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Structural Study
at
Schofield Barracks
Whole Barrack Renewal PH2C2
of
Shrinkage Cracking

August 29, 2006

A. Background

The completed construction for this project is exhibiting significant cracking of the cast-in-place concrete. The study examines the implications of shrinkage across the length of a five-story cast in place concrete building. These barracks buildings consist of two wings of barracks rooms extending from a central elevator lobby area. The building is about 290 feet long, about 55 feet wide with 12 foot floor heights. The building is constructed of cast in place concrete with masonry infill walls. Concrete is 4,000 psi with 60,000 psi reinforcing. The building was constructed one floor at time with an approximate six week lag between floor pours.

B. Modeling

For this analysis, a two-dimensional finite element model was created within the structural program Risa 3-D. Each plate element was a 12" x 12" square and 8 inches thick and had a dead load of 100 #/SF applied. The barracks room doors were removed from each shear wall. The building was assumed symmetrical about the central corridor lobby and only half the building was modeled. The lower right plate corner was fixed with the remaining bottom plates and side wall plates modeled as roller reactions

For normal weight concrete, the total shrinkage strain after several years is estimated at:

$$\in = 600 \text{ X } 10^{-6} \text{ in/in}$$

For these 290 foot long buildings, expected shrinkage contraction would be estimated at a little over 2 inches. Shrinkage varies over time based on following equation:

$$\in_t = \in_{total} * t/(t+35) \qquad \text{where t is measured in days}$$

This relationship is diagramed in the attached spreadsheet chart. At 6 weeks, 56% of the strain is anticipated, and across a 145 foot shear wall, the contraction is estimated at 0.59". In the table, the expected contractions are listed for the six week intervals followed for the construction of the barracks.

Risa allowed the shrinkage to be simulated as a temperature contraction. Six weeks after pouring the foundation, it contracted 0.59" (See Figure 1c). To simulate this shrinkage contraction, a temperature of -56.3ºF was applied to the FEM plates, contracting the foundation 0.59". Then the first floor shear wall was poured at this contracted point. This 0.59" was labeled the initial deflection of the first floor.

At 12 weeks, the foundation had contracted a total of 0.75" (or 0.16" more) and the first floor had experienced a 0.59" contraction (see Figure 2C). As shown on the second section in the table, the initial delta and the expected shrinkage at that level were combined, and a net temperature for that level calculated. These temperatures were inserted into Risa, and the net position of the structure evaluated. At the beginning of the pouring of the 2nd floor shear wall, the top end of level one was 0.97" from the initial alignment of the foundation pour. This 0.97" become the "initial delta" for the 2nd floor. This pattern was repeated for each floor, eventually evaluating the structure 2 years after the work started.

C. Results

The results are shown color coded for each of the construction phases. Plate loads are shown in the horizontal and vertical directions in kips/lineal foot. In Model # 2 (Figures 2A, 2B and 2C) stresses are building up around the door openings as the first floor concrete contracts, compressing the foundation and putting itself in tension. Peak forces above the doors are calculated at 110,000 #/foot (Figure 2A). Although the model has applied a dead load to the shear wall, uplift forces of 76 Kips/ft are observed at the lower left foundation.

By the time the fifth floor has cured for a year and a half, horizontal forces are over 250 Kips/ft. High tensile forces occur at the door re-entrant points, and the lower left part of the foundation is still in uplift. The building has contracted an average of 2", with the top floor slanted inward over ¾" from the effects of the shrinkage post-tensioning the buildings upper floors.

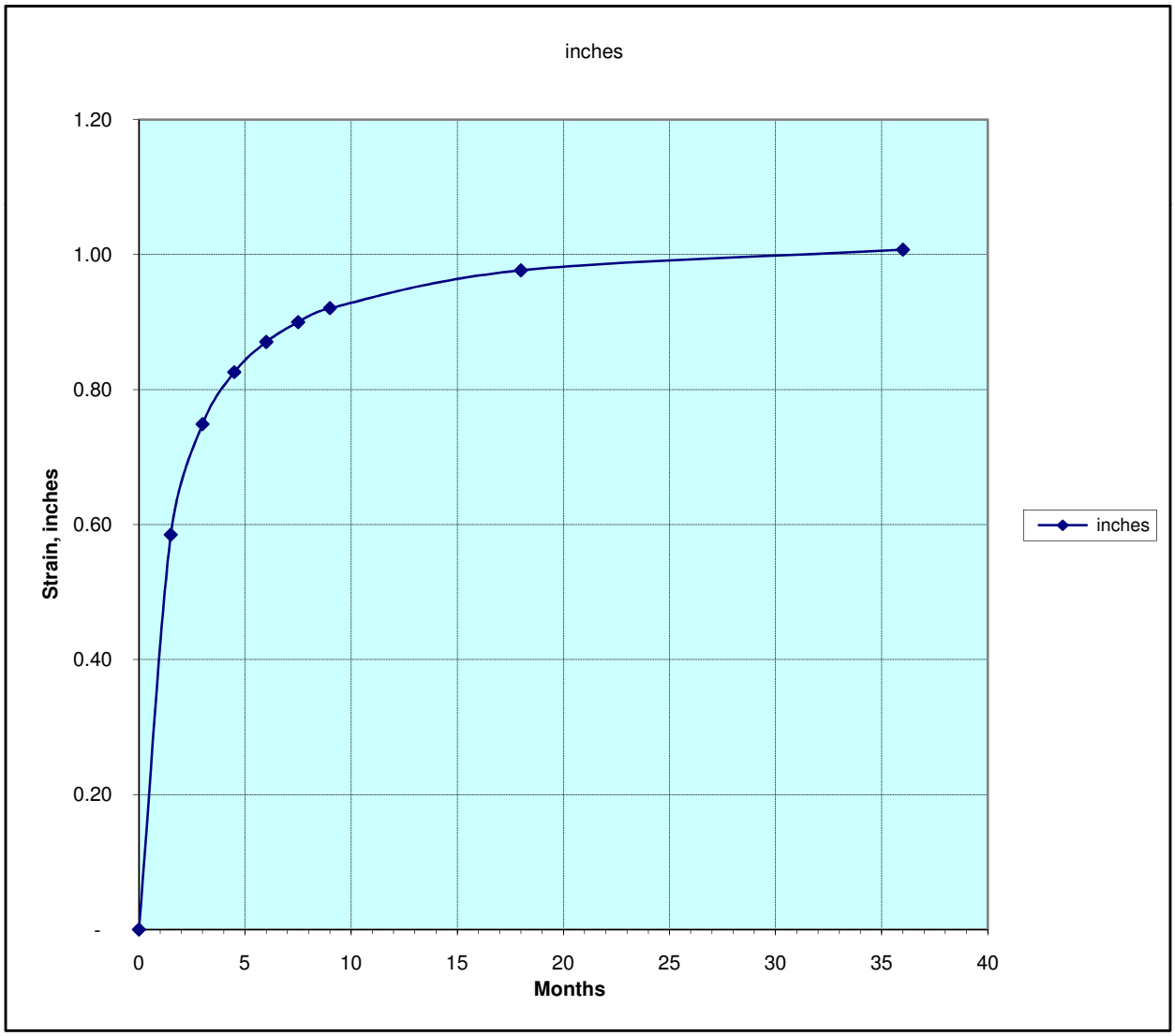
D. Conclusions

The compressive forces observed in the model are not of concern . An 8" x 12" section of reinforced concrete can support over 200 Kips/ft. But the shear wall cannot resist the high tensile forces, calculated at over 250 k/ft. The tensile strength of the concrete in an 8" x 12" plate element is less that 25 kips. Yield strength of two # 4's is also less than 25 kips. All tensile forces above 50 kips will open a crack and yield the embedded rebar. This will redistribute the forces into adjacent plate elements, but the crack will remain open (as observed). It might be prudent to evaluate the effect of these residual shrinkage stresses combined with the expected live, wind, and seismic loads.

Based on this study, the shrinkage cracks will get larger with time. Significant cracks will also grow larger due to debris formation within the crack. For the cracks observed so far, (larger than .02"), I recommend the contractor encapsulate the surface and pressure inject epoxy grout to fully seal the fissure.

Schofield Barracks **total strain =1.04" across 145 feet of shear wall.**
Shrinkage analysis

Pouring	t - months	t weeks	t - days	shrinkage strain %	est strain inches	delta strain, ln
fdn	0	0	0	0%	-	
1	1.5	6	45	56%	0.59	0.59
2	3	12	90	72%	0.75	0.16
3	4.5	18	135	79%	0.83	0.08
4	6	24	180	84%	0.87	0.04
5	7.5	30	225	87%	0.90	0.03
	9	36	270	89%	0.92	0.02
	18	72	540	94%	0.98	0.06
	36	104	1080	97%	1.01	0.09



Time	Task	Level	conc age	From Risa init delta	plus shrinkage	total delta	delta temp	Model No
Week 0	Pour Fdn	Fdn	0	-	-	-	-	
Week 6		Fdn	6	-	0.59	0.59	(56.30)	1
	pour	1st flr	0	**0.59**		0.59		
Week 12		Fdn	12	-	0.75	0.75	(71.56)	2
		1st flr	6	0.59	0.59	1.18	(112.60)	
	pour	2nd flr	0	**0.97**		0.97		
Week 18		Fdn	18	-	0.83	0.83	(79.20)	3
		1st flr	12	0.59	0.75	1.34	(127.86)	
		2nd flr	6	0.97	0.59	1.56	(148.57)	
	pour	3rd flr	0	**1.28**		1.28		
Week 24		Fdn	24	-	0.87	0.87	(83.02)	4
		1st flr	18	0.59	0.83	1.42	(135.50)	
		2nd flr	12	0.97	0.75	1.72	(163.84)	
		3rd flr	6	1.28	0.59	1.87	(178.53)	
	pour	4th flr	0	**1.54**				
Week 30		Fdn	30	-	0.90	0.90	(85.97)	5
		1st flr	24	0.59	0.87	1.46	(139.31)	
		2nd flr	18	0.97	0.83	1.80	(171.47)	
		3rd flr	12	1.28	0.75	2.03	(193.80)	
		4th flr	6	1.54	0.59	2.13	(203.15)	
	pour	5th flr	0	**1.81**	-	1.81	(172.61)	
Week 36		Fdn	36	-	0.92	0.92	(87.79)	6
		1st flr	30	0.59	0.90	1.49	(142.27)	
		2nd flr	24	0.97	0.87	1.84	(175.29)	
		3rd flr	18	1.28	0.83	2.11	(201.43)	
		4th flr	12	1.54	0.75	2.29	(218.42)	
		5th flr	6	1.81	0.59	2.40	(228.91)	
Week 104		Fdn	104	-	1.00	1.00	(95.42)	7
		1st flr	98	0.59	1.00	1.59	(151.72)	
		2nd flr	92	0.97	1.00	1.97	(187.69)	
		3rd flr	86	1.28	1.00	2.28	(217.65)	
		4th flr	80	1.54	1.00	2.54	(242.27)	
		5th flr	74	1.81	1.00	2.81	(268.03)	