Stress Control Design to Prevent Cracking in Post-Tensioned Floor

One of the advantages of the post-tensioned floor is the control over surface cracks due to bending stresses that occur to the slabs. EIT 1009-34 standards in consistent with ACI318 (American Concrete Institute) specify the following surface tensile stress and compressive stress:

EIT 1009, Section 3.2.1 (ACI 18.4.1) on surface stress of concrete after immediate load transfer.

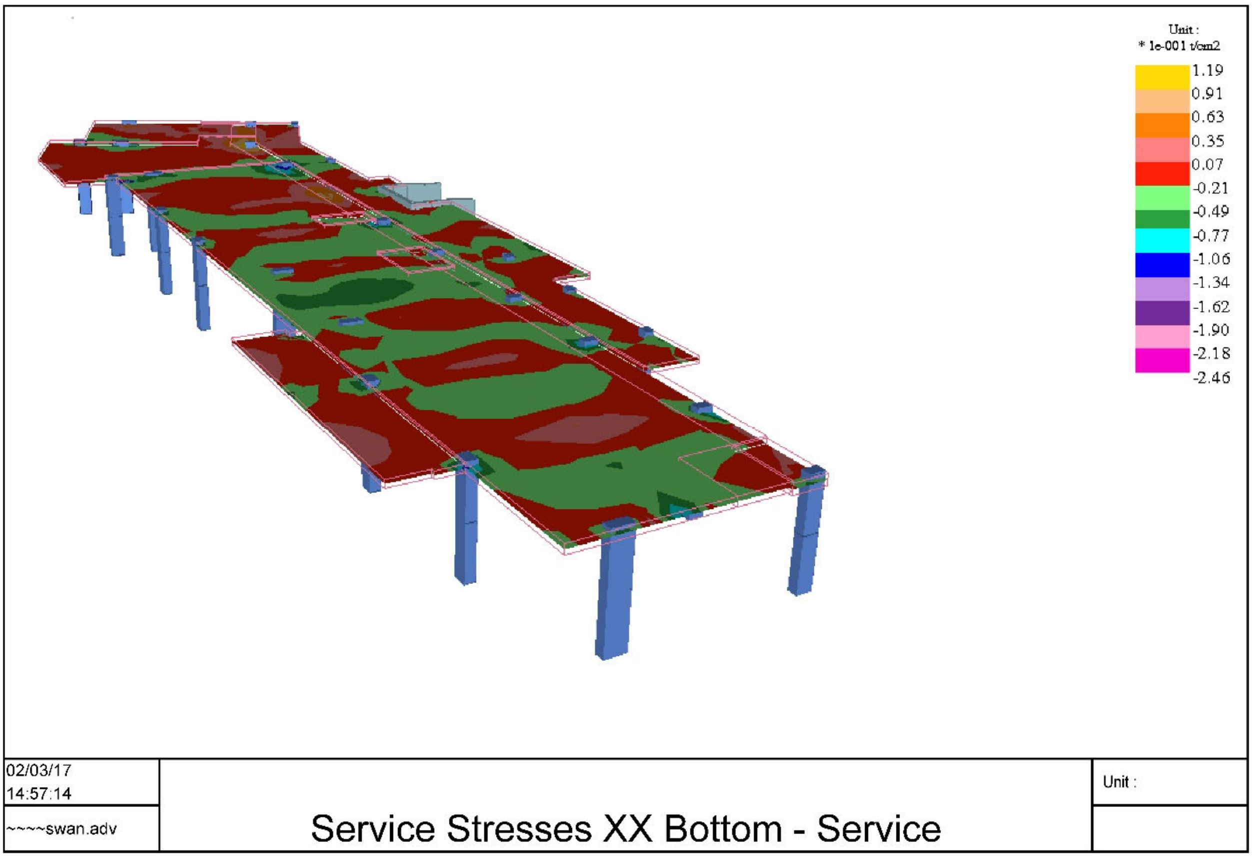
- Surface with compressive stress shall not exceed 0.60 fc'i ksc
- Surface with tensile stress shall not exceed 0.795 √fc'i ksc

fc'i is the compressive strength of concrete at the time of compression.

EIT 1009, Section 3.2.2 (ACI 18.4.2) on surface stress of concrete at surface at live load.

- Surface with compressive stress shall not exceed 0.45 fc' ksc
- Surface with tensile stress shall not exceed 1.59 √fc'i ksc

fc' is the compressive strength of concrete at live load.



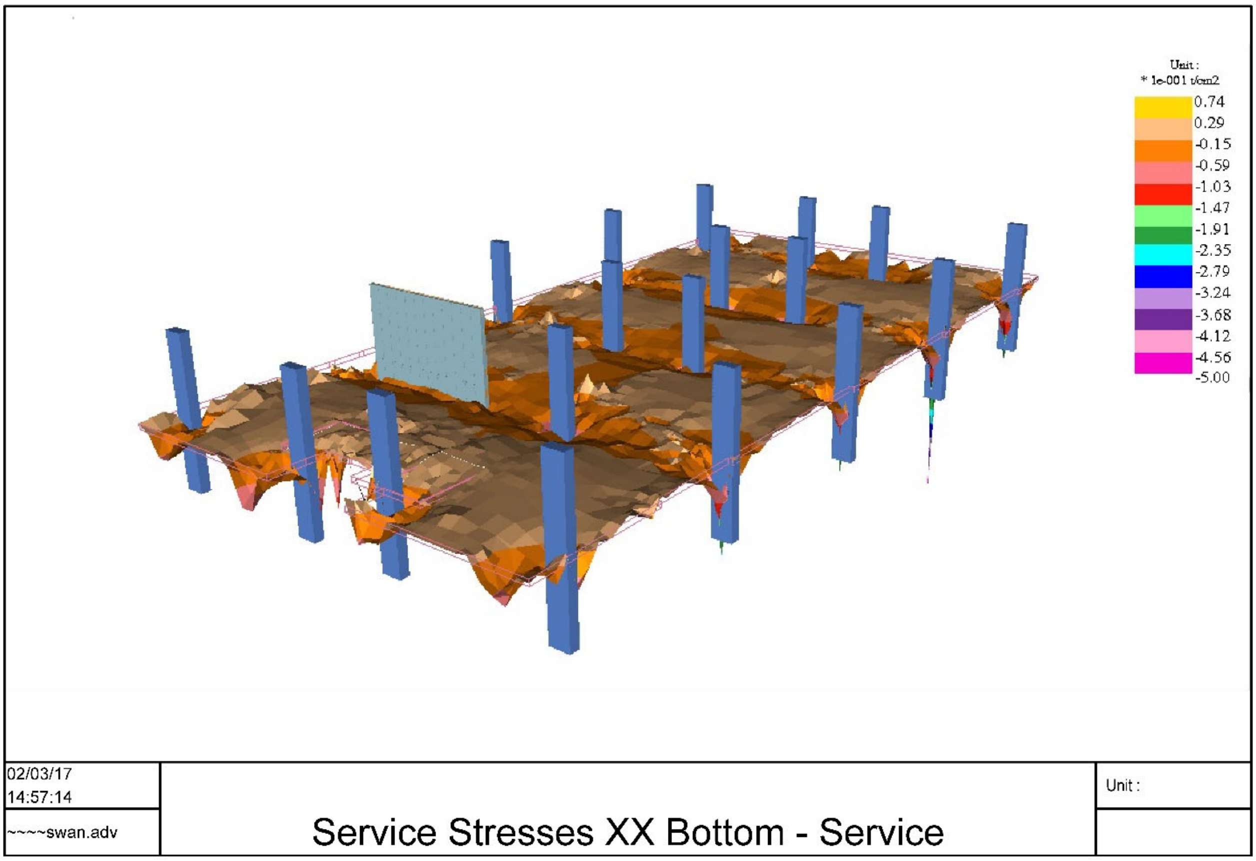
This requirement was revised into ACI318 in 2002 by controlling the tensile stress of working concrete surface. The changes are as follows:

Prestressed concrete parts that accommodate bending stress are divided into 3 classes.

1. Class U (Uncracked) is a part with non-cracked surface. Tensile stress does not exceed $1.99 \sqrt{fc'}$

2. Class T (Transition) is a transition from cracking to non-cracking. Tensile stress is over $1.99 \sqrt{fc'}$ but not exceeding $3.18 \sqrt{fc'}$

3. Class C (Cracked) is a part with cracked surface. Tensile stress is beyond $3.18 \sqrt{fc'}$



Controlling tensile stress and compressive stress on concrete surface after immediate load transfer remains in accordance with section 18.4.1 in the preceding ACI and controlling compressive stress on concrete surface on live load still remains in accordance with section 8.4.2 in the preceding ACI.

The difference in inspecting working state of each class:

- In stress calculation of Class U and Class T, uncracked cross section can be used to calculate for the stress values. In terms of Class C, stress value from cracked cross section must be used for the calculation.

- Calculation of long term deflection range on Class U can use I, gross whereas I, effective is used for Class T and Class U.

- In terms of Class C, it is important to control the spacing of strands and reinforcing steel bars to control the occurred cracks as specified in ACI 18.4.4.1.

- In Class C, the value of Δfps must be calculated, where Δfps is the difference between stress value of strands by calculating from the cracked cross section and tensile efficiency, fse. The Δfps value must not exceed 2500ksc. If Δfps is not greater than 1400 ksc, it will not be necessary to control the distance of strands and reinforcing steel bars in Class C as specified in ACI 18.4.4.1.

ACI standards can be summarized in the following table:

	Prestressed			Nonprestressed
	Class U	Class T	Class C	
Assumed behavior	Uncracked	Transition between uncracked and cracked	Cracked	Cracked
Section properties for stress calculation at service loads	Gross section 18.3.4	Gross section 18.3.4	Cracked section 18.3.4	No requirement
Allowable stress at transfer	18.4.1	18.4.1	18.4.1	No requirement
Allowable compressive stress based on uncracked section properties	18.4.2	18.4.2	No requirement	No requirement
Tensile stress at service loads 18.3.3	$\leq 7.5\sqrt{f'_c}$	$7.5\sqrt{f'_c} < f_t \leq 12\sqrt{f'_c}$	No requirement	No requirement
Deflection calculation basis	9.5.4.1 Gross section	9.5.4.2 Cracked section, bilinear	9.5.4.2 Cracked section, bilinear	9.5.2, 9.5.3 Effective moment of inertia
Crack control	No requirement	No requirement	10.6.4 Modified by 18.4.4.1	10.6.4
Computation of Δf_{ps} or f_s for crack control	—	—	Cracked section analysis	$M/(A_s$ x lever arm), or $0.6f_y$
Side skin reinforcement	No requirement	No requirement	10.6.7	10.6.7

Nonetheless, in ACI318-2002 and standards of subsequent years, it has been specified that two-way prestressed concrete floor system must be designed as Class U.

In terms of ACI318-2014, there is a new chapter organization. The designs of the building is categorized into chapters to assemble the design and detail of each building type into the same chapter. It may be unfamiliar to those who are more familiar with ACI318 in 2011 nevertheless, it is worth getting familiarized for the sake of development tracking in regards with ACI318 standards in the future. Permitted stress in of prestressed concrete slabs is discussed in Section 24.5. The content has not been changed from ACI318-2011, but is has been summarized as a table for easier read.

Try to study and see how foreign standards or documentations on post-tensioned floor design are different in terms of stress control to prevent cracking.

Technical Report No.43 Post-Tensioned concrete floors design handbook

It is a handbook created by a team individuals who work in structural design companies in foreign countries.

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Stress control in concrete is done to prevent cracking as discussed in section 5.8.1. Serviceability Limit states: stresses after all losses and 5.8.2 Serviceability Limit states: stresses at transfer detailed as

follows:

For the period of use

Table 4: Allowable average stresses in flat slabs for full panel width.

Location	In Compression	In Tension	
		With bonded reinforcement[2]	Without bonded reinforcement
Support	$0.3f_{ck}$[1]	$0.9f_{ctm}$	$0.3f_{ctm}$
Span	$0.4f_{ck}$[1]		

Note: Bonded reinforcement may be either bonded tendons or un-tensioned reinforcement.
[1] If ductility check is carried out this limit may be exceeded
[2] The spacing of bars or tendons should be ≤ 500mm, otherwise the stress for 'without bonded reinforcement' should be used.

If equivalent frame method is used in the analysis.

Table 5: Allowable stresses in flat slabs using 'design strip' approach.

Location	In Compression	In Tension	
		With bonded reinforcement[2]	Without bonded reinforcement
Support Span	$0.4f_{ck}$[1]	$1.2f_{ctm}$	$0.4f_{ctm}$

[1] If ductility check is carried out this limit may be exceeded
[2] The spacing of bars or tendons should be ≤ 500mm, otherwise the stress for 'without bonded reinforcement' should be used.

Where fck is the characteristic compressive strength of concrete at 28 days

fctm is the mean value of axial tensile strength of concrete.

Strength classes for concrete															Analytical relation / Explanation
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90	
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105	2.8
f_{cm} (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98	$f_{cm} = f_{ck}+8$(MPa)
f_{ctm} (MPa)	1,6	1,9	2,2	2,6	2,9	3,2	3,5	3,8	4,1	4,2	4,4	4,6	4,8	5,0	$f_{ctm}=0,30\times f_{ck}^{(2/3)}$ ≤C50/60 $f_{ctm}=2,12\cdot\ln(1+(f_{cm}/10))$ > C50/60
$f_{ctk,0,05}$ (MPa)	1,1	1,3	1,5	1,8	2,0	2,2	2,5	2,7	2,9	3,0	3,1	3,2	3,4	3,5	$f_{ctk;0,05} = 0,7\times f_{ctm}$ 5% fractile
$f_{ctk,0,95}$ (MPa)	2,0	2,5	2,9	3,3	3,8	4,2	4,6	4,9	5,3	5,5	5,7	6,0	6,3	6,6	$f_{ctk;0,95} = 1,3\times f_{ctm}$ 95% fractile

For the period of load transfer

Stress control in concrete to prevent cracking employs something similarly to the table analyzed using finite element method where fck value is changed to fci where fci is Concrete strength at transfer

British Standard BS8110

BS8110 Design Standards contains stress control in concrete to prevent cracking which can be seen in section 4.4 for floors unintended to be used as beam, which is discussed in section 4.3.5 Serviceability limit state for beam and section 4.3.5 Stress limitation at transfer for beams detailed as follows:

For the period of use

Surface compressive stress must not exceed 0.33fcu at mid-span and 0.40 fcu at supporting area.

For the period of use

Class 1 Zero surface tensile stress

Class 2 Surface tensile stress occurs but not to exceed 0.36 √fcu" and the occurred crack is not visible to the naked eye.

Table 4.1 Design flexural tensile stresses for class 2 members: serviceability limit state: cracking

Type of prestressed member	Design stress for concrete grade			
	30 N/mm^2	40 N/mm^2	50 N/mm^2	60 N/mm^2
Pre-tensioned	—	2.9	3.2	3.5
Post-tensioned	2.1	2.3	2.6	2.8

Class 3 Surface tensile stress occurs which causes crack marks of no more than 0.10 mm in width in area of severe environment and no more than 0.20 mm in every other building. Tensile stress values are in accordance with table 4.2 and adjusted by the multipliers in table 4.3, where fcu is the characteristic compressive cube strength of concrete.

Table 4.2 Design hypothetical flexural tensile stresses for class 3 members

Group	Limiting Crack width mm	Design stress for concrete grade 30 N/mm^2	40 N/mm^2	50 and over N/mm^2
a) Pre-tensioned tendons	0.1	-	4.1	4.8
	0.2	-	5.0	5.8
b) Grouted post-tensioned tendons	0.1	3.2	4.1	4.8
	0.2	3.8	5.0	5.8
c) Pre-tensioned tendons distributed in the tenzile zone and positioned close to the tension faces of the concrete	0.1	-	5.3	6.3
	0.2	-	6.3	7.3

Table 4.3 Depth factors for design tensile stresses for class 3 members

Depth of member mm	Factor
200 and under	1.1
400	1.0
600	0.9
800	0.8
1000 and over	0.7
NOTE: Intermediate values are found by interpolation.	

fcu Characteristic compressive cube strength of concrete

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-Surface compressive stress must not exceed 0.50fci

-Surface tensile stress can be categorized into following classes:

Class 1: Surface tensile stress occurs at not exceeding 1.0 N/mm2

Class 2 : Surface tensile stress occurs at not exceeding 0.36 √fci Additional reinforcing steel bars are required for surfaces with such tensile stress, N/mm2

Class 3 : Surface tensile stress occurs exceeding.36 0.36 √fci Design must be calculated as cracked cross section, N/mm2

It can be seen that each of the example standards has different method of stress control where the compressive stress control being an equation that varies with fc', which is slightly different from the ACI standard. This may be due to the fact that they base their standards on different design principles and research findings.

In case of Post-Tensioning Manual, which is produced by Post-Tensioning Institute or PTI, it also contains standardized design content. Most standard designs are based on ACI318-2002 in setting stress for crack control which is quite similar to the one previously discussed at the beginning of the article. In addition, post-tension flooring sequence takes a vital role in controlling the quality of post-tension floor job. This manual offers recommendations on work sequence as well as operational standard inspections. In addition, PTI has also been offering knowledge in prestressed concrete in forms of newsletter, training, and dissemination of knowledge for 40 years. For more information, please look up http://www.post-tensioning.org In addition, to enhance the knowledge on post-tension job, SNP Post Tension Co., Ltd. has also been a member of PTI Institute and make use of the provided knowledge in corporate as well as technological development to further improve post-tensioning construction technology.

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