RECLAMATION

Managing Water in the West

Mechanical Properties of Self Consolidating Concrete

Research and Development Office Science and Technology Program (Final Report) ST-2016-3587-01

U.S. Department of the Interior
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Research and Development Office

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15. SUBJECT TERMS SCC, self consolidating concrete, creep		

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Mechanical Properties of Self Consolidating Concrete

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Acronyms and Abbreviations

ASTM – ASTM International

psi – pounds per square inch

SCC – Self consolidating concrete

Executive Summary

It is well known that Reclamation is a leader in conventional and mass concrete and has obtained a tremendous amount of data regarding the mechanical properties of either of these types of concrete. The mechanical properties of concrete is necessary for the design of concrete structures. However, Reclamation is behind the private industry and other federal agencies on their use of self consolidating concrete (SCC). The private sector has been using SCC since the 1980's and since 1990, self-consolidating concrete has been proven to be advantageous for several reasons:

1. SCC can be placed at a faster rate with no mechanical vibration and less screeding, resulting in savings in placement costs.
2. Improved and more uniform surface finish with little to no remedial surface work.
3. Ease of filling restricted sections and hard-to-reach areas. Opportunities to create complicated structural shapes and surface finishes not achievable with conventional concrete.
4. Improved consolidation around reinforcement and bond with reinforcement.
5. Improved pumpability.
6. Improved uniformity of in-place concrete by eliminating variable operator-related effort of consolidation.
7. Labor savings.
8. Shorter construction periods and resulting cost savings.
9. Quicker concrete truck turn-around times, enabling the producer to service the project more efficiently.
10. Reduction or elimination of vibrator noise, potentially increasing construction hours in urban areas.
11. Minimizes movement of ready mixed trucks and pumps during placement.
12. Increased jobsite safety by eliminating the need for consolidation.

This study measured creep in SCC cast with materials local to the Denver area. Three strengths of SCC were targeted – 4,000 psi, 6,500, psi and 7,500 psi. The samples were moist cured for 28 days before loading.

The creep of the self consolidating concrete tested measured slightly higher than creep of conventional slump concrete. This should not preclude SCC from being used in concrete design for elements which may undergo creep. Proper mix design techniques as well as enhanced design can overcome any issues associated with creep in self consolidating concrete.

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Introduction

For this study, local materials were utilized. The concrete mix designs and self consolidating concrete were supplied by Bestway Concrete (Burnco). The mix designs ranged in strength from 4,000 psi to 7,500 psi. Specimens were cast on June 1st, 2017 at the Bestway Concrete Lab in Westminster, CO.

Test specimens were cast and mechanical testing included: Compressive Strength and Elastic Properties, Creep and Autogenous Length Change.

This report presents the results of concrete physical property and creep testing. Creep results are presented for each reading interval and graphs are shown for each individual mix, as well as a summary for all mixes.

Concrete Creep and Length Change

Concrete for creep testing was batched on June 1, 2017 and Bestway Concrete's Materials Laboratory for Mix ID 4K, 6K and 7.5K, loading at age 28 days. Testing was performed in accordance with ASTM C512, *Creep of Concrete in Compression*. Results are shown in Table 1 for the final reading, one year from the time of loading. The complete creep results for each reading are shown in Appendix A. Fresh properties for the three mixes are summarized in Table 2.

Table 1: Creep Results Summary

Mix	4K	6K	7.5K
Average Compressive Strength, psi	5,410	6,960	7,530
Preload, psi	90	90	90
Average Applied Load, psi	2,160	2.810	**
Instantaneous Elastic Modulus, psi x 10^6	2.08	2.52	**
Creep Rate, microstrain/psi per (*t* + 1) day	0.0970	0.0591	**

** During initial loading, the seal on the creep frame for Mix 7.5K failed and the specimens were subjected to an excessive load and were cracked. No data was obtained for this mix.

Table 2: Mix Fresh Properties

Mix	4K	6K	7.5K
Spread, in.	25.3	22.0	24.0
Air Content, %	< 3	< 3	< 3
Unit Weight, pcf	141.0	138.6	139.0
Temperature, (F)	78	77	78

The 6 inch (152 mm) diameter by 12 inch (305 mm) long creep specimens were cast vertically with three sets of two gage points spaced approximately 8 inches laterally and equidistant around the circumference of the specimen for a total of six gage points per specimen. The samples were stored at 100% humidity for 7 days and then stored in the creep environment of 73.5 ± 1.5°F (23.1 ± 2.7°C) and 50 ± 4% humidity for the duration of testing. All specimens were sulfur capped prior to placing in the hydraulically operated load frames.

Two specimens from each mix were loaded into the frame with 6 inch (152 mm) dummy cylinders of the same mix placed at the top and the bottom of the test specimens. Two additional specimens per mix were prepared similarly for unloaded shrinkage control. Compressive strength was determined at 28 days just prior to loading to set the creep load at 40-percent of the ultimate strength. Preloading was used to determine eccentricities and to calibrate the hydraulic system.

Readings were taken before loading, during the preload, after loading, at 2 hours, 9 hours, 1 day intervals for a week, 1 week intervals for a month, and 1 month intervals for a year. In some instances, data collection occurred ± 3 days due to scheduling conflicts.

Readings were taken using a dial gauge calibrated with a standard bar reading. Three readings were taken at all three gage point sets for each specimen including the unloaded (shrinkage) controls. The readings were averaged at each location and normalized with the gage point length to compute strain (length change per unit length).

Individual plots of total strain and shrinkage strain, in millionths, were generated. The total load-induced strain per pound force per square inch was calculated as the difference between the average strain values of the loaded and control (shrinkage) specimens divided by the average stress. Creep strain was also normalized and plotted on a log scale in $(t + 1)$ days where t is the age at loading.

The magnitudes of the creep parameters $1/E$ and $F(K)$ are based on the empirical logarithmic function below. Since the strain readings were measured manually and there was some time between the loading condition and the first reading, the y-intercept was extrapolated by the method of least squares representing $1/E$, where E is the instantaneous modulus of elasticity.

$$\varepsilon = \frac{1}{E} + F(K)\ln(t+1)$$

Where:

ε	=	total strain per unit stress, inverse pounds per square inch (megapascal),
E	=	instantaneous elastic modulus, pounds force per square inch (gigapascal),
$F(K)$	=	creep rate (calculated as slope of a straight line representing creep curve on semilog plot), microstain per pounds per square inch per day (microstain per megapascal per day),
ln	=	natural logarithmic function, and
t	=	time after loading, days

The shrinkage strain determined from the control specimens was subtracted from the test specimen strain to give creep strain as shown in Figures 1 – 2. The data is shown on a log time graph with a logarithmic least squares regression model to give the initial elastic strain (y-intercept) and the creep rate (slope). Figure 3 compares the normalized creep for all mixes.

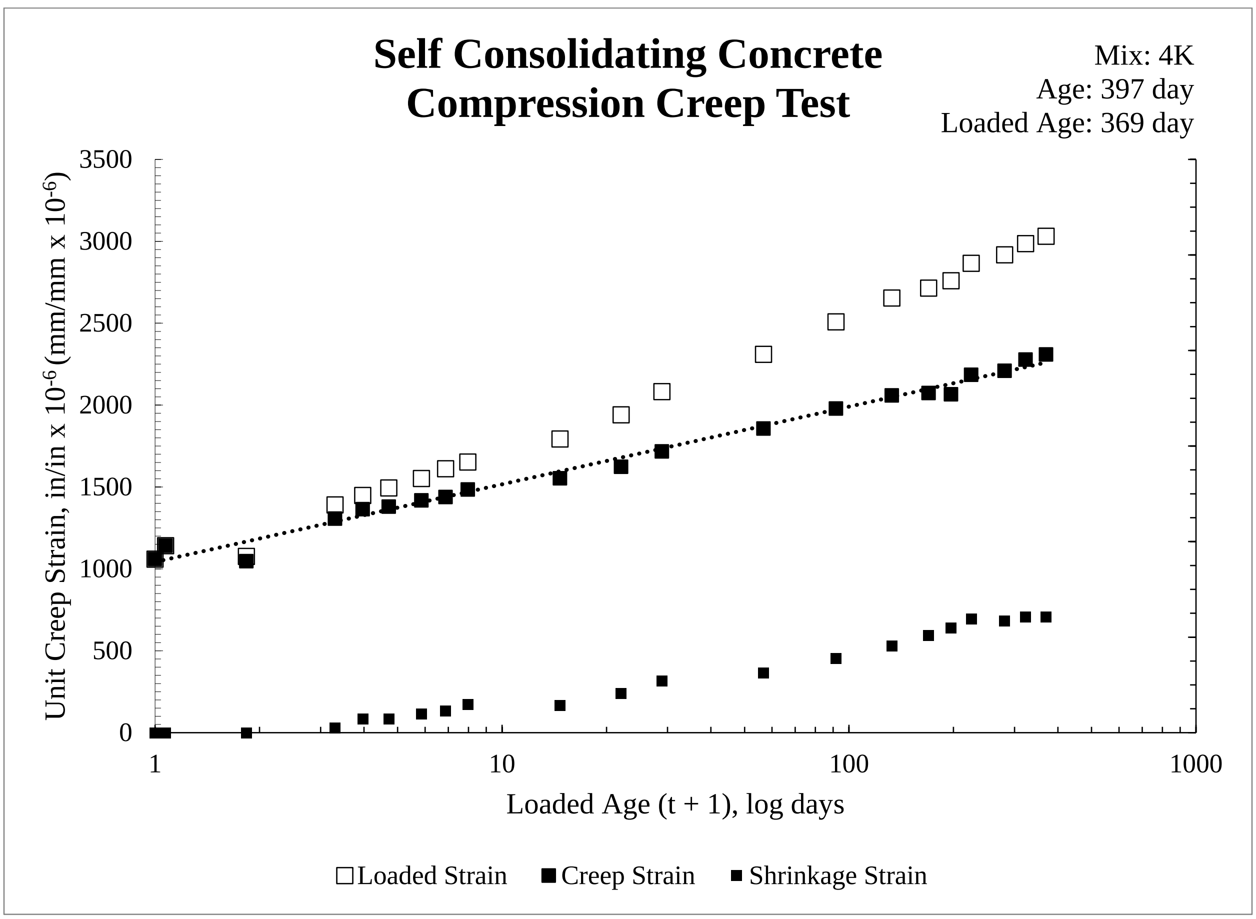

Figure 1: Unit Creep Graph for Mix ID 4K

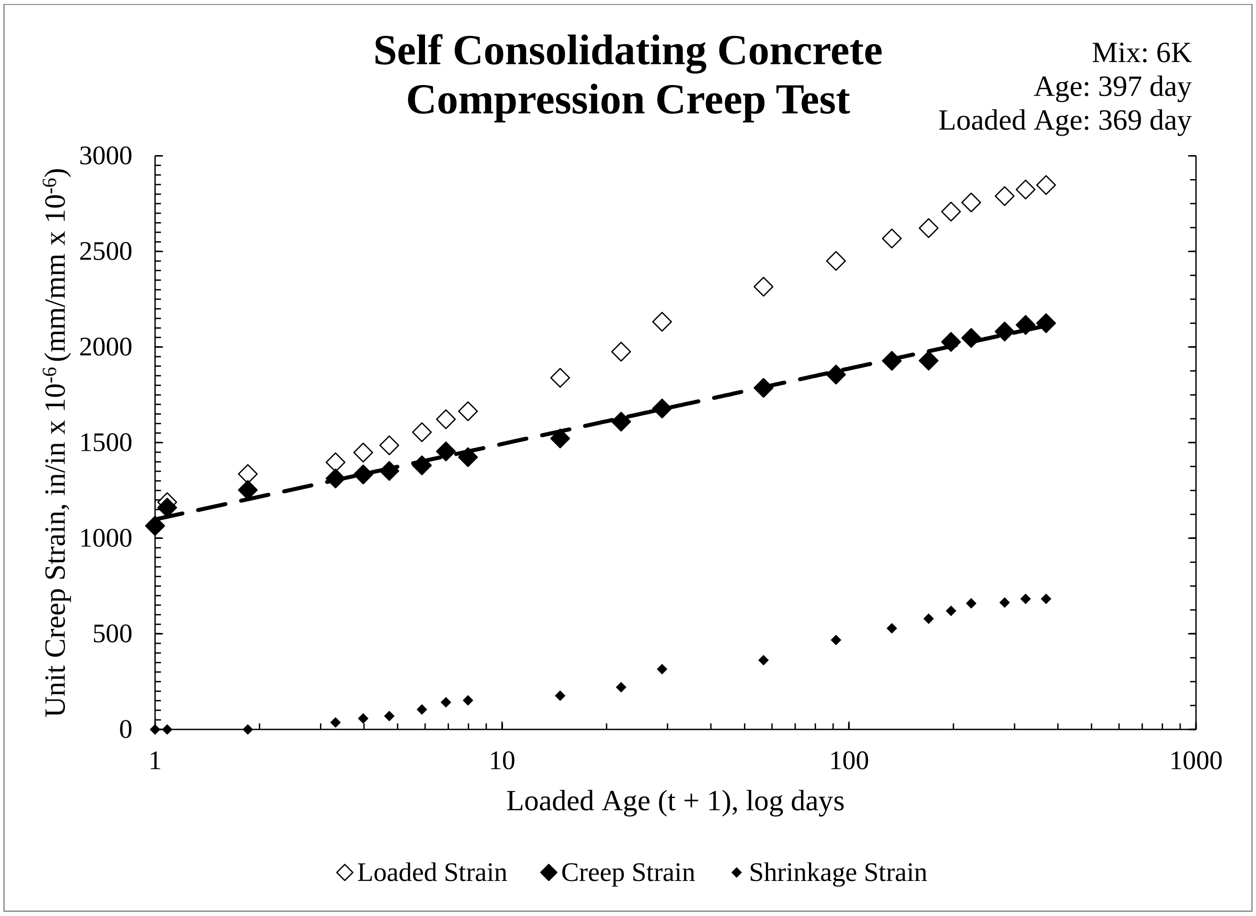

Figure 2: Unit Creep Graph for Mix ID 6K

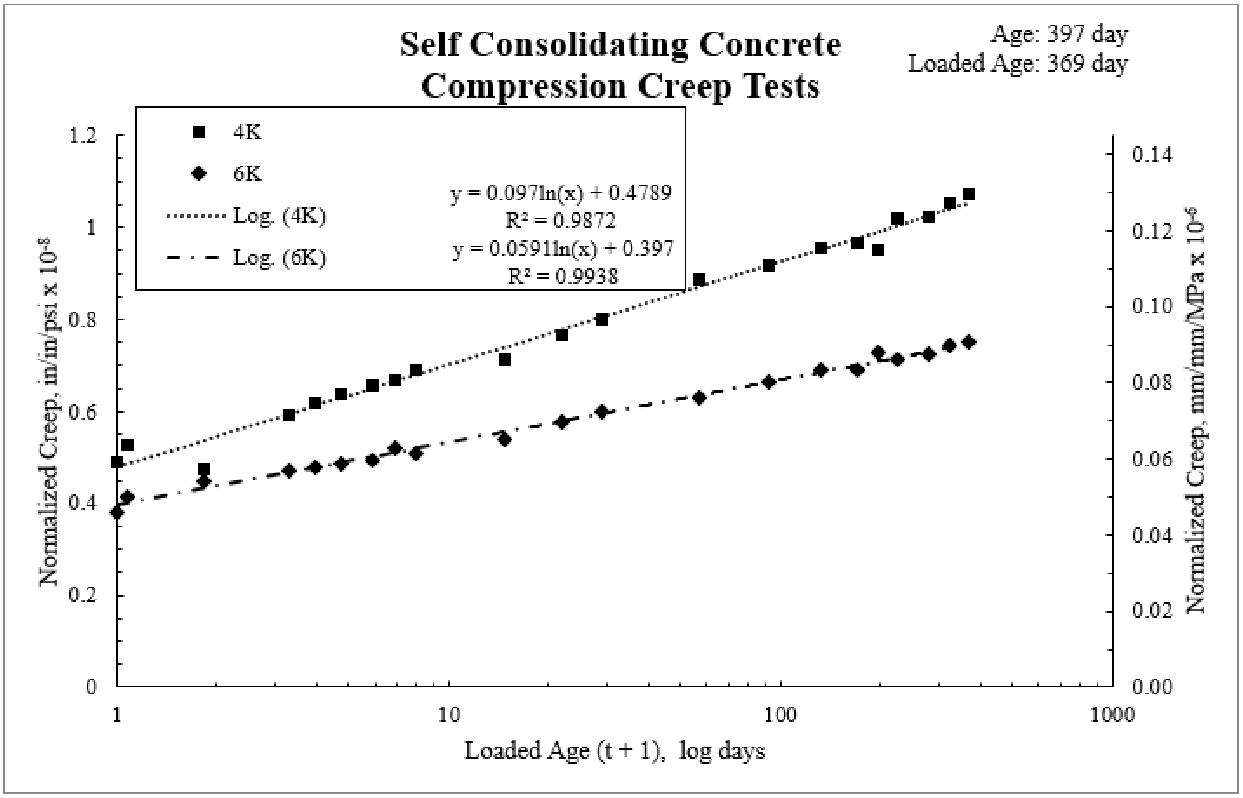

Figure 3: Creep Results for All Mixes

Conclusions

Creep is dependent upon many factors including constituent material properties, concrete mix design properties including strength and water content, curing, in-service environment, age at loading, amount of reinforcement, etc. These factors make it difficult to determine a typical value for creep. The self-consolidating concrete in this study appeared to have a slightly higher creep than conventional concrete mixes tested within Reclamation recently. That should not preclude SCC from being used in structures where creep may be a concern. The potential for increased creep can be mitigated by developing a well-designed concrete mix, performing pre-construction creep testing with the planned materials and taking the design steps necessary to account for any movement/issues that occur due to creep.

References

ASTM C512. (2015). Standard Test Method for Creep of Concrete in Compression. West Conshohocken: American Society for Testing and Materials.

U.S. Bureau of Reclamation. (1988). *Concrete Manual, 8th Edition - Revised.* Washington, D.C.: U.S. Department of the Interior.

USBR 4512-92. (1992). Creep of Concrete in Compression. Denver: U.S. Department of the Interior.

Appendix A – Summary of Creep Results

Table A 1. Summary of Mix ID 4K Creep Data

ASTM C512 - Creep of Concrete in Compression

Project: SCC S&T
Test Agency: USBR Materials Engineering and Research Laboratory
Location: Denver, Colorado

			Type	Source		
Mix Number:	4K	Cement:			Cast date:	6/1/2017
Cement content:		Fine Aggregate:			Cast position:	Vertical
						Prior to Load / Loaded
Water-cement ratio:		Course Aggregate:			Storage conditions:	100% RH @ 73.5°F / 54% RH @ 74.0°F
Max Aggregate Size:		Admixure A:			Loading age:	28 day
Spread	23.5	Admixure B:			Compressive strength:	5410
Air Content:	<3				Strain measuring device:	8.000 inch dial gauge comparator

Test Time Description	Date	Time, h:min	Loaded Age + 1, days	Stress, lb/in^2	Standard Bar Base Reading	Loaded Strain	Shrinkage Strain	Creep Strain	Strain per Unit Stress, $(lb/in^2)^{-1}$	Instantaneous Elastic Modulus (E), $lb/in^2 \times 10^6$	Creep Rate, F(K)
No Load	Thursday, June 29, 2017	3:00 PM	NA	0	0.0448	NA	NA	NA	NA	NA	NA
Preload	Thursday, June 29, 2017	3:30 PM	NA	90	0.0448	NA	NA	NA	NA	NA	NA
Load	Thursday, June 29, 2017	3:45 PM	1.0	2160	0.0449	1059.72	0.00	1059.72	0.49	NA	NA
Hour 2	Thursday, June 29, 2017	5:30 PM	1.1	2160	0.0447	1141.67	0.00	1141.67	0.53	2.04	NA
Day 1	Friday, June 30, 2017	11:45 AM	1.8	2205	0.0447	1075.69	0.00	1047.22	0.47	1.96	-0.0539
Day 2	Saturday, July 01, 2017	11:00 PM	3.3	2205	0.0446	1390.28	28.47	1306.25	0.59	2.03	0.0614
Day 3	Sunday, July 02, 2017	3:00 PM	4.0	2205	0.0444	1448.61	84.03	1363.89	0.62	2.05	0.0802
Day 4	Monday, July 03, 2017	9:00 AM	4.7	2160	0.0445	1494.44	84.72	1379.86	0.64	2.06	0.0887
Day 5	Tuesday, July 04, 2017	12:21 PM	5.9	2160	0.0446	1552.08	114.58	1418.06	0.66	2.06	0.0923
Day 6	Wednesday, July 05, 2017	12:46 PM	6.9	2151	0.0445	1611.81	134.03	1438.89	0.67	2.07	0.0936
Day 7	Thursday, July 06, 2017	2:55 PM	8.0	2151	0.0445	1652.78	172.92	1484.72	0.69	2.07	0.0958
Week 2	Thursday, July 13, 2017	8:24 AM	14.7	2178	0.0445	1793.06	168.06	1552.78	0.71	2.05	0.0904
Week 3	Thursday, July 20, 2017	4:36 PM	22.0	2115	0.0446	1940.97	240.28	1623.61	0.77	2.05	0.0905
Week 4	Thursday, July 27, 2017	1:04 PM	28.9	2142	0.0445	2082.64	317.36	1716.67	0.80	2.06	0.0918
Month 2	Thursday, August 24, 2017	8:42 AM	56.7	2097	0.0447	2310.42	365.97	1856.25	0.89	2.08	0.0953
Month 3	Thursday, September 28, 2017	8:32 AM	91.7	2160	0.0446	2508.33	454.17	1978.47	0.92	2.08	0.0956
Month 5	Wednesday, November 08, 2017	1:25 PM	132.9	2160	0.0447	2653.47	529.86	2059.03	0.95	2.08	0.0960
Month 6	Friday, December 15, 2017	7:47 AM	169.7	2142	0.0447	2713.89	594.44	2073.61	0.97	2.08	0.0956
Month 7	Thursday, January 11, 2018	12:37 PM	196.9	2169	0.0447	2759.72	640.28	2065.97	0.95	2.06	0.0937
Month 8	Thursday, February 08, 2018	1:11 PM	224.9	2142	0.0449	2865.97	693.75	2184.72	1.02	2.07	0.0951
Month 10	Thursday, April 05, 2018	1:12 PM	280.9	2160	0.0447	2917.36	681.25	2209.03	1.02	2.08	0.0952
Month 11	Thursday, May 17, 2018	9:20 AM	322.7	2160	0.0450	2986.11	708.33	2277.78	1.05	2.08	0.0961
Month 13	Tuesday, July 03, 2018	10:04 AM	369.8	2151	0.0451	3031.25	708.33	2309.03	1.07	2.09	0.0970

Note: Strain readings are all in microstrain

Table A 2. Summary of Mix ID 6K Creep Data

ASTM C512 - Creep of Concrete in Compression

Project: SCC S&T
Test Agency: USBR Materials Engineering and Research Laboratory
Location: Denver, Colorado

				Type	Source			
Mix Number:	6K	Cement:				Cast date:	6/1/2017	
Cement content:		Fine Aggregate:				Cast position:	Vertical	
Water-cement ratio:		Course Aggregate:					Prior to Load	Loaded
Max Aggregate Size:		Admixure A:				Storage conditions:	100% RH @ 73.5°F	54% RH @ 74.0°F
Spread	22	Admixure B:				Loading age:	28 day	
Air Content:	<3					Compressive strength:	6960	
						Strain measuring device:	8.000 inch dial gauge comparator	

Test Time Description	Date	Time, h:min	Loaded Age + 1, days	Stress, lb/in^2	Standard Bar Base Reading	Loaded Strain	Shrinkage Strain	Creep Strain	Strain per Unit Stress, (lb/in^2)$^{-1}$	Instantaneous Elastic Modulus (E), lb/in^2 x 10^6	Creep Rate, F(K)
No Load	Thursday, June 29, 2017	3:00 PM	NA	0	0.0448	NA	NA	NA	NA	NA	NA
Preload	Thursday, June 29, 2017	3:15 PM	NA	90	0.0448	NA	NA	NA	NA	NA	NA
Load	Thursday, June 29, 2017	3:30 PM	1.0	2790	0.0449	1064.58	0.00	1064.58	0.38	NA	NA
Hour 2	Thursday, June 29, 2017	5:30 PM	1.1	2790	0.0447	1188.89	0.00	1160.42	0.42	2.62	NA
Day 1	Friday, June 30, 2017	11:54 AM	1.9	2790	0.0447	1336.11	0.00	1252.08	0.45	2.54	0.0919
Day 2	Saturday, July 01, 2017	11:00 PM	3.3	2790	0.0446	1397.22	36.11	1312.50	0.47	2.51	0.0654
Day 3	Sunday, July 02, 2017	3:00 PM	4.0	2790	0.0444	1447.92	57.64	1333.33	0.48	2.50	0.0605
Day 4	Monday, July 03, 2017	9:00 AM	4.7	2790	0.0445	1486.11	70.14	1352.08	0.48	2.50	0.0576
Day 5	Tuesday, July 04, 2017	12:27 PM	5.9	2790	0.0446	1554.17	104.17	1381.25	0.50	2.49	0.0557
Day 6	Wednesday, July 05, 2017	12:54 PM	6.9	2790	0.0445	1622.22	142.36	1454.17	0.52	2.50	0.0585
Day 7	Thursday, July 06, 2017	3:03 PM	8.0	2790	0.0445	1663.89	152.08	1423.61	0.51	2.50	0.0565
Week 2	Thursday, July 13, 2017	8:29 AM	14.7	2817	0.0445	1838.89	176.39	1521.53	0.54	2.48	0.0540
Week 3	Thursday, July 20, 2017	4:41 PM	22.0	2790	0.0446	1975.69	220.83	1609.72	0.58	2.49	0.0552
Week 4	Thursday, July 27, 2017	1:18 PM	28.9	2799	0.0445	2132.64	315.28	1678.47	0.60	2.50	0.0568
Month 2	Thursday, August 24, 2017	8:49 AM	56.7	2835	0.0447	2315.97	362.50	1786.11	0.63	2.50	0.0569
Month 3	Thursday, September 28, 2017	8:39 AM	91.7	2799	0.0446	2450.69	468.06	1856.25	0.66	2.51	0.0575
Month 5	Wednesday, November 08, 2017	1:30 PM	132.9	2799	0.0447	2568.06	529.17	1927.78	0.69	2.51	0.0582
Month 6	Friday, December 15, 2017	7:52 AM	169.7	2790	0.0447	2622.22	579.17	1928.47	0.69	2.51	0.0578
Month 7	Thursday, January 11, 2018	12:48 PM	196.9	2790	0.0447	2708.33	620.14	2027.08	0.73	2.52	0.0591
Month 8	Thursday, February 08, 2018	1:19 PM	224.9	2871	0.0449	2756.25	659.72	2047.92	0.71	2.52	0.0589
Month 10	Thursday, April 05, 2018	1:19 PM	280.9	2871	0.0447	2789.58	663.89	2081.25	0.72	2.52	0.0587
Month 11	Thursday, May 17, 2018	9:20 AM	322.7	2844	0.0450	2823.61	682.64	2115.28	0.74	2.52	0.0590
Month 13	Tuesday, July 03, 2018	10:11 AM	369.8	2835	0.0451	2847.22	682.64	2125.00	0.75	2.52	0.0591

Note: Strain readings are all in microstrain