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Test for Design Equation of Development Length on High - Strength Reinforcement in Nuclear Power Plant

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1. Introduction

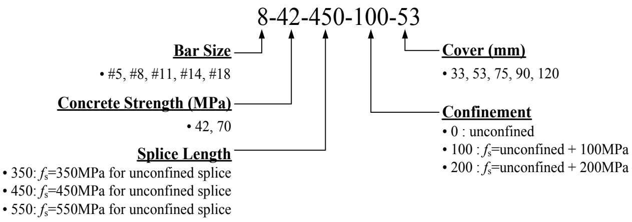
In Korea, NPP (Nuclear Power Plant) structures are constructed with Gr. 60 rebars. The use of high strength rebars with higher grade (Gr. 80) offers advantages: reducing the required amount of rebar materials and area; and improving the constructability and economics of NPP reinforced concrete structures by increasing rebar spacing. ACI 349-13(KEPIC-SNC), code requirements for nuclear safety-related structures, allows the use of ASTM A615 Gr. 60, Gr. 75, Gr. 80 rebars without changing standard hooks, minimum bend diameter and rebar spacing. However, since the development length increases proportional to the yield strength and reflects a safety factor of 1.2, such uses may adversely affect the reduction of rebar amount, which is the purpose of using high strength rebars. Therefore, this research studied the ACI 349-13 design codes and conducted bending member tests with high strength rebars, to compare and analyze use and non-use of development length calculation formulas.

2. Design Equation of Rebar Development Length for NPP Structure

We can calculate the development length of rebar using Equations 12-1 and 12-2 in ACI 318-08, which is for Gr 40 and Gr. 60 rebars. ACI 349-13 allows the above equations to be applied to Gr. 75 and Gr. 80 rebars, provided that the calculation results should be further multiplied by 1.2 times (120%) to be used as the development length. ACI 349-13 has been established based on the research findings of ACI 408-03, which showed when using the equations 12-1 and 12-2 from ACI 318-08 for calculating the development length of Gr. 75 and Gr. 80 rebars, the calculation results are less conservative than that of Gr. 60 rebars. To maintain the traditional margin for splitting failure that corresponds to the calculations of development length for Gr. 60 rebar, the calculation result of development length for Gr. 75 and Gr. 80 rebars should be multiplied by an arbitrary factor of 1.2. The factor of 1.2 assumes that shear and transverse reinforcements are used. One can use, as an alternative to 1.2, ACI Committee Report ACI 408R-03 for calculating the development lengths for Gr. 75 and Gr. 80 bars. As reviewed above, the development length of a high strength rebar is calculated merely by multiplying the traditional calculation result by 1.2. Now we consider that more practical factor, rather than the incremental factor of 1.2 specified by ACI 349-13, needs to be provided. Accordingly, we determined that tests to review development lengths should be conducted. In addition, the research should provide calculation methods for high strength rebars that can make sure the existing safety margin is maintained.

3. Test Plan

This research established test parameters including bar diameter, lap splice length, cover thickness, and use/non-use of transverse reinforcement, and prepared 26 test specimens (Table 1).



As shown in Figure 1, while 4 points of the beam were loaded, displacement meters were installed on the line of loading and in the bottom center of specimens to measure the deflection of specimens and 3 rebar strain gauges were installed to the equivalent moment section of main rebars to measure the strain rate of rebars.

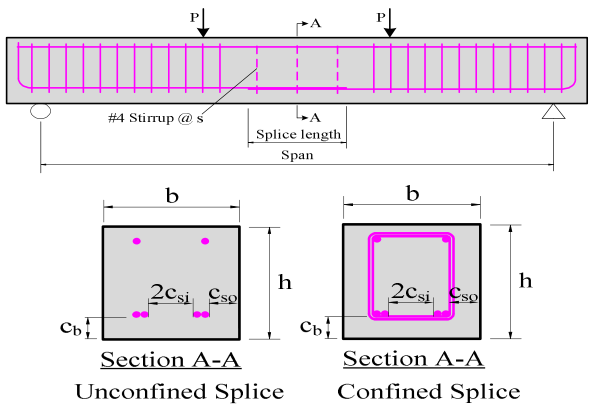


Fig. 1. Specimen Diagram

Table 1. Test List

Group	Specimen	Materials: Measured f_c' (MPa)	Materials: Bar #	Cross section: b (mm)	Cross section: h (mm)	Measured cover: c_b (mm)	Measured cover: c_{so} (mm)	Measured cover: c_{si} (mm)	Splice length (mm)	Stirrup spacing (mm)	Span (mm)	Target Stress (MPa)
1	5-42-550-0-53	40.0	5	276	361	53	53	53	360	N/A	3000	550
	5-42-450-0-53	40.0				53	53	53	280	N/A		450
	5-42-450-100-53	40.0				53	53	53	280	260		550
	8-42-550-0-53	40.0	8	314	466	45	53	53	852	N/A	3000	550
	8-42-450-0-53	40.0				56	53	53	670	N/A		450
	8-42-450-100-53	40.0				53	53	53	670	335		550
	11-42-550-0-53	40.0	11	355	471	55	53	53	1567	N/A	5800	550
	11-42-450-0-53	40.0				60	53	53	1205	N/A		450
	11-42-450-100-53	40.0				69	53	53	1205	380		550
	14-42-550-0-53	39.0	14	384	575	53	53	53	2154	N/A	6000	550
	14-42-450-0-53	39.0				53	53	53	1545	N/A		450
	14-42-450-100-53	39.0				53	53	53	1545	386		550
	18-42-550-0-53	48.6	18	441	782	53	53	53	3490	N/A	8000	550
	18-42-450-0-53	43.7				53	53	53	2650	N/A		450
	18-42-450-100-53	43.7				53	53	53	2650	663		550
2	5-42-550-0-33	40.0	5	197	341	42	33	33	532	N/A	3000	550
	5-42-450-100-33	40.0				33	33	33	415	400		550
	11-42-550-0-75	40.0	11	442	493	72	75	75	1197	N/A	5800	550
	11-42-450-100-75	40.0				85	75	75	920	307		550
	14-42-550-0-90	39.0	14	531	611	90	90	90	1440	N/A	6000	550
	14-42-450-100-90	39.0				90	90	90	1033	258		550
	18-42-550-0-120	42.0	18	708	848	120	120	120	1920	N/A	8000	550
	18-42-450-100-120	42.0				120	120	120	1455	364		550
3	11-42-350-200-75	40.0	11	442	493	75	75	75	642	107	5800	550
	14-42-350-200-90	39.0	14	531	611	90	90	90	730	104	6000	550
	18-42-350-200-120	36.7	18	707	847	120	120	120	995	124	8000	550

4. Test results

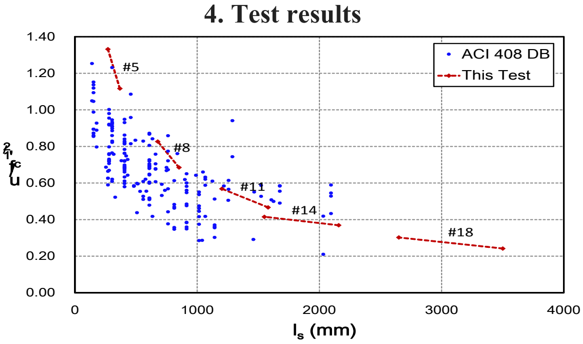


Fig. 2. Unconfined specimens (ACI 349)

The ACI 349 design formula assumes that the bond stress is fixed, regardless of the development length, as the following equation.

$$\frac{u}{\sqrt{f_c'}} = 0.276\frac{(c_b + K_{tr})}{d_b}$$

However, this research found that the bond stress tends to decrease as the length of lap splice (development length) increases, as in Figure 2.

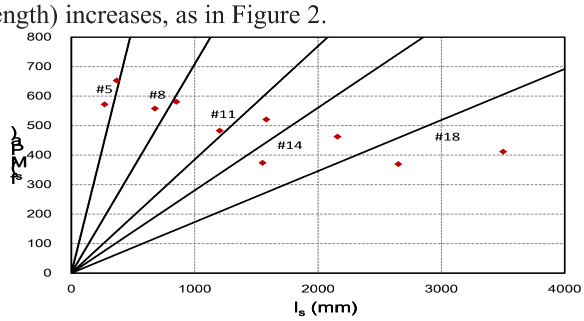


Figure 3. Unconfined specimens (ACI 349)

If transverse reinforcements are not placed in the lap splice section, the diameter of rebar increase as in Figure 3, making an excessive increase of lap splice length, from which point of view the ACI 349 design formula appears to overestimate the bond stress following the increase of lap splice.

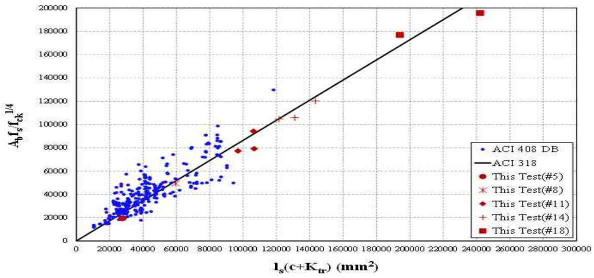


Figure 4. Confined specimens (ACI 349)

If transverse reinforcements are placed in the lap splice section as in Figure 4, the required length of lap splice could be reduced to present the identical stress. And for the same reason, in case of placement of transverse reinforcements, the rebar stress that was calculated with the ACI 349 design formula was similar to the rebar stress that is measured in the test specimen.

5. Conclusion.

This test analyzed the impact of development length on the bond stress when using high strength rebars. It was found that the use of Gr. 80 increased the development length (or length of lap splice), resulting in the ACI 349-13 design formula overestimating the bond stress. Therefore, the use of high strength rebar with transverse reinforcement can allow application of the ACI 349-13 design formula without using the safety factor of 1.2. Furthermore, to propose the proper calculation methods of development length for high strength rebar, more tests should be conducted in the future, taking account of the impact of transverse reinforcement.

ACKNOWLEDGMENTS

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