

Tahoe Parking Cracked Beams Slab Strengthening Utilizing the LOCTITE Tyfo FRP Systems

Structural Engineer of Record:

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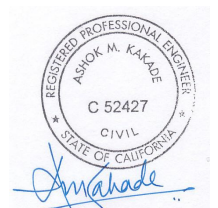
Calculations:

1. Slab Flexural Strengthening Calculations

Disclaimer: Fyfe did not analyze the capacity of the existing structural members or its condition, nor did Fyfe provide the loading demand values used for the FRP design. The composite system was designed only to provide the additional capacity as noted in the calculations. Additionally, thermal gradation effects were not considered in the FRP design.

REFERENCES

1. ACI PRC-440.2-23, Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures.
2. ACI 318-19, Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary
3. Fyfe Design Manual for the Tyfo System. Version 13. December 2024.



Tahoe Data Center

Slab Flexural Strengthening Calculations

1.0 DESIGN GOAL

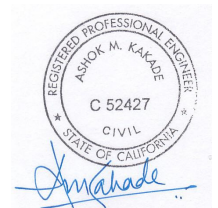
Design the LOCTITE Tyfo FRP systems to provide 275 kip-ft. of additional positive moment capacity and 334 kip-ft. of additional negative moment capacity of an existing reinforced concrete slab, as specified by Concrete Science, Inc.

2.0 GENERAL NOTES AND ASSUMPTIONS

1. Assumed existing concrete compressive strength of 3000 psi for all slabs to be strengthened.
2. Assumed effective depth (moment arm) of FRP to be 90% of the total slab depth.
3. Assume exterior environment for roof application.
4. Assumed maximum effective strain in FRP reinforcement to be the minimum of 0.004 in/in or the intermediate crack-induced de-bonding strain per ACI PRC-440.2-23 section 10.1.1.
5. Moment due to existing loading conditions on the structural member at the time of FRP installation has not been provided to Fyfe. Therefore, the initial strain in the substrate at the time of FRP installation is assumed to be negligible. Further, the moments due to service loads have not been provided to Fyfe. Therefore, Fyfe has not completed any calculations to determine the service stresses in the existing steel or concrete to check compliance with the service stress limitations of ACI 440.

3.0 PROPERTIES OF THE LOCTITE TYFO SCH-41-2X CARBON COMPOSITE SYSTEM

$C_E := 0.85$	environmental reduction factor for exterior environment (ACI PRC-440.2-23 Table 9.4)
$f_{fu} := 131 \cdot \text{ksi}$	ultimate tensile stress
$f_f := C_E \cdot f_{fu} = 111.4 \text{ ksi}$	design ultimate tensile stress (eq. 9.4a)
$\varepsilon_{fu} := 0.009 \frac{\text{in}}{\text{in}}$	ultimate tensile strain
$\varepsilon_f := C_E \cdot \varepsilon_{fu} = 0.0077 \frac{\text{in}}{\text{in}}$	design ultimate tensile strain (eq. 9.4b)
$E_f := \frac{f_f}{\varepsilon_f} = 14556 \text{ ksi}$	ultimate modulus of elasticity
$E_f := 12660 \text{ ksi}$	design modulus of elasticity
$t_f := 0.08 \cdot \text{in}$	thickness per layer



4.0 MOMENT STRENGTHENING CALCULATIONS - Positive Moment for Slab at Grid C2 / 16-17

$f'_c := 3000 \text{ psi}$ assumed concrete compressive strength

$B_s := 29.55 \text{ ft}$ total slab width

$M_{req.total} := 275 \text{ kip} \cdot \text{ft}$ total additional moment capacity

$M_{req} := \frac{M_{req.total}}{B_s} \cdot \text{ft} = 9.3 \text{ kip} \cdot \text{ft}$ required additional moment capacity (per ft.)

$h := 8 \cdot \text{in}$ total slab thickness

$w_f := 24 \cdot \text{in}$ width of FRP

$s_f := 36 \cdot \text{in}$ spacing of FRP

$s_{max} := w_f + \min(3 \cdot h, 18 \text{ in}) = 42 \text{ in}$ max. spacing of FRP

$n := 1$ number of layers of FRP

$A_f := n \cdot t_f \cdot w_f \cdot \frac{12 \text{ in}}{s_f} = 0.64 \text{ in}^2$ effective composite area

$\epsilon_{fd} := 0.083 \cdot \sqrt{\frac{f'_c}{n \cdot t_f \cdot \frac{1}{\text{in}} \cdot E_f}} = 0.0045$ de-bonding FRP strain

$\epsilon_{fe} := \min(\epsilon_{fd}, 0.9 \cdot C_E \cdot \epsilon_{fu}, 0.004) = 0.004$ effective FRP strain

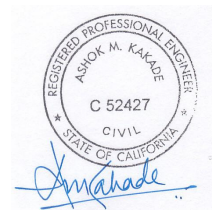
$f_{fe} := E_f \cdot \epsilon_{fe} = 50.6 \text{ ksi}$ effective FRP stress

$\phi := \begin{cases} \text{if } \epsilon_{fd} \geq 0.005 \\ \quad \quad \quad 0.90 \\ \text{also if } 0.002 \leq \epsilon_{fd} < 0.005 \\ \quad \quad \quad 0.65 + \frac{0.25 \cdot (\epsilon_{fd} - 0.002)}{0.005 - 0.002} \\ \text{else} \\ \quad \quad \quad 0.65 \end{cases} = 0.9$ strength reduction factor

$\psi_f := 0.85$ FRP reduction factor

$\phi M_f := \phi \cdot \psi_f \cdot A_f \cdot f_{fe} \cdot (0.9 \cdot h) = 14.2 \text{ kip} \cdot \text{ft}$ factored moment capacity provided by FRP (per ft.)

$DCR := \frac{M_{req}}{\phi M_f} = 0.65$



4.1 MOMENT STRENGTHENING CALCULATIONS - Negative Moment for Slab at Grid C2 / 16-17

$f'_c := 3000 \text{ psi}$ assumed concrete compressive strength

$B_s := 18.25 \text{ ft}$ total slab width

$M_{req, total} := 334 \text{ kip} \cdot \text{ft}$ total additional moment capacity

$M_{req} := \frac{M_{req, total}}{B_s} \cdot \text{ft} = 18.3 \text{ kip} \cdot \text{ft}$ required additional moment capacity (per ft.)

$h := 8 \cdot \text{in}$ total slab thickness

$w_f := 24 \cdot \text{in}$ width of FRP

$s_f := 36 \cdot \text{in}$ spacing of FRP

$s_{max} := w_f + \min(3 \cdot h, 18 \text{ in}) = 42 \text{ in}$ max. spacing of FRP

$n := 2$ number of layers of FRP

$A_f := n \cdot t_f \cdot w_f \cdot \frac{12 \text{ in}}{s_f} = 1.28 \text{ in}^2$ effective composite area

$\varepsilon_{fd} := 0.083 \cdot \sqrt{\frac{f'_c}{n \cdot t_f \cdot \frac{1}{\text{in}} \cdot E_f}} = 0.0032$ de-bonding FRP strain

$\varepsilon_{fe} := \min(\varepsilon_{fd}, 0.9 \cdot C_E \cdot \varepsilon_{fu}, 0.004) = 0.0032$ effective FRP strain

$f_{fe} := E_f \cdot \varepsilon_{fe} = 40.4 \text{ ksi}$ effective FRP stress

$\phi := \begin{cases} \text{if } \varepsilon_{fd} \geq 0.005 & 0.7 \\ \text{also if } 0.002 \leq \varepsilon_{fd} < 0.005 & 0.90 \\ 0.65 + \frac{0.25 \cdot (\varepsilon_{fd} - 0.002)}{0.005 - 0.002} & \\ \text{else} & \\ 0.65 & \end{cases} = 0.7$

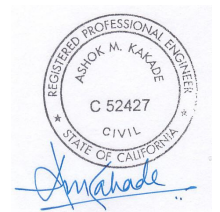
strength reduction factor

$\psi_f := 0.85$

FRP reduction factor

$\phi M_f := \phi \cdot \psi_f \cdot A_f \cdot f_{fe} \cdot (0.9 \cdot h) = 19.8 \text{ kip} \cdot \text{ft}$ factored moment capacity provided by FRP (per ft.)

$DCR := \frac{M_{req}}{\phi M_f} = 0.92$



Tyfo SCH Composite Anchor Capacity Calculation

$$f_{fa} := 110 \cdot \text{ksi}$$

design ultimate tensile stress for anchors up to 7/8" diameter

$$w_f := 6 \cdot \text{in}$$

tributary width of fiber for one anchor (6" O.C. anchor spacing)

$$\alpha := 1.5$$

tension amplification factor

$$T_{req} := \alpha \cdot \psi_f \cdot n \cdot w_f \cdot t_f \cdot f_{fe} = 49.5 \text{ kip}$$

required tension force for 6" FRP width

$$d := \frac{7}{8} \cdot \text{in}$$

diameter of composite anchor

$$A_{fa} := \frac{\pi \cdot d^2}{4} = 0.60 \text{ in}^2$$

area of composite anchor

$$T_{fa} := A_{fa} \cdot f_{fa} = 66.1 \text{ kip}$$

governing anchor capacity

$$n_{fa} := \frac{T_{req}}{T_{fa}} = 0.7$$

req. number of anchors per 6 in. fiber width

$$n_{fa} := 1$$

number of anchors to be used per 6 in. fiber width

Anchor Development Calculation - Bonding to Fiber

$$T_{reqa} := \frac{T_{req}}{n_{fa}} = 49.5 \text{ kip}$$

tension to be developed between anchors and FRP for (1) anchor

$$\sigma := 500 \cdot \text{psi}$$

minimum bond strength of FRP to composite anchor

$$l_{sw} := 6 \cdot \text{in}$$

anchor splay width

$$l_s := 18 \cdot \text{in}$$

minimum anchor splay length

$$n := 2$$

number of layers

$$T_b := \left\| \begin{array}{l} \text{if } n = 1 \\ \left\| \frac{1}{2} \cdot l_{sw} \cdot l_s \cdot \sigma \right\| \\ \text{if } n > 1 \\ \left\| l_{sw} \cdot l_s \cdot \sigma \right\| \end{array} \right\| = 54 \text{ kip}$$

tension to be developed through bond for one layer of FRP (bonded on one face)

tension to be developed through bond for two or more layers of FRP (bonded on both faces)

$$T_b = 54 \text{ kip}$$

tension to be developed through bond

$$DCR_A := \frac{T_{reqa}}{T_b} = 0.92$$



5.0 CONCLUSION

Positive Moment for Slab at Grid C2 / 16-17:

Install one (1) layer of the LOCTITE Tyfo SCH-41-2X system, 24" wide strip spaced at 36" O.C. (12" clear between strip), applied on the underside of the reinforced concrete slab, to provide an additional moment capacity of 9.3 kip-ft./ft.

Negative Moment for Slab at Grid C2 / 16-17:

Install two (2) layers of the LOCTITE Tyfo SCH-41-2X system, 24" wide strip spaced at 36" O.C. (12" clear between strip), applied on the topside of the reinforced concrete slab, to provide an additional moment capacity of 18.3 kip-ft./ft.

Install 7/8" diameter LOCTITE Tyfo SCH composite anchors spaced maximum 6" on center to fully develop the laminate in tension. Use a minimum 6" anchor splay width and minimum 18" anchor splay length.

* All FRP moment strengthening calculations are summarized in the table below. All calculations shown in the table below conform the calculation procedure set forth in sections 4.0 to 4.1.

Summary Table - Slab Strengthening - LOCTITE Tyfo SCH 41-2X System

ID#	Slab #	Moment type	Direction	B _s	M _{req, total}	M _{req}	# Layers	w _f	s _f	A _{fr}	e _{fr}	f _{fr}	φM _f	DCR
1*	C2 / 16-17	Positive	Horizontal	29.55 ft	275.0 kip-ft	9.3 kip-ft/ft	1	24 in	36 in	0.64 in ² /ft	0.004	51 ksi	14.2 kip-ft/ft	0.655
2			Transverse	18.25 ft	275.0 kip-ft	15.1 kip-ft/ft	2	24 in	36 in	1.28 in ² /ft	0.003	40 ksi	19.8 kip-ft/ft	0.762
3		Negative	Horizontal	29.55 ft	334.0 kip-ft	11.3 kip-ft/ft	1	24 in	36 in	0.64 in ² /ft	0.004	51 ksi	14.2 kip-ft/ft	0.795
4*			Transverse	18.25 ft	334.0 kip-ft	18.3 kip-ft/ft	2	24 in	36 in	1.28 in ² /ft	0.003	40 ksi	19.8 kip-ft/ft	0.925
5	C2 / 17-18	Positive	Horizontal	18.95 ft	275.0 kip-ft	14.5 kip-ft/ft	2	24 in	36 in	1.28 in ² /ft	0.003	40 ksi	17.3 kip-ft/ft	0.838
6			Transverse	12.54 ft	275.0 kip-ft	21.9 kip-ft/ft	2	24 in	24 in	1.92 in ² /ft	0.003	40 ksi	26.0 kip-ft/ft	0.844
7		Negative	Horizontal	18.95 ft	334.0 kip-ft	17.6 kip-ft/ft	2	24 in	30 in	1.54 in ² /ft	0.003	40 ksi	20.8 kip-ft/ft	0.848
8			Transverse	12.54 ft	334.0 kip-ft	26.6 kip-ft/ft	2	24 in	24 in	1.92 in ² /ft	0.003	40 ksi	26.0 kip-ft/ft	1.026
9	C2 / 19-20	Positive	Horizontal	17.65 ft	275.0 kip-ft	15.6 kip-ft/ft	2	24 in	36 in	1.28 in ² /ft	0.003	40 ksi	17.3 kip-ft/ft	0.900
10			Transverse	12.75 ft	275.0 kip-ft	21.6 kip-ft/ft	2	24 in	24 in	1.92 in ² /ft	0.003	40 ksi	26.0 kip-ft/ft	0.831
11		Negative	Horizontal	17.65 ft	334.0 kip-ft	18.9 kip-ft/ft	2	24 in	30 in	1.54 in ² /ft	0.003	40 ksi	20.8 kip-ft/ft	0.911
12			Transverse	12.75 ft	334.0 kip-ft	26.2 kip-ft/ft	2	24 in	24 in	1.92 in ² /ft	0.003	40 ksi	26.0 kip-ft/ft	1.009

ID*: Sample Calculation

