Transactions, **SMiRT-24**
BEXCO, Busan, Korea - August 20-25, 2017
Division IX (include assigned division number from I to X)

ACI/ASME Code Change for Application of Application of High-Strength Reinforcing Bars on Nuclear Power Plant Structures

Sang-Jun Lim[1], Byung-Soo Lee[2], Seong-Taeg Kim[3]

[1] Researcher, Korea Hydro & Nuclear Power Co. Ltd, Korea
[2] Senior Manager, Korea Hydro & Nuclear Power Co. Ltd, Korea
[3] General Manager, Korea Hydro & Nuclear Power Co. Ltd, Korea

ABSTRACT

KHNP(Korea Hydro & Nuclear Power) reduces excessive reinforcing bar amount which can cause the possibility of poor construction of concrete through design standard development of nuclear facility structure using high strength reinforcing bar to raise economics and has its purpose to maintain the high-level safety and the durability as they are.

According to this, KHNP uses high strength reinforcing bar with 550MPa grade of yield strength.

In order to apply them to containment structures, it is necessary to change ASME-CC code and ACI 349 code. ASME and ACI code specifies that the yield strength of shear reinforcement be limited to 420 MPa (60,000psi) in design equation. The structural performance tests of wall & beam have been done to compare Gr.80(550MPa) with Gr.60(420MPa) shear bars. The test results and code change proposal were presented to ACI Committee.

INTRODUCTION

The domestic nuclear power plants use reinforcing bars with the yield strength of 420Mpa. If a high strength reinforcing bar with the yield strength of 550mPa is used, there is a reduction in the amount of rebar and in section, and the spacing of the reinforcement can be spread, so there is an advantage that the workability and economical efficiency of the reinforced concrete structure of the nuclear power plant can be improved. After the recent earthquake, the structural safety requirements of nuclear power plants increased, which further increased the amount of rebar in reinforced concrete nuclear structures. It is, therefore, necessary to consider the use of high strength reinforcing bar with 550Mpa grade of yield strength to improve the workability and economic feasibility and to meet the increased safety requirements of nuclear power plants. The ACI 349-13, the design standard for nuclear safety-related structures, allows the use of reinforcing bars up to ASTM A615 550 MPa grade of yield strength without changing the standard hooks, minimum bend diameter, and spacing. However, the yield strength of shear reinforcement is limited to 420 MPa. KHNP is conducting research to revise the requirements for limiting the yield strength of reinforcing bars in ACI design standard in order to apply 550 MPa high yield strength bar to nuclear facility structures. This study will describe the current effort to revise the ACI and ASME codes in order to apply high strength bar to nuclear facility structures.

Limitations in the use of high strength reinforcing bar

Currently, domestic and international design standards limit the use of high strength bars by specifying the maximum yield strength of steel bars. The reason for this is that if a steel with a high yield strength is used, excessive cracks or deflection can occur in a reinforced concrete structure due to the load applied, and it is difficult to exclude the negative problems of ductility and seismic performance, which are important performances of structures. Since the same problem can occur when applied to nuclear facility structures, high strength bars are not introduced to concrete structures. Also, since the lap joint length and

the fixing length increase in proportion to the yield strength of the bar, problems such as an increase in fixing and joint length can occur.

There is a concern about the brittle characteristics in the high strength material and the weak cracking performance expected from the increased stress acting on the reinforcing bar. On the other hand, there is a lack of experimental data of structural members using high strength bars, and as a result, the ACI and ASME technical standards limit the design yield strength of reinforcing bars to 60,000psi.

Table 1: Limitations in the use of high strength reinforcing bar

Types		**ASME CC - 10 (KEPIC SNB)**	**ACI 349-06 (KEPIC SNC)**	**ACI 318-08 (KEPIC SGB)**
Yield strength	**Tensile rebar**	**CC-3422.1 (tensile) :** 60,000 psi ※ Case N-807 : increased to 80,000 psi	**9.4 :** 60,000 psi ※ 2013 revision : increased to 80,000 psi	**9.4 :** 60,000 psi ※Excluding prestressing of steel wire & lateral restraint reinforcement
	Shear rebar	**CC-3424.5 (shear friction)** 60,000 psi	**9.4 / 11.5.2 / 21.2.5** 60,000 psi	**9.4 / 11.4.2 / 21.1.5.5** 60,000 psi
	Wall shear rebar	-	**9.4 / 11.5.2 / 21.2.5** 60,000psi (general rebar) 80,000psi (wire welding)	**9.4 / 11.4.2 / 21.1.5.5** 60,000 psi (general rebar) 80,000 psi (wire welding)
	Torsion rebar	-	**9.4 / 11.6.3.4~6** 60,000 psi Excluding the twist resistance of concrete	**9.4 / 11.5.3.4~6** 60,000 psi Excluding the twist resistance of concrete

Here is a table with each design standard specification and characteristic organized by rating item created after investigating domestic and international design standards that are applied to the designing of nuclear power plants. The technical standard limits the maximum design reference yield strength for cast iron rods, shear reinforcement, torsion reinforcement, and expanded beam reinforcement. Lap joints, calculation of length of fixation and crack control are also related to the design standard of yield strength.

In ACI 349, the yield strength of steel reinforcement is specified to be 420 MPa or less. The design yield strength of shear and torsion reinforcement is limited to 420 MPa. The torsion resistance only takes the rebar resistance into account and excludes the concrete resistance. In chapter 21, Earthquake Special Rules, the design yield strength of all shear reinforcement used in special moment frames and special structural walls is specified to be less than 420 MPa.

Test results of structural performance

Table 2 : Summary table of performance evaluation result

Types	Performance evaluation
Repeated behavior of wall	➢ Shear strength : Confirmed a stable repetition behavior of similar level between Gr.80 and Gr. Test (similar shear strength and failure modes) ➢ Ductility capacity : Gr.80 and Gr.60 Test specimens behave with similar ductility and reach flexural failure (similar in ductility capacity)
Shearing performance	➢ Motion : Gr.80 and Gr.60 Test specimen show similar motion ➢ Crack : Satisfies the sign length crack width reference value (0.016 in) ✓ Technical standard: ACI 318 & 349 ✓ Load requirement : Working load (40% of design load)

Suggested revision to code on shear reinforcement & current status

▷ACI 349

☐ 3.5.3.2 Supplementary method for determining high strength reinforcing bars yield strength

3.5.3 Deformed Reinforcement

3.5.3.2 ~~Same as ACI 318-08~~.

Deformed reinforcing bars shall conform to one of the ASTM specifications listed in 3.5.3.1.~~, except that for bars with f_y exceeding 60,000 psi, the yield strength shall be taken as the stress corresponding to a strain of 0.35 percent~~. See 9.4.

R3.5.3.2 Same as in ACI 318-~~08~~ 14 section R20.2.1.2 - except ASTM A615 includes provisions for Grade 75 and Grade 80 bars in sizes No. 3 through 18 and ASTM A706 includes provisions for Grade 80 bars in sizes No. 3 through 18.

☐ 9.4 Raise the yield strength requirements for reinforcement in the design criteria

9.4 - Design strength for reinforcement

The specified f_y and f_{yt} used in construction shall be that used in design and shall not exceed 80,000 psi, except for prestressing steel, and for transverse reinforcement in 10.9.3 ~~and 21.1.5.4.~~ For development of headed deformed bars, yield strength shall be limited to 60,000 psi in accordance with 12.6.1.

R9.4 - Design strength for reinforcement

~~Same as ACI 318-08 with the following addition:~~

In addition to the upper limit of 80,000 psi for specified yield strength of nonprestressed reinforcement, there are limitations on yield strength in other sections of the Code. In ~~11.4.2~~, 11.5.3.4, 11.6.6, 12.6.1,

and 18.9.3.2, the maximum value of f_y or f_{yt} that may be used in design is 60,000 psi. ~~The deflection provisions of 9.5 and the limitations on distribution of flexural reinforcement of 10.6 become increasingly critical as f_y increases.~~

☐ 11.4 Raise the yield strength requirements for shear reinforcement in the design criteria

11.4 Shear Strength Provided by Shear Reinforcement

11.4.2 ~~Same as ACI 318-08~~.

The values of f_y and f_{yt} used in design of shear reinforcement shall not exceed 80,000 psi.

R11.4.2 ~~Same as ACI 318-08~~.

The values of f_y and f_{yt} used in design of shear reinforcement was revised to 80,000 psi based on recent research (Ref. 11.18-11.20 & 11.74-11.76) which has indicated that the performance of higher-strength steels as shear reinforcement is satisfactory and comparable to that of Gr.60 for diagonal crack control.

☐ 11.5 Raise the yield strength requirements for torsion in the design criteria

11.5 Design for Torsion

11.5.3.4 ~~Same as ACI 318-08~~.

The values of f_y and f_{yt} used for design of torsional reinforcement shall not exceed 80,000 psi.

R11.5.3.4 ~~Same as ACI 318-08~~.

The values of f_y and f_{yt} used in design of torsion reinforcement is allowed to 80,000 psi which has shown to provide a comparable control on diagonal crack control widths with that of Grade 60 reinforcement (Ref 11.74-11.76).

☐ 11.6 Raise the yield strength requirements for shear-friction reinforcement in the design criteria

11.6 Shear-Friction

11.6.6 ~~Same as ACI 318-08~~.

The values of f_y and f_{yt} used for design of shear-friction reinforcement shall not exceed 80,000 psi.

The ACI349 3.5.3 proposes a method for determining the yield point of high strength reinforcement. Prior to revision, the yield strength of reinforcing bars exceeding 80,000 psi was determined by stress corresponding to 0.35% strain. After the revision, as in the case of reinforcing bars below 60,000 psi, even if the yield point is clear and the strain is increasing according to ASTM requirements, stress is static or falling, and when the yield point is unclear, it is the 0.2% offset Method part.
In paragraph 9.4 of ACI349, only 80,000psi torsion reinforcement was permitted prior to the revision. After the revision, shear-related items with a limit of 80,000psi were deleted. 11.4.2 proposes increase of the maximum yield strength of shear reinforcement, 11.5.3.4 proposes increase of the torsion design yield strength, and 11.6.6 proposes increase of the shear-friction design yield strength as an amendment.

▷ASME Sec.Ⅲ Div.2

☐ CC-2331.2 ASTM A615 Addition of restrictions

CC-2331.2 Acceptance Standards.

The acceptance standards shall be in conformance with the tensile requirements of ASTM A615 or ASTM A706, as applicable. If a test specimen fails to meet the tensile requirements, two additional specimens from the same heat and of the same bar size shall be tested. If either of the two additional specimens fails to meet the tensile requirements, the material represented by the tests shall not be accepted.

ASTM A615 shall be further subject to the following conditions:

(a) The actual yield strength based on mill tests shall not exceed f_y by more than 18,000 psi (125MPa).

(b) The ratio of the actual tensile strength to the actual yield strength shall not be less than 1.25.

(c) For Grade 60 bars, the minimum elongation in 8 in.(200㎜) shall be at least 14% for bar sizes No. 3(D10) through No.6(D19), at least 12% for bar sizes No.7(D22) through No.11(D36), and at least 10% for bar sizes No. 14(D43) and No. 18(D57).

(d) For Grade 80 bars, the minimum elongation in 8 in. (200 ㎜) shall be at least 12% for bar sizes No.3(D10) through No.11(D36) and at least 10% for bar sizes No.14(D43) and No.18(D57).

☐ CC-3422.1 Increase in the design standard yield strength of tensile steel

CC-3422 Reinforcing Steel

CC-3422.1 Tension.

(a) The design yield strength of reinforcement shall not exceed ~~60,000 psi (420 MPa)~~ 80,000 psi (550 MPa).

☐ CC-3532.1.7. Added criteria for calculating the settlement length of high-strength reinforcing bars

CC-3532.1.7 Grade 75 and 80 Reinforcement.

Development length of Gr. 75 and Gr. 80 reinforcement calculated using CC-3532.1.2(i) shall be multiplied by a factor of 1.2.

[Note: The factor of 1.2 presumes the presence of transverse or confining reinforcement. Alternatively, calculations for development length of Grade 75 and Grade 80 reinforcing bars may be performed using ACI 408R-03]

☐ CC-4333-1 Added requirements for mechanical reinforcing bar splices, mechanically headed deformed bars and welded joints

Table CC-4333-1
Tensile Requirements for Mechanical Reinforcing Bar Splices, Mechanically Headed Deformed Bars, and Welded Joints

	Reinforcing Bar Properties			Splice, Mechanically Headed Deformed Bar, or Joint Strength Requirements	
Specification	Bar Grade	Minimum Yield Strength, psi (MPa)	Minimum Tensile Strength, psi (MPa)	Minimum Average Mechanical Splice, Mechanically Headed Deformed Bar, or Welded Joint Tensile Strength, psi (MPa) [Note (1)]	Minimum Single Mechanical Splice, Mechanically Headed Deformed Bar, or Welded Joint Tensile Strength, psi (MPa) [Note (2)]
ASTM A615	Grade 40	40,000 (280)	70,000 (480)	70,000 (480)	50,000 (350)
ASTM A615	Grade 60	60,000 (420)	90,000 (620)	90,000 (620)	75,000 (520)
ASTM A706	...	60,000 (420)	80,000 (550)	80,000 (550)	75,000 (520)

NOTES:
(1) See CC-4333 and Mandatory Appendix D2-VIII.
(2) These values are equivalent to 125% of the yield strength of each bar grade.

☐ CC-3422.3 Added requirements for Tangential Shear reinforcement

CC-3422.3 Shear.

(a) Design yield strength of reinforcement shall not exceed 80,000 psi (550 MPa).

(b) For the purpose of calculating the required radial, peripheral and torsional shear, the yield strength of reinforcement shall be limited to 60,000psi (420MPa).

☐ CC-3424.5 Enhancement of design criteria yield strength of shear-friction reinforcement

CC-3424.5 Strength of Reinforcement.

Design yield strength of shear-friction reinforcement shall not exceed ~~60,000 psi (420 MPa)~~ 80,000 psi (550 MPa).

The CC-2331.2 Acceptance Standards added the upper limit of actual yield strength and added the lower limit requirement for the actual tensile strength ratio to actual yield strength. In addition, although ACI 349-13 has no relevant requirements, Minimum Elongation requirement was added in accordance with ACI 318-14 requirement.

Suggested to allow ASTM 615 Grade 75, 80 and ASTM A706 Grade 80 high strength tensile reinforcement containment structures to be used in CC-3422 reinforcing steel.

Added CC-3532.1.7 item to reflect the requirements of high strength reinforcement application factor 1.2 when calculating the settlement length in ASME CC-Code.

In CC-4333-1, minimum reinforcement yield strength and tensile strength of ASTM A615 Gr.75, 80 and A706 Gr.80 high strength reinforcing materials were added, and added the minimum average tensile strength and individual strength of mechanical joining materials of reinforcing bars and fixing materials.

In CC-3422.3, the maximum design basis yield strength requirement for tangential shear reinforcing bars was newly established. In this section, design criteria yield strength requirements for tangential shear reinforcement and radial, peripheral and torsion shear reinforcement are clearly proposed.

In CC-3424.5, the maximum design basis yield strength standard of shear-friction reinforcement was proposed, but the design basis yield strength of the shear-friction reinforcement was excluded to meet the ACI 349 code amendment.

CONCLUSION

The code amendment (draft) to raise the design criteria for reinforcement bars limited to 60,000psi to 80,000psi was drawn and presented in ACI349 and ASME Sec. III Div.2. The amendment was put to a ballot for the Design Division of the ACI 349 Committee, went through the resolution of the subcommittee, then the amendment to raise the yield strength of shear reinforcement was approved by the ACI 349 Main Committee. The decision will be published through the Public Comments of the Tech. Activity Committee in the future.

The ASME Sec. Ⅲ Div.2 Committee will put the ASME CC to a ballot. When it is resolved in this stage, ACI TAC comments will be gathered and the revised version will be published after the amendment is resolved by the ASME Board and approved by the ANSI.

In order to apply high-strength rebar to nuclear power plants, the shear-rebar yield strength must be revised in addition to the shear reinforcement, and the technical standard of the headed bar must be allowed to the high-strength and large-diameter rebar. The additional structural performance will be submitted to the ACI and ASME committees after completion of additional tests.

REFERENCES

ACI Committee 349, "Code Requirements for Nuclear Safety-Related Concrete Structures (ACI 349M-06) and Commentary 2006, Farmington Hills, 157 pp.

ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary 2011, Farmington Hills, 509 pp.

ACI 224R-90, “Control of Cracking in Concrete Structures.”

Aruna Munikrishma, Amr Hosny, Sami Rizkalla and Paul Zia, “Behavior of Concrete Beams Reinforced with ASTM A1035 Grade 100 Stirrups Under Shear.”, ACI Structural Journal, Vol.108.NO.4, 2011, pp. 34-41.

ACI Committee 359, "ASME Boiler and Pressure Vessel Code, Section III, Division 2 Code for Concrete Containments," ACI, New York, USA, 2010, 56 pp.

ASTM A970/A970M-09, Standard Specification for Headed Steel Bars for Concrete Reinforcement, West Conshohocken, PA., 2009, 8 pp.

Cardenas, A.E.; Hanson, J.M.; Corley, W.G.; and Hognestad, E., "Design Provisions for Shear Walls," ACI Journal Proceedings, V. 70, No. 3, 1973, pp. 221-230.

Kabeyasawa, T., and Hiraishi, H., "Tests and Analyses of High-Strength Reinforced Concrete Shear Walls in Japan," ACI Special Publication, V. 176, 1998, pp. 281-310.

Ferguson, P. M., and Thompson, J. N., Development Length of High Strength Reinforcing Bars in Bond, ACI Journal, V. 59, No. 7, July 1962, pp. 887-922