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Lyles Residence
Carmel, CA

Prepared for
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A. INTRODUCTION

This report discusses the flexural and shear capacities of Aslan 100 reinforced retaining walls as related to the Valera Lyles Residence in Carmel, CA. Aslan 100 GFRP bars are corrosion resistant and therefore ideal for use in environments which are exposed to chlorides. The site plan is shown below in Figure 1 and the conceptual design is shown in Figure 2. Design was performed using “Guide for The Design and Construction of Structural Concrete Reinforced with FRP Bars” reported by ACI Committee 440 (ACI 440.1R-06), and published by the American Concrete Institute.

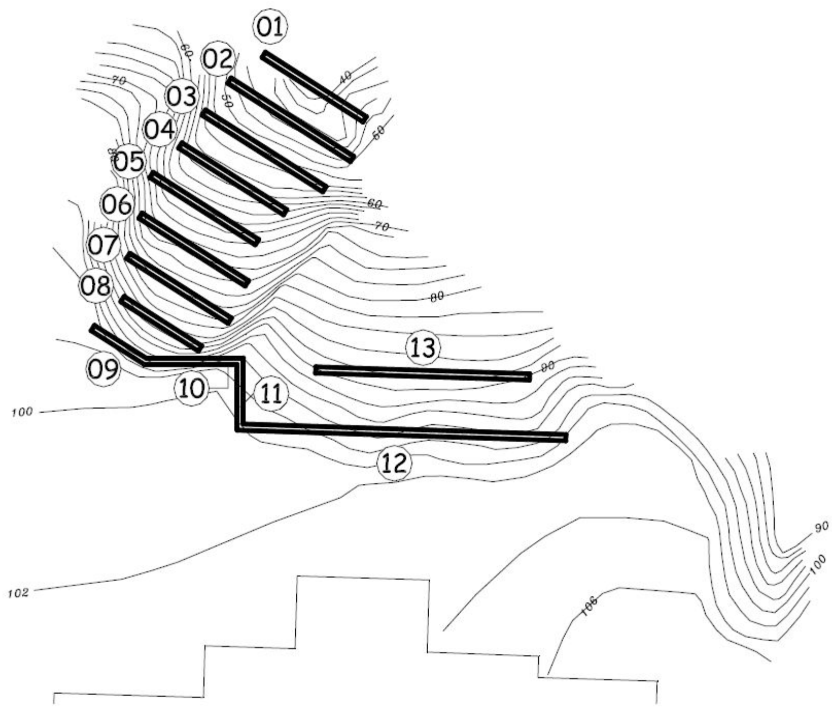

Figure 1 Site Plan

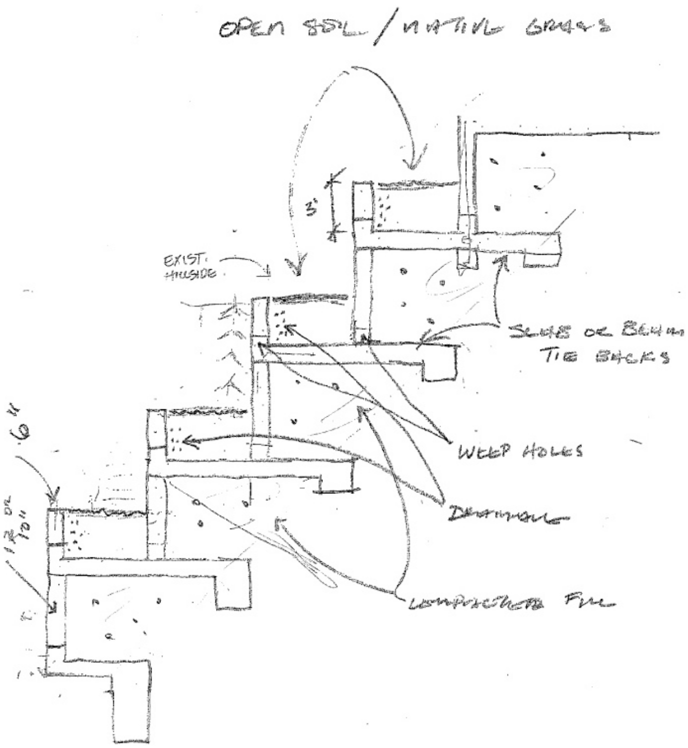

Figure 2 Conceptual Wall Design

B. STRUCTRUAL ANALYSIS

Hughes Brothers, Inc. did not perform any structural analysis and assumes no responsibility as such. The required shear and moment capacities were provided by M.J. Martin Engineering and are shown below in Table 1. The shear demand was given in pounds per square inch, so the required shear demand was calculated by multiplying the shear stress by the area of the wall and dividing by 1.5.

Table 1 Factored Moment and Shear Forces

	M_u (k-ft/ft)	V_u (k/ft)
4’ Cantilevered	.512	.333
6’ Cantilevered	1.73	.742
6’ Restrained	.665	.877
8’ Restrained	1.58	.993

C. GFRP RC DESIGN

C.1. Assumptions

- The concrete strength of the wall was assumed to have an ultimate strength, f_c’, of 2500psi.
- It was assumed that the moment and shears acting on the wall were sustained demands and therefore checked against creep rupture failure.
- A long term deflection of l/480 was considered acceptable.

C.2. Material Properties

Aslan 100 GFRP bars manufactured by Hughes Brothers are used as internal reinforcement. The guaranteed tensile properties are summarized in Table 2.

Table 2 Guaranteed Tensile Properties

Size	E_f *(psi)	f_{fu}* (psi)	ε_{fu}*
4	$5.9*10^6$	100,000	.01689
5	$5.9*10^6$	95,000	.01605
6	$5.9*10^6$	90,000	.01525

C.3. Design Tensile Properties

Per ACI 440 material properties of the FRP reinforcement reported by manufactures, such as the ultimate tensile strength, typically do not consider long-term exposure to environmental conditions, and should be considered as initial properties. FRP properties to be used in all design equations are given as follows (ACI 440.1R-06)

$$f_{fu} = C_E f_{fu}^* \quad (7\text{-}1)$$

$$\varepsilon_{fu} = C_E \varepsilon_{fu}^* \quad (7\text{-}2)$$

where f_{fu} and ε_{fu} are the FRP design tensile strength and ultimate strain considering the environmental reduction factor (C_E) as given in table 7.1 (ACI 440.1R-06), and f_{fu}* and ε_{fu}* represent the FR guaranteed tensile strength and ultimate strain as reported by Hughes Brothers, Inc. (see Table 1). The FRP design modulus of elasticity is the average value as reported by Hughes Brothers, Inc. The wall is exposed to both earth and air and so the environmental reduction factor, C_E, should be taken as .7.

C.4. Flexural Design

The flexural design of FRP reinforced concrete is similar to the design of steel reinforced concrete. The main difference is that both concrete crushing and FRP rupture are allowable failure mechanisms. FRP reinforced concrete members are generally less ductile than a corresponding steel reinforced concrete member, and therefore require a greater reserve strength. In order to achieve this ACI uses strength reduction factor (ϕ). Table 3 shows the flexural capacity, ϕM_n , of 6" and 8" thick walls reinforced with #6 Aslan 100 GFRP spaced at 8" o.c. and a concrete compressive strength of 2500psi and the required Ultimate Moment, M_u.

Table 3 Flexural Strength using Aslan 100 GFRP

	ϕM_n (k-ft/ft)	M_u (k-ft/ft)
4' Cantilevered	6.59	.512
6' Cantilevered	6.59	1.73
6' Restrained	6.59	.665
8' Restrained	6.59	1.58

C.5. Shear Design

The design of FRP shear reinforcement is based on the strength design method of ACI 318. The contribution of the steel reinforcement to the shear capacity is replaced by the FRP contribution, V_f, as stated in EQ (9-2) of ACI 440.1R-06. The concrete shear capacity, V_{cf}, is slightly different for FRP reinforced members to take into account the relatively low modulus of elasticity and dowel action, and for the lower tensile strength of the bent portion of an FRP bar compared to that of a straight portion. The contribution of the concrete is expressed in EQ (9-1) of ACI 440.1R-06. Table 4 reports the shear capacity of the wall reinforced with Aslan 100 GFRP longitudinal rebar. ACI requires shear reinforcing if the shear demand is greater than ½ V_c, all of the walls are above this limit.

$$V_c = 5\sqrt{f'_c}\,b_w c \qquad (9\text{-}1)$$

$$V_f = \frac{A_{fv} f_{fv} d}{s} \qquad (9\text{-}2)$$

Table 4 Shear Capacity using Aslan 100 GFRP

	ϕV_n (k/ft)	V_u (k/ft)
4' Cantilevered	2.12	.333
6' Cantilevered	2.12	.742
6' Restrained	2.12	.877
8' Restrained	2.12	1.024

C.6. Creep Rupture

Under sustained loads, a bar may suddenly fail after a time period called the endurance time. This phenomenon is known as creep rupture. In order to prevent this type of failure ACI 440.1R-06 limits the allowable sustained stress on the bar to 20% of its ultimate capacity (f_{fu}). Table 5 summarizes the results of this check. The sustained moment was assumed to be the ultimate moment divided by a load factor of 1.6. The sustained stress is slightly higher than the allowable but is with in an acceptable range.

Table 5 Sustained Stresses

	M_s (k-ft/ft)	$f_{f,s}$ (psi)	$f_{f,s\,(Allowable)}$ (psi)
4' Cantilevered	.320	1333	12600
6' Cantilevered	1.08	4500	12600
6' Restrained	.416	1732	12600
8' Restrained	.990	4106	12600

C.7. Crack width

Crack width needs to be checked for two reasons, corrosion protection and aesthetics. FRP bars are corrosion resistant and therefore the primary reason that crack widths need to be checked is for aesthetic reasons. ACI 440 recommends that the crack widths be limited to .02 inches for exterior members. The crack width can be calculated by EQ (8-9) shown below.

$$w = 2\frac{f_f}{E_f}\beta k_b\sqrt{d_c^{\ 2} + \left(\frac{s}{2}\right)^2} \qquad (8\text{-}9)$$

where f_f is the stress in the rebar, β is the ratio of the distance between the neutral axis and tension face to the distance between neutral axis and the centroid of the reinforcement, d_c is the thickness of cover from the tension face to the center of the closest bar, and s is the bar spacing. Table 6 below shows the results of this check. The crack widths in the 6' cantilevered and 8' restrained wall are slightly larger than the allowable value but are with in an acceptable range.

Table 6 Crack Widths using Aslan 100 GFRP

	w (in)	$w_{allowable}$ (in)
4' Cantilevered	.0066	.0200
6' Cantilevered	.0224	.0200
6' Restrained	.0086	.0200
8' Restrained	.0204	.0200

C.8. Deflection

An FRP reinforced member can have deflections up to 3 times larger than a comparably reinforced steel member. ACI 440 doesn't allow a prescriptive method for controlling deflections based on member size requirements, but instead requires that the deflections be checked using a direct method. ACI 440 allows deflections to be calculated using an effective moment of inertia calculated based on EQ (8-13a) shown below.

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 \beta_d I_g + \left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \leq I_g \qquad (8\text{-}13a)$$

Where M_{cr} is the cracking moment M_a is the applied moment β_d is a reduction coefficient related to the reduced tension stiffening exhibited by FRP reinforced members. The long-term deflections were calculated and checked against a limit of l/360, the results are shown in Table 7 below.

Table 7 Deflections using Aslan 100 GFRP

	δ (in)	$\delta_{allowable}$ (in)
4' Cantilevered	.0015	.0100
6' Cantilevered	.0111	.0150
6' Restrained	.0015	.0150
8' Restrained	.018	.200

C.9. Development Length and Lap Splices

The basic equation for development length is expressed in EQ (11-6) of ACI 440.1R-06

$$l_d = \frac{\alpha \frac{f_{fr}}{\sqrt{f'_c}} - 340}{13.6 + \frac{C}{d_b}} \qquad (11\text{-}6)$$

where f_{fr} is the required stress in the bar C is the clear and α is a top bar modification factor. ACI 318-05 section 12.5 requires that a lap splice in a tension zone be 1.3 times the required development length.

ACI uses separate equations for the development of hooked bars and is defined in EQ (11-5)

$$l_{bhf} = \begin{cases} 2000 \frac{d_b}{\sqrt{f'_c}} & for\ f_{fu} \leq 75{,}000\,psi \\ \frac{f_{fu}}{37.5} \frac{d_b}{\sqrt{f'_c}} & for\ 75{,}000 < f_{fu} < 150{,}000\,psi \\ 4000 \frac{d_b}{\sqrt{f'_c}} & for\ f_{fu} \geq 150{,}000\,psi \end{cases} \qquad (11\text{-}5)$$

The required development lengths and lap splices are summarized below in Table 8

Table 8 Development and Lap Splice Length

	l_d (in)	Lap Splice (in)	l_{bh} (in)
4' Cantilevered	41.8	54	20
6' Cantilevered	41.8	54	20
6' Restrained	41.8	54	20
8' Restrained	41.8	54	20

C.10. Shrinkage and Temperature Reinforcement

Hoizontal reinforcement will be provided to control both crack widths and shrinkage of the concrete. ACI 440.1R-06 EQ (10-1)

$$\rho_{f,ts} = .0018 \frac{60{,}000}{f_{fu}} \frac{E_s}{E_f} \qquad (10\text{-}1)$$

sets the minimum reinforcement ratio for shrinkage and temperature reinforcing. ACI allows a cap of .0036 to be placed on this ratio.

For slabs on grade ACI replaces the shrinkage and temperature reinforcement equation with EQ (A-2) as shown below

$$A_{f,sh} = \frac{\mu L w}{2(.0012 E_f)} \tag{A-2}$$

where m is 1.5, L is the distance between joints, w is the self-weight of the slab. A joint spacing of 10 feet was assumed for the shrinkage and temperature calculation. The recommended value from EQ A-2 was less than that obtained from EQ 10-1 so EQ 10-1 was used. Table 9 below summarizes the size and spacing of bars to achieve these requirements.

Table 9 Shrinkage and Temperature Reinforcement

	Size	Spacing	$\rho_{f,ts}$
Walls	5	12" o.c.	.0035
Slab	5	12" o.c. E.F. E.W.	.0035

C.11 . Reinforcement Summary

The reinforcing details can be seen in Figure 3 and Figure 4 below.

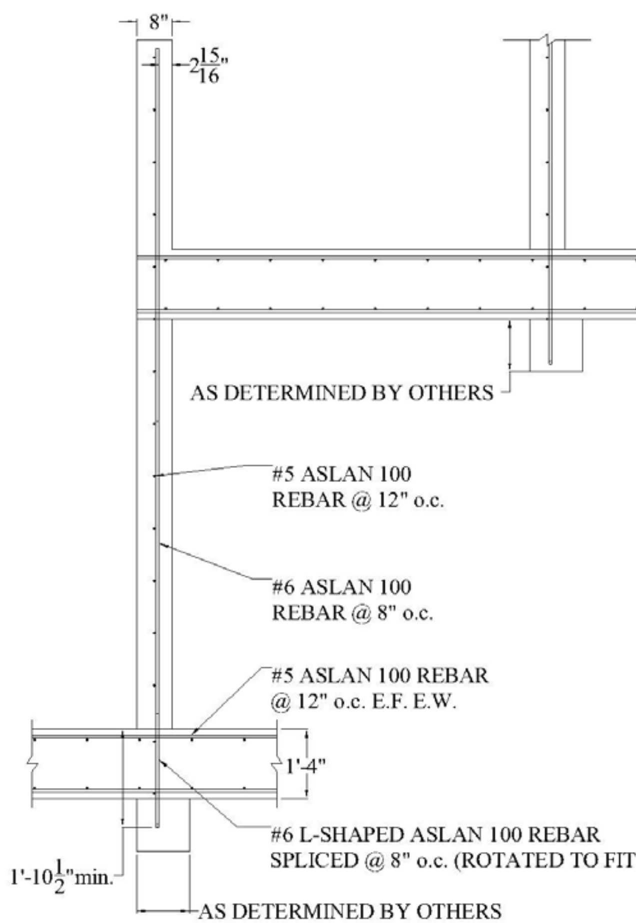

Figure 3 Reinforcing Detail

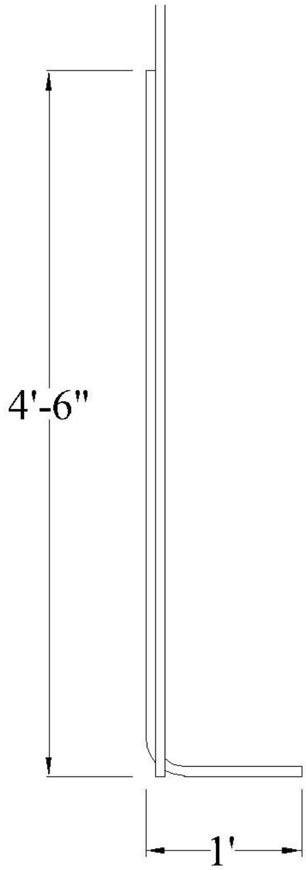

Figure 4 Splice Detail

D. REFERENCES

ACI 440.1R-06 “Guide for the Design and Construction of Concrete Reinforced with FRP Bars”, Published by the American Concrete Institute, Farmington Hills, MI.
ACI 318-02 “Building Code Requirements for Structural Concrete and Commentary”, Published by the American Concrete Institute, Farmington Hills, MI.