary conservatism in analysis/design

2. **Use higher grade reinforcement**

3. **Utilize headed bars/mechanical splices**

4. **Explore rebar modeling**

5. Use high-performance concrete

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**High Strength Rebar and Nuclear?**

- What about Ductility?

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Strategy

- How does higher grade reinforcement compare to Gr 60?
- How much ductility does higher grade reinforcement offer?
- How much ductility do we need in nuclear structures?
- Has it been used elsewhere?

Gr 75 Experience

- Covered under ASTM A615
- In use since 1987 – 20 years
- Allowed in ACI 318
- Allowed in AASHTO for bridges
- No reported problems
How different is Gr 75 from Gr 60

- Covered under the same ASTM A615 that Gr 60 is covered under
- Same chemistry control as Gr 60
Ductility of Gr 75 vs. Gr 60

### TABLE 2  Tensile Requirements

<table>
<thead>
<tr>
<th>Bar Designation No.</th>
<th>Tensile strength, min. psi (MPa)</th>
<th>Yield strength, min. psi (MPa)</th>
<th>Elongation in 8 in. (203.2 mm), min. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 [10]</td>
<td>60 000 [420]</td>
<td>40 000 [280]</td>
<td>11</td>
</tr>
<tr>
<td>4, 5, 6 [13, 16]</td>
<td>90 000 [620]</td>
<td>60 000 [420]</td>
<td>9</td>
</tr>
<tr>
<td>0 [19]</td>
<td>100 000 [690]</td>
<td>75 000 [520]</td>
<td>7</td>
</tr>
<tr>
<td>7, 8 [22, 25]</td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>9, 10, 11 [29, 32, 36]</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>14, 18 [43, 57]</td>
<td></td>
<td></td>
<td>7</td>
</tr>
</tbody>
</table>

*A Grade 40 [280] bars are furnished only in sizes 3 through 6 [10 through 19].

Ductility of Gr 75 vs. Gr 60

### TABLE 3  Bend Test Requirements

<table>
<thead>
<tr>
<th>Bar Designation No.</th>
<th>Pin Diameter for Bend Tests*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade 40 [280]</td>
</tr>
<tr>
<td>3, 4, 5 [10, 13, 16]</td>
<td>3½ d **</td>
</tr>
<tr>
<td>6 [19]</td>
<td>5d</td>
</tr>
<tr>
<td>7, 8 [22, 25]</td>
<td>...</td>
</tr>
<tr>
<td>9, 10, 11 [29, 32, 36]</td>
<td>...</td>
</tr>
<tr>
<td>14, 18 [43, 57]</td>
<td>...</td>
</tr>
</tbody>
</table>

*A Test bends 180° unless noted otherwise.  
** d = nominal diameter of specimen.
Ductility and Cyclic Tests

- ACI 349 structures are designed to remain elastic under SSE.

- Current state of practice and processes involved add significant overstrength to design (actual strengths may be 2-3 times the required strengths).

- ASTM A615 requires a minimum elongation of 6% for Gr 75 (actual elongation ~12% by Darwin).

- There is sufficient overstrength margin and ductility capacity for beyond design basis event.

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**Ductility Required – ACI 318 Structures**

\[ V_E \]  
\[ V_D \]  
\[ R = 8 \]  
\[ \Delta_D \]  
\[ \Delta_{IE} \sim \Delta_E \]
Ductility Required – ACI 349 Structures

\[ V_{BDBE} = 2 V_{DBE} \]

\[ \Delta_{DBE} \]

\[ \Delta_{BDBE} \approx 2 \Delta_{DBE} \]

Comparison – ACI 318 vs. ACI 349 Structures

\[ V_{BDBE} = 2 V_{DBE} \]

ACI 349

ACI 318
Bond and development of Gr 75

- Addressed in ACI 318, need 25% higher development lengths and splice lengths for Gr 75 steel

- Alternative – can use ACI 408R-03

High Strain Rate Loading Effect

- Gr 75 is less sensitive to strain rate effect

- Ultimate strain capacity not affected with higher strain rate loading

- Static ultimate strain limits are valid for dynamic conditions

- Use same DIF as for Gr 60
Has anyone else used higher grade for nuclear application?

- Eurocode 2 allows Fe E 500 (500 MPa ~ 75 Gr steel) with minimum elongation of 5%

- Gr 500 used in N4 series 1450 MW of CIVAUX2 in containment and UHS structures

Industry Trend

- Several recent high profile projects have showcased up to 100 ksi steel - MMFX

- ACI Special task group ITG-6 has recommended:
  - 100 ksi steel for flexural tension/confinement
  - 80 ksi for compression
  - 60-80 ksi for shear
Committee Activity

• Discussion started in Fall 08

• Developed and Circulated White Paper on Gr 75/80

ACI 349 Activity

• First Ballot SP01 issued on Sept 13, 2009

• 2nd Ballot SP02 issued on Feb 14, 2010
  – Included an additional factor of 1.2 for development/splice length
  – Included ASTM A706 Gr 80

• 3rd Ballot SP03 on June 18, 2010
Activity in ASME Section III, Div 2
Code for Concrete Containments

• Code Case Proposal for Grades 75 and 80
ASTM A615 and ASTM A706 Gr 80 introduced by in early 2009

• Code Case Approved

• To be included in the Code Revision in the next Update

New ASTMs Referenced

• A615/A615M-09b Standard Specification for Deformed and Plain Carbon Steel Bars for Concrete Reinforcement

• A706/A706M-09b Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
Concluding Remarks

• Higher Grade 75/80 will help relieve congestion of rebar and improve concrete placement

• Single “Q” ASTM A615/A706
  – Gr 60 for No. 3 - 8 bars (for example, #3, #5, #7)
  – Gr 80 for No. 9 and larger bars

Great Progress!…

• Achieved within 2 years

• Some limitations remain pertaining to bent bar development and shear reinforcement
  – need testing

• Active member and industry help/participation is appreciated!
The nuclear industry is no doubt in a shock!

• But it is not time to give up

• It is time to Evaluate – Correct – Improve

• As we always have….