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STRUCTURAL CALCULATIONS

FOR

Sound Barrier Reinforcement

Honolulu Rail Transit
Oahu, Hawaii

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Exp: 4-30-2018

This work was prepared by me or under my supervision and construction of this project will be under my observation.

Engineer's Seal and Signature

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STRUCTURAL CALCULATIONS

BUILDING CODE: IBC 2006 with Honolulu City and County Amendments

REFERENCE DOCUMENTS:

- Architectural Drawings: Sound Barrier Details I and II by Kiewit HNTB

LOADING CRITERIA:

Loading conditions for the guideway design include:

H. Wind Load:

1. Wind on Structure (WS) – Calculate and apply per AASHTO 3.8.
   a. Reference wind velocity, V_{30} (fastest mile wind speed) 100 mph
   b. SUBURBAN condition shall be assumed in selection of Vo and Zo values in AASHTO Table 3.8.1.1-1.
2. Wind on Live Load (WL) does not affect the design of the sound barriers.

I. Creep and Shrinkage (CR & SH) – Calculate strains per CEB-FIP, Chapter 2. Mean annual relative humidity for design: 70%.

REINFORCING REPLACEMENT:

It is proposed that the steel reinforcing bars originally specified in the details of the sound barriers be replaced with Basalt Fiber Reinforced Bars (BFRP) marketed under the tradename of GatorBar™.

GatorBar reinforcement is immune to corrosion, so will provide a considerably longer service life than steel reinforcing bars. The reinforcement that is most highly exposed to corrosion (top bar in each sound barrier panel) is already specified as “#3 FRP Bar” complying with ASTM D7205 “Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars”. It is assumed that this would be a #3 Glass Fiber Reinforced Polymer (GFRP) bar.

It is assumed that the original steel reinforcing bars were designed to resist both the “Wind on Structure (WS)” loads and the “Creep and Shrinkage (CR & SH)” requirements specified for this project. This document therefore provides the equivalent GatorBar reinforcement to match the original steel reinforcement.

GatorBar Reinforcement Properties

Mechanical properties of #3 (3/8" diameter) GatorBar reinforcing bars were determined by test performed at Michigan Technological University (Fraley, 2016)[1]. These results are listed in Table 1 along with corresponding results for Aslan 100 Glass Fiber Reinforced Polymer reinforcing bars (Hughes Brothers, Inc., 2011)[2].

Table 1: Average Tensile and Shear Test Results for Neuvokas Corp. GatorBar BFRP bars and Aslan GFRP and CFRP bars, for comparison.

Bar Type	Bar Diameter (in.)	Guaranteed tensile strength (ksi)	Average tensile modulus (ksi)	Strain at failure	Average shear strength (ksi)
GatorBar BFRP[1]	0.375	145	6,885	0.0211	28.8
Aslan 100 GFRP[2]	0.375	120	6,700	0.0179	22.0

[1]Fraley, 2016; [2] Hughes Brothers, Inc., 2011

GatorBar to Rebar Equivalence

Consider a 5" thick by 84" wide concrete panel (fc' = 5,000 psi) with (7) #4 steel reinforcing bars centered on the panel.

The design bending capacity of the panel is given by:

$$\phi M_n = \phi A_s F_y (d - a/2)$$

where:

$$\phi = 0.9$$

$$A_s = 7 \times 0.2 = 1.4 in^2$$

$$F_y = 60 ksi$$

$$d = 2.5 in$$

and

$$a = \frac{A_s F_y}{0.85 f_c' b} = \frac{1.4 \times 60}{0.85 \times 5 \times 84} = 0.235 in$$

Therefore

$$\phi M_n = 0.9 \times 1.4 \times 60(2.5 - 0.235/2) = 180k - in = 15.0k - ft$$

[1] Fraley, P., 2016. *Test Results for Neuvokas Corp.*, Letter Report, Michigan Technological University, Houghton, Michigan, June 7, 2016.

[2] Hughes Brothers, Inc., 2011. *Glass Fiber Reinforced Polymer (GFRP) Rebar – Aslan 100 series; Fiberglass Rebar*, Seward, Nebraska, http://www.aslanfrp.com/Media/Aslan100.pdf

Consider the same 5” thick by 84” wide concrete panel with (11) #3 GatorBar reinforcing bars centered on the panel.

The design bending capacity of the panel is given by:

$$\phi M_n = \phi \rho_f f_f (1 - 0.59 \frac{\rho_f f_f}{f_c'}) b_w d^2 \text{ if } \rho_f \le \rho_{fb}$$

or $$\phi M_n = \phi A_f f_f (d - a/2) \text{ if } \rho_f > \rho_{fb}$$

where: $$\phi = 0.55 \text{ if } \rho_f \le \rho_{fb}$$

$$\phi = 0.3 + 0.25 \frac{\rho_f}{\rho_{fb}} \text{ if } \rho_f \le 1.4 \rho_{fb}$$

$$\phi = 0.65 \text{ if } \rho_f > 1.4 \rho_{fb}$$

$$A_f = 11 \times 0.11 = 1.21 in^2$$

$$f_f = \sqrt{\frac{(E_f \varepsilon_{cu})^2}{4} + \frac{0.85 \beta_1 f_c'}{\rho_f} E_f \varepsilon_{cu}} - 0.5 E_f \varepsilon_{cu}$$

$$E_f = 6{,}885{,}000 \, psi$$

$$\varepsilon_{cu} = 0.003$$

$$\beta_1 = 0.85$$

$$f_c' = 4{,}000 \, psi$$

$$\rho_f = \frac{A_f}{b_w d} = \frac{1.21}{84 \times 2.5} = 0.00576$$

$$\rho_{fb} = 0.85 \beta_1 \frac{f_c'}{f_{fu}} \frac{E_f \varepsilon_{cu}}{E_f \varepsilon_{cu} + f_{fu}} = 0.85 \times 0.85 \frac{5}{145} \frac{6885 \times 0.003}{6885 \times 0.003 + 145} = 0.00311$$

Therefore,

$$f_f = \sqrt{\frac{(6885000 \times 0.003)^2}{4} + \frac{0.85 \times 0.85 \times 5000}{0.00576} \times 6885000 \times 0.003} - 0.5 \times 6885000 \times 0.003 = 104000 \, psi$$

and $$\rho_f > 1.4 \rho_{fb} = 1.4 \times 0.00311 = 0.00435$$

so $$\phi = 0.65$$

$$a = \frac{A_f f_f}{0.85 f_c' b} = \frac{1.21 \times 104000}{0.85 \times 5000 \times 84} = 0.353 in$$

$$\phi M_n = \phi A_f f_f (d - a/2) = 0.65 \times 1.21 \times 104000 (2.5 - 0.353/2) = 190000 lb - in = 15.8 k - ft$$

Therefore, using 5,000 psi concrete, (7)#4 steel reinforcing bars in an 84” wide by 5” thick panel can be replaced with (11)#3 GatorBars in the same panel.