SLAC National Accelerator Laboratory

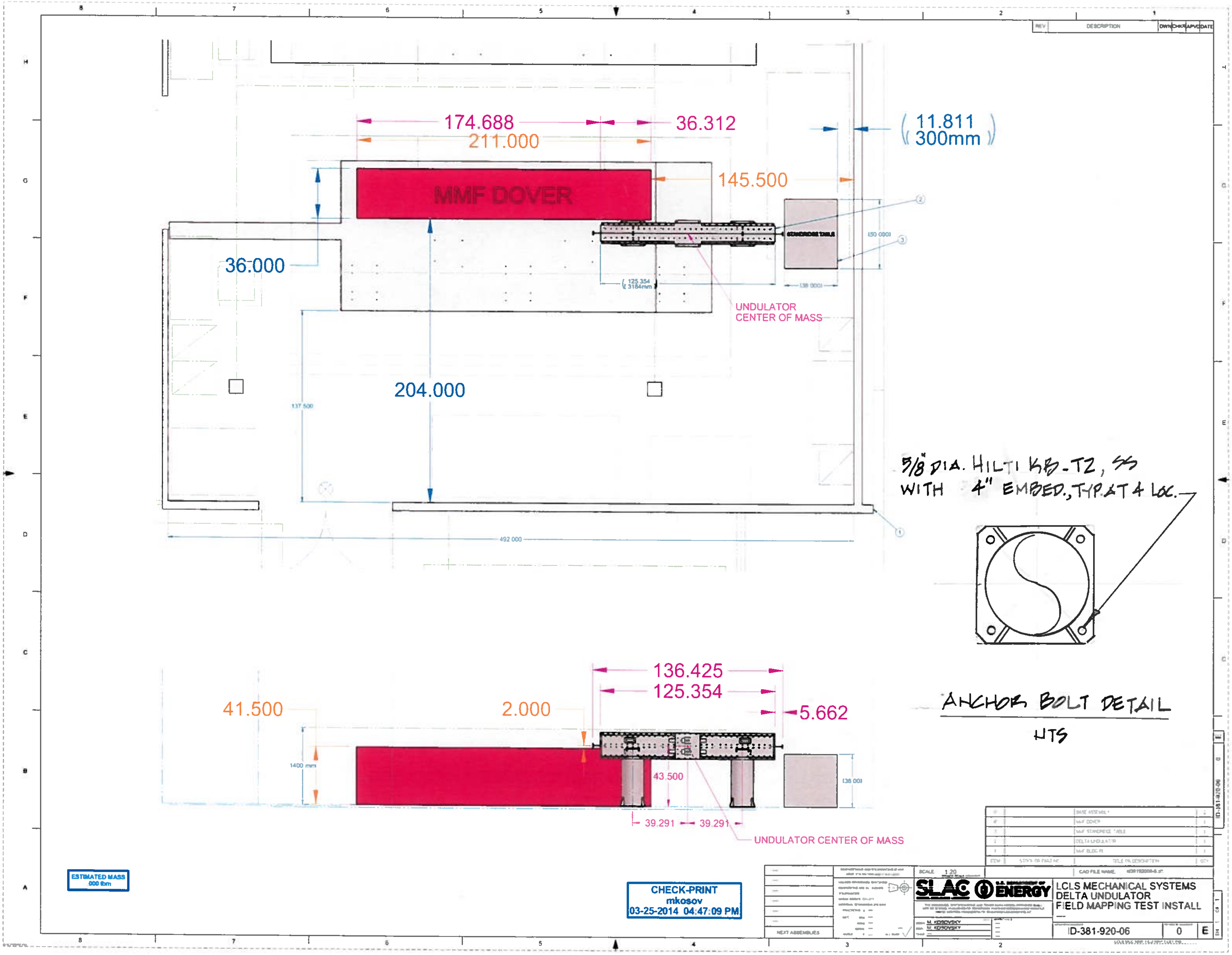
Structural Calculation

Delta Undulator Anchor Bolt Design

Location: B081

By: Felix K. Adikara

April 9, 2014


174.688
211.000
36.312
11.811
300mm
145.500
MMF DOVER
36.000
UNDULATOR
CENTER OF MASS
204.000
5/8" DIA. HILTI KB-TZ, SS
WITH 4" EMBED., TYP. AT 4 LOC.
ANCHOR BOLT DETAIL
NTS
136.425
125.354
5.662
41.500
2.000
43.500
39.291
39.291
UNDULATOR CENTER OF MASS
ESTIMATED MASS
CHECK-PRINT
mkosov
03-25-2014 04:47:09 PM
SLAC
ENERGY
LCLS MECHANICAL SYSTEMS
DELTA UNDULATOR
FIELD MAPPING TEST INSTALL
ID-381-920-06
0
E

Project: To calculate the anchor bolt requirement for the delta undulator

Location: B081 First Floor

Note: Undulator is not part of this calculation

Reference:

1. 2013 California Building Code
2. ASCE 7-10 Minimum Design Loads for Buildings and Other Structures
3. AISC ninth edition
4. Drawings: SLAC: ID-381-920-06-C0
5. ESR - 1917 dated 5/1/2013 for HILTI Kwik Bolt TZ
6. SLAC-I-720-0A24E-001-R004D: Seismic Design Specification for Buildings, Structures, Equipment and Systems: 2014
   Rev. 4D has not been issued at this time, but calculation is conservative relative to Rev. 3

Governing code:

Ref. 2 - Chapter 13: Seismic design requirements for non-structural component that are permanently attached to structure.

Paragraph 13.3: Seismic demands on non-structural component

Input Data: Occupancy category II (Ref. 1 Table 1-1)

Weight of undulator =	3900	lbs	Provided by user
Weight of pipe support (16" dia. Std. 3 feet ea)=	376	lbs	
Weight of top and bott plates (18"x18"x 1/2") =	92	lbs	
Weight of equipment + pipe stand +plates =	4367	lbs	
Height of equipment =	44.00	inch	Ref. 4
Dist. betw cg of equip. and top of floor h =	43.50	inch	Ref. 4
Distance between post d =	15.00	inch	Field measurement

Ip =	1	Importance factor	Ref. 2 Table 11.5-1 for occupancy category II
Rp =	2.5	Response modification factor	Ref. 2 Table 13.5-1 for laboratory equipment
ap =	1	Component amplification factor	Ref. 2 Table 13.5-1 for laboratory equipment

Seismic Ground Motion Value: Location 13 (max. value) Ref. 6

Soil classification: D

Ss =	3.001 g	MCE spectral acceleration at short period
S1 =	1.198 g	MCE spectral acceleration at one period
SDs =	2.000 g	Design spectral acceleration at short period
SD1 =	1.198 g	Design spectral acceleration at one second

Base shear:

The horizontal seismic design force Fp:	z =	0 ft (height in structure of point of attachment, z = 0 for first floor)
	H =	20 ft (height of roof)

Fp = [(0.4 x ap x SDs x Wp) / (Rp/Ip)] x (1 + 2 z/H) =	1398 lbs		Ref.2 Eq. 13.3-1
Fp max = 1.6 x SDs x Ip x Wp =	13976 lbs		Ref.2 Eq. 13.3-2
Fp min = 0.3 x SDs x Ip x Wp =	2620 lbs	**Control**	Ref.2 Eq. 13.3-3
	0.60 Wp		

1. Anchor Bolt:

Strength Design load combination: 0.5 D + 1.0 E — Ref.2 Section 12.4.2.3, Ref. 2 Section 13.3.1

Applied load to the base plate:	fv = Fp / 2 =	1310 lbs
	Mo = (1.0 E x h) / 2 =	56996 in.lbs
	DL = (0.5 x DL)	-2184 lbs

4 - HILTI KB-TZ, SS 5/8" diameter with 4" embedment per leg is adequate

2. Pipe 16" std. pipe: Allow. Stress Design: 1.3 D + 0.7 E — Ref.2 Section 12.4.2.3 and Ref. 2 Section 13.3.1

Area A =	18.4 inch^2		S =	70.30 inch^3	
M = (0.7 x Fp x 0.5) x (h) =				39897 inch. lbs	
Axial load Pa = 0.5 x 1.3 x DL =				2839 lbs	
Shear load fv = 0.5 x 0.7 x Fp =				917 lbs	
Yield Strength Fy for SS 304 =				30000 psi	
fa = Pa / A =	154 psi	<	Fa =	18000 psi	OK
fb = M / S =	568 psi	<	Fb =	18000 psi	OK
fv = fv / A =	50 psi	<	Fb =	12000 psi	OK

Pipe 16" std. pipe is acceptable

Note: Stress is very low, therefore weld between base plate and pipe is OK
Axial load is small, therefore local stress/punching shear on exist. Slab is OK

Figure 2 SLAC Map

Table 2 Seismic Ground Motion Values

Location	S_s	S_1	S_{DS}	S_{D1}	SDC R.C. I/II	SDC R.C. III	SDC R.C. IV
1	2.166	0.0.917	1.444	0.917	E	E	F
2	2.170	0.923	1.447	0.923	E	E	F
3	2.267	0.952	1.512	0.952	E	E	F
4	2.358	0.977	1.572	0.977	E	E	F
5	2.563	1.014	1.709	1.014	E	E	F
6	2.403	0.973	1.602	0.973	E	E	F
7	2.483	0.991	1.655	0.991	E	E	F
8	2.613	1.022	1.742	1.022	E	E	F
9	2.745	1.055	1.830	1.055	E	E	F
10	2.840	1.094	1.893	1.094	E	E	F
11	2.897	1.132	1.931	1.132	E	E	F
12	2.946	1.164	1.964	1.164	E	E	F
13	3.001	1.198	2.000	1.198	E	E	F
14	2.315	0.958	1.543	0.958	E	E	F

*The SDS values are based on site class D

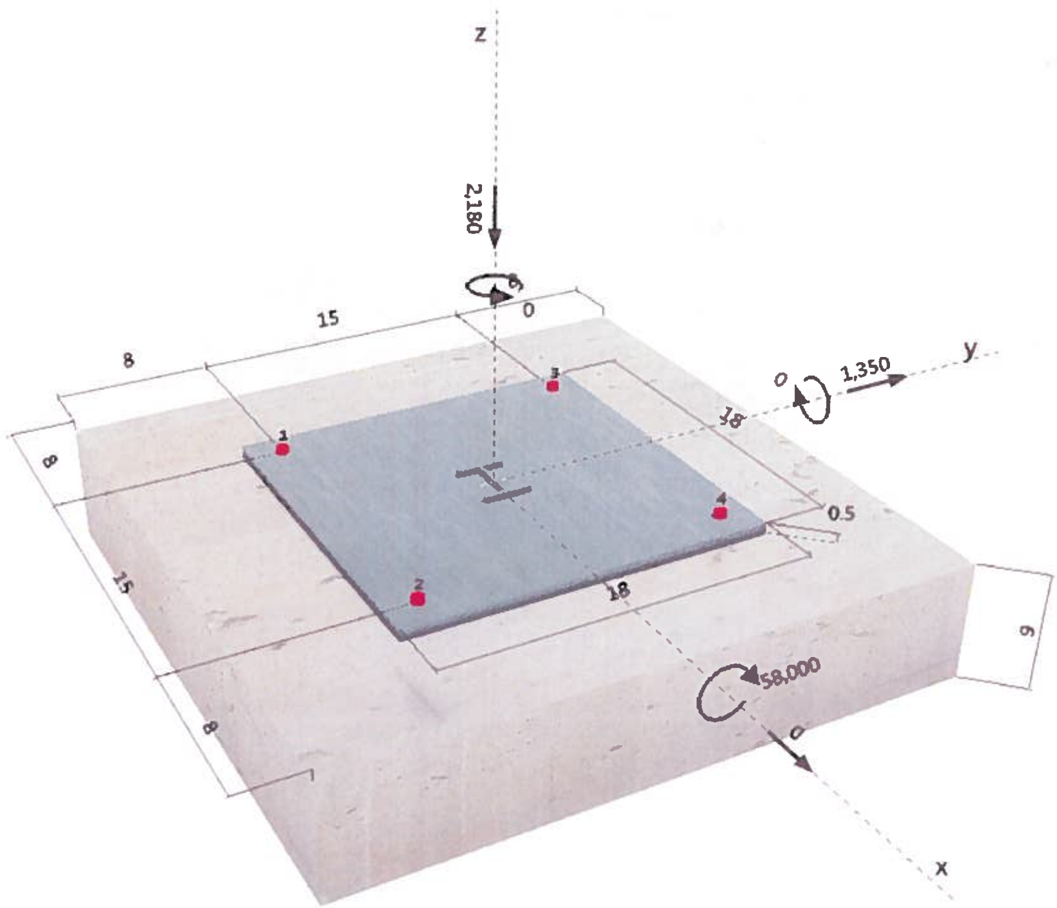
Company:	SLAC National Accelerator Laboratory	Page:	1
Specifier:	Felix K. Adikara	Project:	Delta Undulator
Address:	2575 Sand Hill Road, Menlo Park, CA 94025	Sub-Project I Pos. No.:	B081 First Floor
Phone I Fax:	|	Date:	4/9/2014
E-Mail:			

Specifier's comments:

1 Input data

Anchor type and diameter:	**Kwik Bolt TZ - SS 304 5/8 (4)**
Effective embedment depth:	h_{ef} = 4.000 in., h_{nom} = 4.438 in.
Material:	AISI 304
Evaluation Service Report:	ESR-1917
Issued I Valid:	5/1/2013 | 5/1/2015
Proof:	design method ACI 318 / AC193
Stand-off installation:	e_b = 0.000 in. (no stand-off); t = 0.500 in.
Anchor plate:	l_x x l_y x t = 18.000 in. x 18.000 in. x 0.500 in.; (Recommended plate thickness: not calculated)
Profile:	S shape (AISC); (L x W x T x FT) = 3.000 in. x 2.330 in. x 0.170 in. x 0.260 in.
Base material:	cracked concrete, 3000, f_c' = 3000 psi; h = 6.000 in.
Reinforcement:	tension: condition B, shear: condition B; no supplemental splitting reinforcement present edge reinforcement: none or < No. 4 bar
Seismic loads (cat. C, D, E, or F)	yes (D.3.3.6)

Geometry [in.] & Loading [lb, in.lb]



Company:	SLAC National Accelerator Laboratory	Page:	2
Specifier:	Felix K. Adikara	Project:	Delta Undulator
Address:	2575 Sand Hill Road, Menlo Park, CA 94025	Sub-Project I Pos. No.:	B081 First Floor
Phone I Fax:	|	Date:	4/9/2014
E-Mail:			

2 Load case/Resulting anchor forces

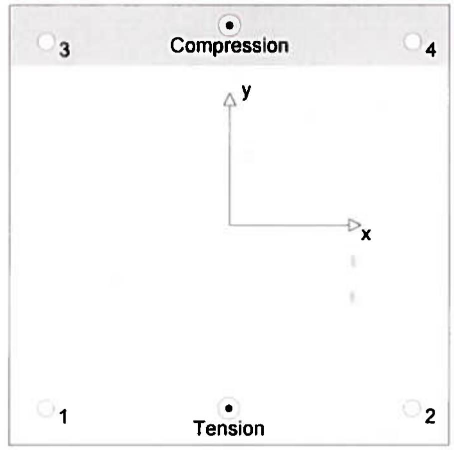
Load case: Design loads

Anchor reactions [lb]

Tension force: (+Tension, -Compression)

Anchor	Tension force	Shear force	Shear force x	Shear force y
1	1283	338	0	338
2	1283	338	0	338
3	0	338	0	338
4	0	338	0	338

max. concrete compressive strain: 0.05 [‰]
max. concrete compressive stress: 211 [psi]
resulting tension force in (x/y)=(0.000/-7.500): 2565 [lb]
resulting compression force in (x/y)=(0.000/8.169): 4745 [lb]



3 Tension load

	Load N_{ua} [lb]	Capacity ϕN_n [lb]	Utilization $\beta_N = N_{ua}/\phi N_n$	Status
Steel Strength*	1283	13972	10	OK
Pullout Strength*	N/A	N/A	N/A	N/A
Concrete Breakout Strength**	2565	5084	51	OK

* anchor having the highest loading **anchor group (anchors in tension)

3.1 Steel Strength

N_{sa} = ESR value refer to ICC-ES ESR-1917
$\phi\, N_{steel} \geq N_{ua}$ ACI 318-08 Eq. (D-1)

Variables

n	$A_{se,N}$ [in.^{2}]	f_{uta} [psi]
1	0.16	115000

Calculations

N_{sa} [lb]
18630

Results

N_{sa} [lb]	ϕ_{steel}	$\phi\, N_{sa}$ [lb]	N_{ua} [lb]
18630	0.750	13972	1283

Company:	SLAC National Accelerator Laboratory	Page:	3
Specifier:	Felix K. Adikara	Project:	Delta Undulator
Address:	2575 Sand Hill Road, Menlo Park, CA 94025	Sub-Project I Pos. No.:	B081 First Floor
Phone I Fax:	|	Date:	4/9/2014
E-Mail:			

3.2 Concrete Breakout Strength

$N_{cbg} = \left(\frac{A_{Nc}}{A_{Nc0}}\right) \psi_{ec,N}\ \psi_{ed,N}\ \psi_{c,N}\ \psi_{cp,N}\ N_b$ ACI 318-08 Eq. (D-5)

$\phi\ N_{cbg} \geq N_{ua}$ ACI 318-08 Eq. (D-1)

A_{Nc} see ACI 318-08, Part D.5.2.1, Fig. RD.5.2.1(b)

$A_{Nc0} = 9\ h_{ef}^2$ ACI 318-08 Eq. (D-6)

$\psi_{ec,N} = \left(\frac{1}{1 + \frac{2\ e_N}{3\ h_{ef}}}\right) \leq 1.0$ ACI 318-08 Eq. (D-9)

$\psi_{ed,N} = 0.7 + 0.3\left(\frac{c_{a,min}}{1.5h_{ef}}\right) \leq 1.0$ ACI 318-08 Eq. (D-11)

$\psi_{cp,N} = \text{MAX}\left(\frac{c_{a,min}}{c_{ac}}, \frac{1.5h_{ef}}{c_{ac}}\right) \leq 1.0$ ACI 318-08 Eq. (D-13)

$N_b = k_c\ \lambda\ \sqrt{f'_c}\ h_{ef}^{1.5}$ ACI 318-08 Eq. (D-7)

Variables

h_{ef} [in.]	$e_{c1,N}$ [in.]	$e_{c2,N}$ [in.]	$c_{a,min}$ [in.]	$\psi_{c,N}$
4.000	0.000	0.000	8.000	1.000

c_{ac} [in.]	k_c	λ	f'_c [psi]
8.875	17	1	3000

Calculations

A_{Nc} [in.^{2}]	A_{Nc0} [in.^{2}]	$\psi_{ec1,N}$	$\psi_{ec2,N}$	$\psi_{ed,N}$	$\psi_{cp,N}$	N_b [lb]
288.00	144.00	1.000	1.000	1.000	1.000	7449

Results

N_{cbg} [lb]	$\phi_{concrete}$	$\phi_{seismic}$	$\phi_{nonductile}$	$\phi\ N_{cbg}$ [lb]	N_{ua} [lb]
14898	0.650	0.750	0.700	5084	2565

Company:	SLAC National Accelerator Laboratory	Page:	4
Specifier:	Felix K. Adikara	Project:	Delta Undulator
Address:	2575 Sand Hill Road, Menlo Park, CA 94025	Sub-Project I Pos. No.:	B081 First Floor
Phone I Fax:	|	Date:	4/9/2014
E-Mail:			

4 Shear load

	Load V_{ua} [lb]	Capacity ϕV_n [lb]	Utilization $\beta_V = V_{ua}/\phi V_n$	Status
Steel Strength*	338	6078	6	OK
Steel failure (with lever arm)*	N/A	N/A	N/A	N/A
Pryout Strength**	1350	21900	7	OK
Concrete edge failure in direction y+**	1350	3337	41	OK

* anchor having the highest loading **anchor group (relevant anchors)

4.1 Steel Strength

$V_{sa,eq}$ = ESR value refer to ICC-ES ESR-1917

$\phi\, V_{steel} \geq V_{ua}$ ACI 318-08 Eq. (D-2)

Variables

n	$A_{se,V}$ [in.^{2}]	f_{uta} [psi]
1	0.16	115000

Calculations

V_{sa} [lb]
9350

Results

V_{sa} [lb]	ϕ_{steel}	$\phi\, V_{sa}$ [lb]	V_{ua} [lb]
9350	0.650	6078	338

4.2 Pryout Strength

$V_{cpg} = k_{cp}\left[\left(\frac{A_{Nc}}{A_{Nc0}}\right)\psi_{ec,N}\,\psi_{ed,N}\,\psi_{c,N}\,\psi_{cp,N}\,N_b\right]$ ACI 318-08 Eq. (D-31)

$\phi\, V_{cpg} \geq V_{ua}$ ACI 318-08 Eq. (D-2)

A_{Nc} see ACI 318-08, Part D.5.2.1, Fig. RD.5.2.1(b)

$A_{Nc0} = 9\, h_{ef}^2$ ACI 318-08 Eq. (D-6)

$\psi_{ec,N} = \left(\frac{1}{1 + \frac{2\, e_N'}{3\, h_{ef}}}\right) \leq 1.0$ ACI 318-08 Eq. (D-9)

$\psi_{ed,N} = 0.7 + 0.3\left(\frac{c_{a,min}}{1.5h_{ef}}\right) \leq 1.0$ ACI 318-08 Eq. (D-11)

$\psi_{cp,N} = \mathrm{MAX}\left(\frac{c_{a,min}}{c_{ac}}, \frac{1.5h_{ef}}{c_{ac}}\right) \leq 1.0$ ACI 318-08 Eq. (D-13)

$N_b = k_c\, \lambda\, \sqrt{f_c'}\, h_{ef}^{1.5}$ ACI 318-08 Eq. (D-7)

Variables

k_{cp}	h_{ef} [in.]	$e_{c1,N}$ [in.]	$e_{c2,N}$ [in.]	$c_{a,min}$ [in.]
2	4.000	0.000	0.000	8.000

$\psi_{c,N}$	c_{ac} [in.]	k_c	λ	f_c' [psi]
1.000	8.875	17	1	3000

Calculations

A_{Nc} [in.^{2}]	A_{Nc0} [in.^{2}]	$\psi_{ec1,N}$	$\psi_{ec2,N}$	$\psi_{ed,N}$	$\psi_{cp,N}$	N_b [lb]
576.00	144.00	1.000	1.000	1.000	1.000	7449

Results

V_{cpg} [lb]	$\phi_{concrete}$	$\phi_{seismic}$	$\phi_{nonductile}$	$\phi\, V_{cpg}$ [lb]	V_{ua} [lb]
59592	0.700	0.750	0.700	21900	1350

Company:	SLAC National Accelerator Laboratory	Page:	5
Specifier:	Felix K. Adikara	Project:	Delta Undulator
Address:	2575 Sand Hill Road, Menlo Park, CA 94025	Sub-Project I Pos. No.:	B081 First Floor
Phone I Fax:	|	Date:	4/9/2014
E-Mail:			

4.3 Concrete edge failure in direction y+

$V_{cbg} = \left(\frac{A_{Vc}}{A_{Vc0}}\right) \psi_{ec,V}\, \psi_{ed,V}\, \psi_{c,V}\, \psi_{h,V}\, \psi_{parallel,V}\, V_b$ ACI 318-08 Eq. (D-22)

$\phi\, V_{cbg} \geq V_{ua}$ ACI 318-08 Eq. (D-2)

A_{Vc} see ACI 318-08, Part D.6.2.1, Fig. RD.6.2.1(b)

$A_{Vc0} = 4.5\, c_{a1}^2$ ACI 318-08 Eq. (D-23)

$\psi_{ec,V} = \left(\frac{1}{1 + \frac{2e_V}{3c_{a1}}}\right) \leq 1.0$ ACI 318-08 Eq. (D-26)

$\psi_{ed,V} = 0.7 + 0.3\left(\frac{c_{a2}}{1.5c_{a1}}\right) \leq 1.0$ ACI 318-08 Eq. (D-28)

$\psi_{h,V} = \sqrt{\frac{1.5c_{a1}}{h_a}} \geq 1.0$ ACI 318-08 Eq. (D-29)

$V_b = \left(7\left(\frac{l_e}{d_a}\right)^{0.2}\sqrt{d_a}\right) \lambda \sqrt{f'_c}\, c_{a1}^{1.5}$ ACI 318-08 Eq. (D-24)

Variables

c_{a1} [in.]	c_{a2} [in.]	e_{cV} [in.]	$\psi_{c,V}$	h_a [in.]
5.333	8.000	0.000	1.000	6.000

l_e [in.]	λ	d_a [in.]	f'_c [psi]	$\psi_{parallel,V}$
4.000	1.000	0.625	3000	1.000

Calculations

A_{Vc} [in.^{2}]	A_{Vc0} [in.^{2}]	$\psi_{ec,V}$	$\psi_{ed,V}$	$\psi_{h,V}$	V_b [lb]
186.00	128.00	1.000	1.000	1.155	5412

Results

V_{cbg} [lb]	$\phi_{concrete}$	$\phi_{seismic}$	$\phi_{nonductile}$	$\phi\, V_{cbg}$ [lb]	V_{ua} [lb]
9080	0.700	0.750	0.700	3337	1350

5 Combined tension and shear loads

β_N	β_V	ζ	Utilization $\beta_{N,V}$ [%]	Status
0.505	0.405	5/3	55	OK

$\beta_{NV} = \beta_N^{\zeta} + \beta_V^{\zeta} <= 1$

6 Warnings

- To avoid failure of the anchor plate the required thickness can be calculated in PROFIS Anchor. Load re-distributions on the anchors due to elastic deformations of the anchor plate are not considered. The anchor plate is assumed to be sufficiently stiff, in order not to be deformed when subjected to the loading!
- Condition A applies when supplementary reinforcement is used. The Φ factor is increased for non-steel Design Strengths except Pullout Strength and Pryout strength. Condition B applies when supplementary reinforcement is not used and for Pullout Strength and Pryout Strength. Refer to your local standard.
- Refer to the manufacturer's product literature for cleaning and installation instructions.
- Checking the transfer of loads into the base material and the shear resistance are required in accordance with ACI 318 or the relevant standard!
- An anchor design approach for structures assigned to Seismic Design Category C, D, E or F is given in ACI 318-08 Appendix D, Part D.3.3.4 that requires the governing design strength of an anchor or group of anchors be limited by ductile steel failure. If this is NOT the case, Part D.3.3.5 requires that the attachment that the anchor is connecting to the structure shall be designed so that the attachment will undergo ductile yielding at a load level corresponding to anchor forces no greater than the controlling design strength. In lieu of D.3.3.4 and D.3.3.5, the minimum design strength of the anchors shall be multiplied by a reduction factor per D.3.3.6.
  An alternative anchor design approach to ACI 318-08, Part D.3.3 is given in IBC 2009, Section 1908.1.9. This approach contains "Exceptions" that may be applied in lieu of D.3.3 for applications involving "non-structural components" as defined in ASCE 7, Section 13.4.2.
  An alternative anchor design approach to ACI 318-08, Part D.3.3 is given in IBC 2009, Section 1908.1.9. This approach contains "Exceptions" that may be applied in lieu of D.3.3 for applications involving "wall out-of-plane forces" as defined in ASCE 7, Equation 12.11-1 or Equation 12.14-10.
- It is the responsibility of the user when inputting values for brittle reduction factors ($\phi_{nonductile}$) different than those noted in ACI 318-08, Part D.3.3.6 to determine if they are consistent with the design provisions of ACI 318-08, ASCE 7 and the governing building code.
  Selection of $\phi_{nonductile}$ = 1.0 as a means of satisfying ACI 318-08, Part D.3.3.5 assumes the user has designed the attachment that the anchor is connecting to undergo ductile yielding at a force level <= the design strengths calculated per ACI 318-08, Part D.3.3.3.

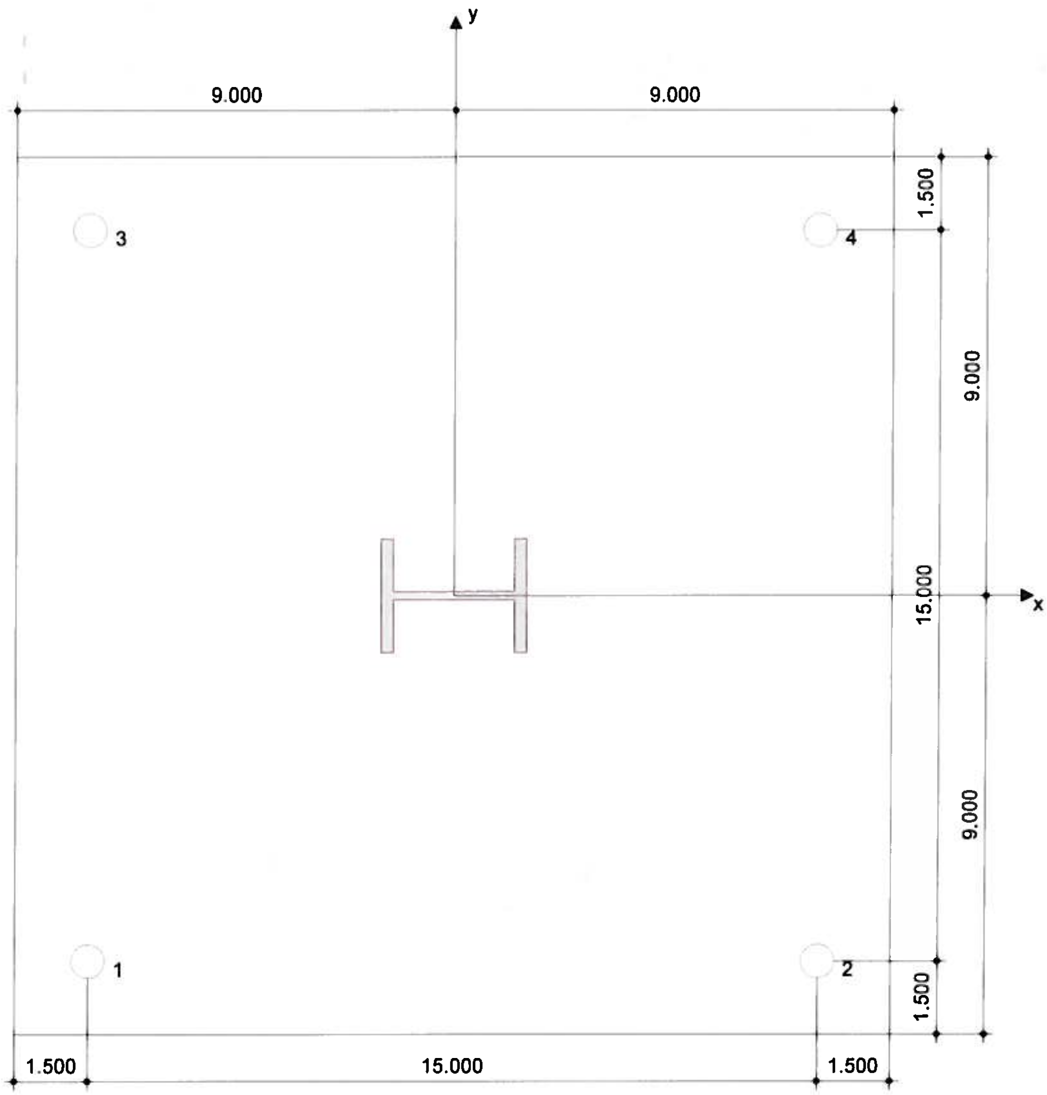
Fastening meets the design criteria!

Company:	SLAC National Accelerator Laboratory	Page:	7
Specifier:	Felix K. Adikara	Project:	Delta Undulator
Address:	2575 Sand Hill Road, Menlo Park, CA 94025	Sub-Project I Pos. No.:	B081 First Floor
Phone I Fax:	|	Date:	4/9/2014
E-Mail:			

7 Installation data

Anchor plate, steel: -
Profile: S shape (AISC); 3.000 x 2.330 x 0.170 x 0.260 in.
Hole diameter in the fixture: d_f = 0.688 in.
Plate thickness (input): 0.500 in.
Recommended plate thickness: not calculated
Cleaning: Manual cleaning of the drilled hole according to instructions for use is required.

Anchor type and diameter: Kwik Bolt TZ - SS 304, 5/8 (4)
Installation torque: 720.001 in.lb
Hole diameter in the base material: 0.625 in.
Hole depth in the base material: 4.750 in.
Minimum thickness of the base material: 6.000 in.



Coordinates Anchor in.

Anchor	x	y	c_{-x}	c_{+x}	c_{-y}	c_{+y}
1	-7.500	-7.500	8.000	23.000	8.000	23.000
2	7.500	-7.500	23.000	8.000	8.000	23.000
3	-7.500	7.500	8.000	23.000	23.000	8.000
4	7.500	7.500	23.000	8.000	23.000	8.000

8 Remarks; Your Cooperation Duties

- Any and all information and data contained in the Software concern solely the use of Hilti products and are based on the principles, formulas and security regulations in accordance with Hilti's technical directions and operating, mounting and assembly instructions, etc., that must be strictly complied with by the user. All figures contained therein are average figures, and therefore use-specific tests are to be conducted prior to using the relevant Hilti product. The results of the calculations carried out by means of the Software are based essentially on the data you put in. Therefore, you bear the sole responsibility for the absence of errors, the completeness and the relevance of the data to be put in by you. Moreover, you bear sole responsibility for having the results of the calculation checked and cleared by an expert, particularly with regard to compliance with applicable norms and permits, prior to using them for your specific facility. The Software serves only as an aid to interpret norms and permits without any guarantee as to the absence of errors, the correctness and the relevance of the results or suitability for a specific application.
- You must take all necessary and reasonable steps to prevent or limit damage caused by the Software. In particular, you must arrange for the regular backup of programs and data and, if applicable, carry out the updates of the Software offered by Hilti on a regular basis. If you do not use the AutoUpdate function of the Software, you must ensure that you are using the current and thus up-to-date version of the Software in each case by carrying out manual updates via the Hilti Website. Hilti will not be liable for consequences, such as the recovery of lost or damaged data or programs, arising from a culpable breach of duty by you.

Adikara, Felix K.

From:	Levashov, Yurii I.
Sent:	Wednesday, March 26, 2014 8:08 AM
To:	Adikara, Felix K.
Subject:	Anchoring DELTA undulator
Attachments:	Measurement set-up.pdf

Hi Felix,

We need to anchor an another undulator, called DELTA, in our lab, Bldg.81, rm.114, next to the our Dover bench, see picture attached.
It is 3.2m long device, ~3900 lbs. weight. It will stay in our lab for 1 month then will be moved into LCLS tunnel.
We'll place the undulator on 2 support stands to be designed. One stand will rest on 3' thick concrete pad. Another one will be on 6" floor.
How should we secure them safely to the floor to meet all requirements? Which anchors should we use, what footprint is required for the supports?

Thanks,
Yurii Levashov
x2178