Report on Applicability of the Hilti HSL4 Heavy Duty Sleeve Anchor for use in Components and Structural Supports in Nuclear Facilities

A Review and Recommendation concerning testing compliance with USNRC General Design Criterion (GDC) 1, "Quality Standards and Records," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, and Appendix B of ACI 349-01

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1. Purpose and Scope

In 2011 Hilti released Report WC 11-02 titled "A Review and Recommendation concerning testing compliance with USNRC General Design Criterion (GDC) 1, "Quality Standards and Records," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, and Appendix B of ACI 349-01" This report evaluated the Hilti HSL-3 Heavy Duty Sleeve Anchor System to determine whether it is in compliance with the requirements of ACI 355.2-01 and ACI 349-01 as recognized by the United States Nuclear Regulatory Commission in USNRC Regulatory Guide 1.199 and provided a design guide in accordance with said documents.
In 2019 Hilti introduced the Hilti HSL4 Heavy Duty Sleeve Anchor System and provided documentation to ICC-ES to demonstrate that the performance of the HSL4 was at least equivalent to the HSL-3. The design tables in the respective ESRs for the HSL4 and HSL-3 are identical.

2. Test Reports and Assessments

The test reports and assessments for the HSL-3 are listed in Report WC 11-02 and are not repeated in this document. The HSL4 underwent testing for comparison to the HSL-3 and testing and assessments were submitted to ICC-ES for evaluation and ESR-4386 was issued.

The following test reports and assessments were submitted to ICC-ES for their evaluation.

EVALUATION REPORT N°SMP 19 26081175 B on HSL4 Torque controlled expansion anchor for use in cracked and uncracked concrete according to ACI 355.2 and ICC-ES AC 193, by CSTB: Centre Scientific et Technique du Batiment, Marne-la-Vallee, France (accredited by COFRAC (full ILAC-member).

Test report n° EEM 19 26080173 Concerning the HILTI HSL4 fasteners for use in cracked/non-cracked concrete according to AC193 / ACI 355.2-07, by

CSTB: Centre Scientific et Technique du Batiment, Marne-la-Vallee, France (accredited by COFRAC (full ILAC-member).

Test report n° EEM 19 26080173 Concerning the HILTI HSL4-G fasteners for use in cracked/non-cracked concrete with hollow drill bit according to AC193 / ACI 355.2-07, by
CSTB: Centre Scientific et Technique du Batiment, Marne-la-Vallee, France (accredited by COFRAC (full ILAC-member).

3. Conclusions and Recommendations

Based on the information cited above ICC-ES issued ESR 4386 with design tables for the HSL4 being identical to the design tables for the HSL-3. Provided in this document in Appendix A are design tables for the HSL4. These tables are identical to the design tables for the HSL-3 contained in Report WC 11-02.

Appendix A

Design information for the Hilti Heavy Duty Sleeve Anchor HSL4 in Accordance with ACI 349-01 Appendix B.

1.0
SCOPE

This guide is intended to provide guidance on the design of anchorages with Hilti Sleeve Anchors HSL4 in accordance with ACI 349-01 Appendix B. Note this design varies from current general industry practice following ACI 318 Chapter 17. It is the responsibility of the engineer of record to verify the accuracy and suitability of all design calculations, methodologies, capacities and code compliance. Information contained in this document was current as of August 30, 2010, and subject to change. Updates and changes may be made based on later testing. If verification is needed that the data is still current, please contact Hilti Technical Services at 1-877-749-6337.

2.0
USES

The Hilti HSL4 Sleeve Anchor is used to resist static, wind, and seismic tension and shear loads in cracked and uncracked normal-weight concrete having a specified compressive strength 2,500 psi ≤ f'_c ≤ 8,500 psi (17.2 MPa ≤ f'_c ≤ 58.6 MPa). The values of f'_c used for calculations in this guide shall not exceed 8000 psi (55.2 MPa).

3.0
INSTALLATION

Installation shall be in accordance with Hilti's printed installation instructions as included in the anchor packaging.

4.0
DESIGN

The design shall be in accordance with this document and ACI 349-01 Appendix B. See Figure 4 for a worked example for static tension loading.

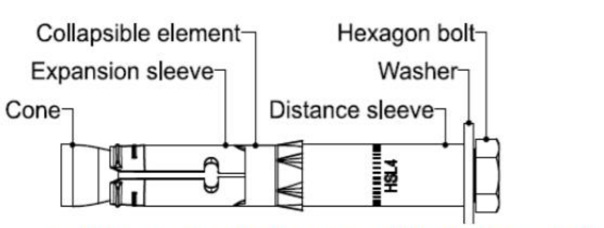


FIGURE 1—COMPONENTS OF THE HSL4 (BOLT VERSION SHOWN)

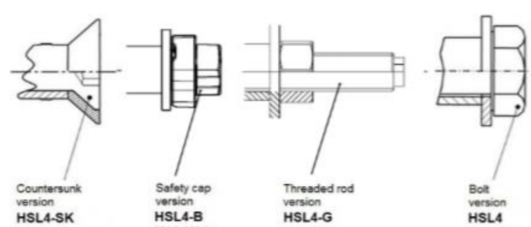


FIGURE 2—HEAD STYLES OF THE HSL4

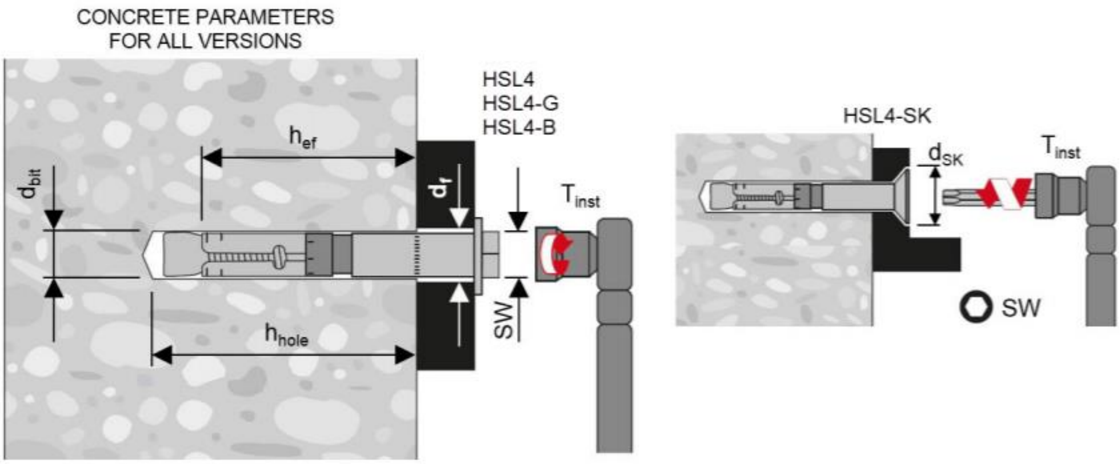


FIGURE 3—HSL4 IN THE INSTALLED CONDITION

Table 1- HSL4 Design Information

Design parameter	Symbol	Units	Nominal anchor diameter					
			M8	M10	M12	M16	M20	M24
Anchor O.D.	d_o	mm	12	15	18	24	28	32
		in.	0.47	0.59	0.71	0.94	1.10	1.26
Effective min. embedment depth	$h_{ef,min}$	mm	60	70	80	100	125	150
		in.	2.36	2.76	3.15	3.94	4.92	5.91
Strength reduction factor for tension, steel failure modes[1]	ϕ	-	0.80					
Strength reduction factor for shear, steel failure modes[1]	ϕ	-	0.75					
Strength reduction factor for concrete breakout, side-face blowout, pullout or pryout strength[1]	ϕ	-	0.75					
Yield strength of anchor steel	f_{ya}	lb/in^2	92,800					
Ultimate strength of anchor steel	f_{uta}	lb/in^2	116,000					
Tensile stress area	A_{se}	in^2	0.057	0.090	0.131	0.243	0.380	0.547
Steel strength in tension	N_s	lb	6,612	10,440	15,196	28,188	44,080	63,452
Effectiveness factor uncracked concrete	k_{uncr}	-	24	24	24	24	24	24
Effectiveness factor cracked concrete[2]	k_{cr}	-	17	21	21	21	21	21
Modification factor for cracked and uncracked concrete – concrete failure[3]	Ψ_3	-	1.4	1.1	1.1	1.1	1.1	1.1
Pullout strength uncracked concrete[4]	$N_{p,uncr}$	lb	4,204	-	-	-	-	-
Pullout strength cracked concrete[4]	$N_{p,cr}$	lb	2,810	4,496	-	-	-	-
Modification factor for cracked and uncracked concrete – pull out failure[4]	Ψ_4	-	1.0	1.0	-	-	-	-
Steel strength in shear HSL4,-B,-SK	V_s	lb	7,239	10,229	14,725	26,707	39,521	45,951
Steel strength in shear HSL4-G	V_s	lb	6,070	8,385	12,162	22,683	33,159	
Coefficient for pryout strength	k_{cp}	-	1.0	2.0				
Load bearing length of anchor in shear	ℓ	mm	24	30	36	48	56	64
		in.	0.94	1.18	1.42	1.89	2.20	2.52
Tension pullout strength seismic[5]	$N_{seismic}$	lb	-	-	-	-	-	14,320
Steel strength in shear, seismic[6] HSL4,-B,-SK	$V_{seismic}$	lb	4,609	8,453	11,892	24,796	29,135	38,173
Steel strength in shear, seismic[6] HSL4-G		lb	3,777	6,924	9,824	21,065	24,459	
Axial stiffness in service load range[7] – uncracked concrete	β_{uncr}	10^3 lb/in.	300					
Axial stiffness in service load range[7] – cracked concrete	β_{cr}		30	70	130	130	130	130

For **SI:** 1 inch = 25.4 mm, 1 lbf = 4.45 N, 1 psi = 0.006895 MPa. For pound-inch units: 1 mm = 0.03937 inches.

[1] See ACI 349-01, Appendix B, section B.4.4. For use with the load combinations of ACI 349-01, section 9.2.

[2] See ACI 349-01 Appendix B, section B.5.2.2 and B.5.2.8

[3] See ACI 349-01 Appendix B, section B.5.2.6

[4] In lieu of ACI 349-01 Appendix B, section B.5.3.1 for pull out failure, $N_{p,cr}$ shall be used to calculate the pull out strength for cracked concrete and $N_{p,uncr}$ shall be used to calculate the pull out strength for uncracked concrete. The modification factor Ψ_4 shall then be taken as 1.0.

[5] $N_{seismic}$ shall be used in lieu of $N_{p,cr}$ for load combinations that include earthquake loads.

[6] $V_{seismic}$ shall be used in lieu of V_s for load combinations that include earthquake loads.

[7] Minimum axial stiffness values, maximum values may be 3 times larger (e.g., due to high-strength concrete).

TABLE 2—HSL4 EDGE DISTANCE, SPACING AND MEMBER THICKNESS REQUIREMENTS[1, 2]

Case	Dimensional parameter	Symbol	Units	Nominal anchor diameter					
				M8	M10	M12	M16	M20	M24
A	Minimum concrete thickness	$h_{min,A}$	in. (mm)	4-3/4 (120)	5-1/2 (140)	6-1/4 (160)	7-7/8 (200)	9-7/8 (250)	11-7/8 (300)
A	Critical edge distance[2]	$c_{ac,A}$	in. (mm)	4-3/8 (110)	4-3/8 (110)	4-3/4 (120)	5-7/8 (150)	8-7/8 (225)	8-7/8 (225)
A	Minimum edge distance[3]	$c_{min,AA}$	in. (mm)	2-3/8 (60)	2-3/4 (70)	3-1/2 (90)	4-3/4 (120)	5 (125)	5-7/8 (150)
A	Minimum anchor spacing[3]	$s_{min,AA}$	in. (mm)	5-1/2 (140)	9-1/2 (240)	11 (280)	12-5/8 (320)	13-3/4 (350)	11-7/8 (300)
A	Minimum edge distance[3]	$c_{min,AB}$	in. (mm)	3-3/8 (85)	5 (125)	6-1/8 (155)	7-7/8 (200)	8-1/4 (210)	8-1/4 (210)
A	Minimum anchor spacing[3]	$s_{min,AB}$	in. (mm)	2-3/8 (60)	2-3/4 (70)	3-1/8 (80)	4 (100)	5 (125)	5-7/8 (150)
B	Minimum concrete thickness	$h_{min,B}$[4]	in. (mm)	4-3/8 (110)	4-3/4 (120)	5-3/8 (135)	6-1/4 (160)	7-1/2 (190)	8-7/8 (225)
B	Critical edge distance[2]	$c_{ac,B}$	in. (mm)	5-7/8 (150)	6-7/8 (175)	7-7/8 (200)	9-7/8 (250)	12-3/8 (312.5)	14-3/4 (375)
B	Minimum edge distance[3]	$c_{min,BA}$	in. (mm)	2-3/8 (60)	3-1/2 (90)	4-3/8 (110)	6-1/4 (160)	7-7/8 (200)	8-7/8 (225)
B	Minimum anchor spacing[3]	$s_{min,BA}$	in. (mm)	7 (180)	10-1/4 (260)	12-5/8 (320)	15 (380)	15-3/4 (400)	15 (380)
B	Minimum edge distance[3]	$c_{min,BB}$	in. (mm)	4 (100)	6-1/4 (160)	7-7/8 (200)	10-5/8 (270)	11-7/8 (300)	12-5/8 (320)
B	Minimum anchor spacing[3]	$s_{min,BB}$	in. (mm)	2-3/8 (60)	2-3/4 (70)	3-1/8 (80)	4 (100)	5 (125)	5-7/8 (150)

For pound-inch units: 1 mm = 0.03937 inches.

[1] The minimum edge distance, spacing and member thickness in this table is based on testing. In addition, the requirements of ACI 349-01, section 8 for post-installed expansion anchors shall apply. Additional combinations for minimum edge distance c_{min} and spacing s_{min} may be derived by linear interpolation between the given boundary values.

[2] See ACI 349-01, B.8 and ACI 355.2-01 9.4.

[3] Denotes admissible combinations of $h_{min,}$ c_{cr}, c_{min} and s_{min}. For example, $h_{min,A} + c_{cr,A} + c_{min,AA} + s_{min,AA}$ or $h_{min,A} + c_{cr,A} + c_{min,AB} + s_{min,AB}$ are admissible, but $h_{min,A} + c_{cr,B} + c_{min,AB} + s_{min,BB}$ is not. However, other admissible combinations for minimum edge distance c_{min} and spacing s_{min} for $h_{min,A}$ or $h_{min,B}$ may be derived by linear interpolation between boundary values (see example for $h_{min,A}$ below).

[4] For the HSL4-SH M8, M10 and M12 diameters, the minimum slab thickness $h_{min,B}$ must be increased by 5 mm (3/16").

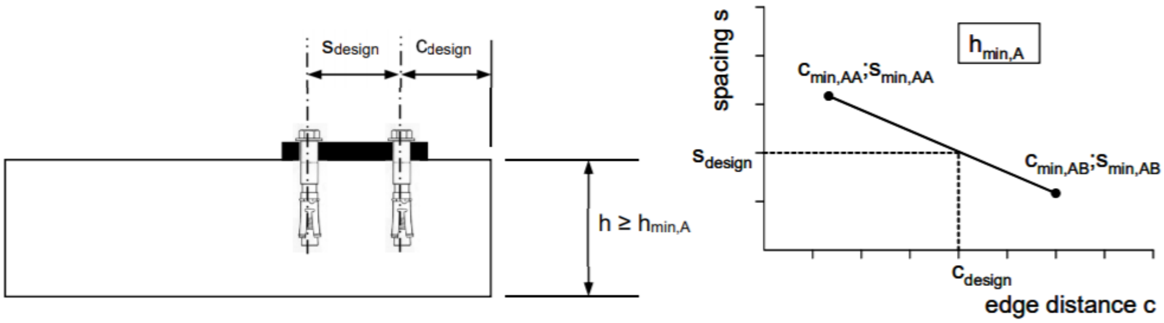


FIGURE 4—EXAMPLE OF ALLOWABLE INTERPOLATION OF MINIMUM EDGE DISTANCE AND MINIMUM SPACING

FIGURE 5—EXAMPLE CALCULATION

Given:

(2) HSL4 M10 anchors under static tension load as shown.

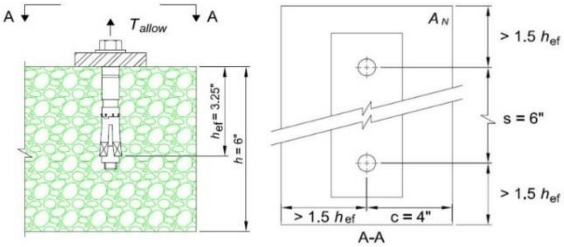
h_{ef} = 2.76 in.

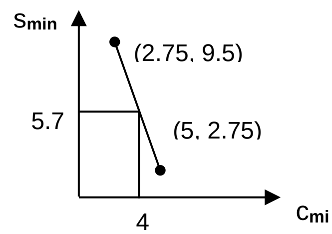
Slab on grade with f'_c = 3,000 psi.

No supplementary reinforcing.

Assume cracked normal-weight concrete.

Calculate the design strength in tension for this configuration.



Calculation per ACI 349-01 Appendix B and this document.	**ACI 349-01**	**Guide Ref.**
Step 1. Calculate steel strength of anchor in tension $N_s = nA_{se,N}f_{ut} = 2 \times 0.090 \times 116{,}000 = 20{,}880\text{lb}$	B.5.1.2	Table 1
Step 2. Calculate steel capacity $\Phi N_s = 0.8 \times 20{,}880 = 16{,}704\text{lb}$	B.4.4 a	Table 1
Step 3. Calculate concrete breakout strength of anchor in tension $N_{cbg} = \frac{A_N}{A_{No}}\Psi_1\Psi_2\Psi_3 N_b$	B.5.2.1	
Step 4. Verify minimum spacing and edge distance: Table 4 Case A: h_{min} = 5-1/2 in. < 6 in. okay $\text{slope} = \frac{9.5 - 2.75}{2.75 - 5} = -3.0$ For $c_{min} = 4\,\text{in.} \Rightarrow$ $s_{min} = 9.5 - [(4 - 2.75)(-3.0)] = 5.75\,[\text{in.}] < 6\,[\text{in.}]$ ∴ okay  	B.8	Table 1 Table 2
Step 5. Calculate A_{No} and A_N for the anchorage: $A_{No} = 9h_{ef}^2 = 9(2.76\text{in.})^2 = 68.6\text{in}^2$ $A_N = (1.5h_{ef} + c)(3h_{ef} + s) = [1.5(2.76) + 4][3(2.76) + 6] = 116.2[\text{in}^2] < 2A_{No}$ ∴ okay	B.5.2.1	Table 1
Step 6. Calculate $N_b = k_{cr}\sqrt{f'_c}\,h_{ef}^{1.5} = 21\sqrt{3{,}000}(2.76)^{1.5} = 5{,}274[\text{lb}]$	B.5.2.2	Table 1
Step 7. Modification factor for eccentricity → no eccentricity $e'_N = 0 \therefore \Psi_1 = 1.0$	B.5.2.4	-
Step 8. Modification factor for edge $1.5h_{ef} = 1.5(2.76\text{in.}) = 4.13\text{in.} > c$ ∴ Ψ_2 must be calculated $\Psi_2 = 0.7 + 0.3\frac{4}{1.5(2.76)} = 0.99$	B.5.2.5	Table 1
Step 9. Modification factor for cracked concrete $\Psi_3 = 1.0$	B.5.2.2 B.5.2.8	Table 1
Step 10. Calculate $N_{cbg} = \frac{116.2}{68.6} \times 1.0 \times 0.99 \times 1.0 \times 5{,}274\text{lb} = 8{,}844\text{lb}$	B.5.2.1	-
Step 11. ϕN_{cbg} = 0.75x8,844 lb = 6,633 lb controls	B.4.4.c	Table 1
Step 12. Calculate pullout strength: $\phi N_{p,cr}$ $\phi N_{p,cr}$ = 0.75 x 4,496 lb = 3,372 lb/anchor x2 anchors = 6,744 lb	B.5.3.2	Table 1
Step 13. Ductility check according to B.3.6.1 For tension $\phi \min[N_{cbg}; N_{p,cr}] \geq A_{se} f_{uta}$ where ϕ = 0.85 0.85 (8,844 lb) < 20,880 lb => ductility not met B.3.6.3 requires an additional reduction factor of 0.6 for non-ductile anchors ϕN_{cbg} = 0.6 x 6,633 = 3,980 lb Note: According to B.3.6.2, alternatively the attachment / base plate can be designed to yield at a load level of 75% of the anchor design strength. In this case, the 0.6 factor would not have to be applied.	B.3.6.1 B.3.6.3 B.4.1	Table 1