

Aslan FRP



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Prepared for

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A. INTRODUCTION

This report discusses the flexural and shear capacities of Aslan 100 reinforced slabs as it relates to the Volkswagen garage roof slabs in Brussels, Belgium. Aslan 100 GFRP bars are highly resistant to corrosion and are therefore perfect for applications with minimal clear cover available. Aslan FRP has been used successfully in around similar projects worldwide. Since no authoritative consensus design guide exists in Euro-Code format the 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 and Figure 2 below shows the framing plan.

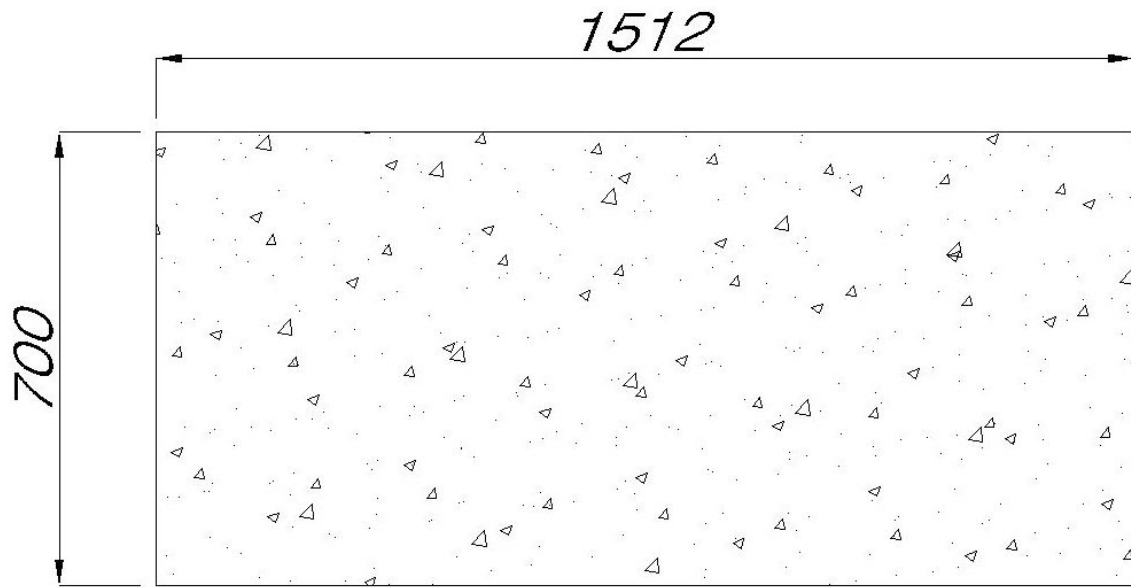


Figure 1 Framing Plan

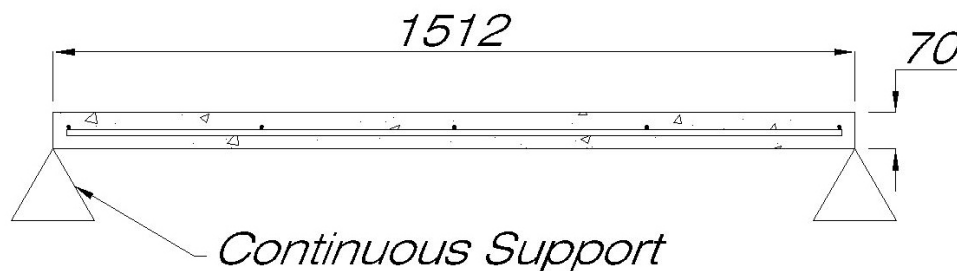


Figure 2 Building Cross Section

B. STRUCTURAL ANALYSIS

Hughes Brothers, Inc. has performed only limited structural analysis and the engineer of record must verify the results. The roof slab was modeled as a simply supported beam with a 150cm span and a thickness of 70cm thickness. The dead load was assumed to be

the self weight of the panel. The live load was assumed to be a 10kN moving point load. Figure 3 below illustrates the loading conditions used to determine the ultimate shear and moment forces. For ultimate design ACI requires that the loads be factored by 1.2 for dead loads and 1.6 for live loads. The required ultimate shear and moment forces are summarized in Table 1 below.

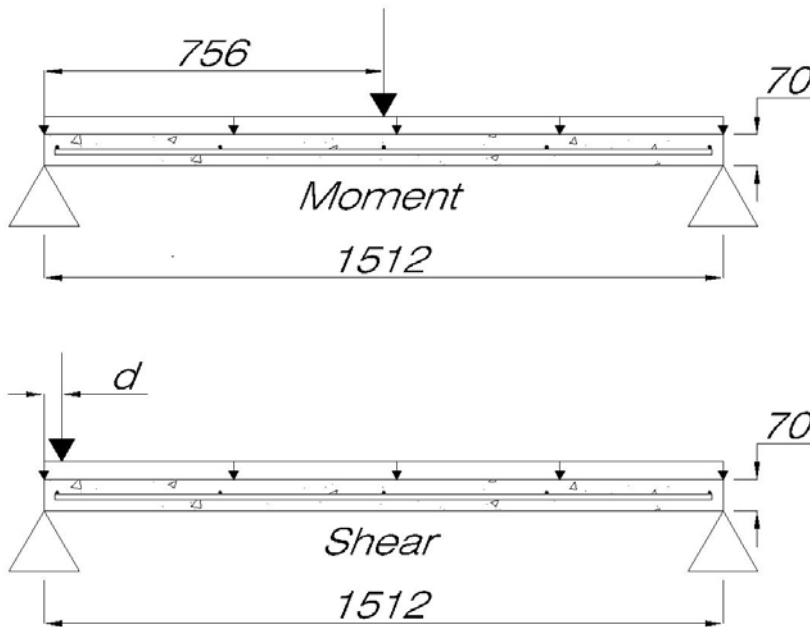


Figure 3 Slab Shear and Moment Diagram

Table 1 Factored Moment and Shear Forces

	Dead Load	Live Load	Ultimate
V (kips)	1.67	9.75	17.6
M (k-ft)	.66	3.78	6.84

C. GFRP RC DESIGN

C.1. Assumptions

The concrete strength of the slab was assumed to have an ultimate strength, f_c' , of 5800psi (40 MPa). The weight of the concrete was assumed to equal 150 pounds per cubic foot. The live load was assumed to act permanently on the panel. Total long-term deflection limit of 1/360 was assumed to be sufficient. It was assumed that punching shear was not a controlling factor in the design. The 10kN live load was assumed to create a greater demand than from rain and snow loads.

C.2. Material Properties

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

Table 2 Guaranteed Tensile Properties

Size	E_f^* (GPa)	f_{fu}^* (MPa)	ϵ_{fu}^*
3	40.8	760	.01858
4	44.1	689	.01689

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)

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

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

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 environmental reduction factor, C_E was taken as .7 (concrete exposed to earth and weather).

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 larger factor of safety. ACI uses the strength reduction factor (ϕ) to achieve the larger factor of safety. Table 3 shows the flexural capacities, ϕM_n , of the designed members and their required Ultimate Moment, M_u .

Table 3 Beam Flexural Strength using Aslan 100 GFRP

ϕM_n (kN-m)	10.56
M_u (kN-m)	6.84

C.5. Shear Design

Roof Slab and Beams

The design of FRP shear reinforcement is based on the strength design method of ACI 318. The concrete shear capacity, V_{cf} , is slightly different for FRP reinforced members to take into account the relatively low modulus of elasticity and the reduced dowel action. The contribution of the concrete is expressed in EQ (9-1) of ACI 440.1R-06.

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

Table 4 reports the shear capacity and demands of the members using Aslan 100 GFRP bars. ACI 440 requires that a minimum amount of shear reinforcing be placed in members in which the factored shear force is greater than $\frac{1}{2}$ the nominal concrete shear capacity. The roof panels reinforced with (15) 13mm bars violates this condition. It is not practical to put shear reinforcing in the panels so several different options are presented in the table to attain this requirement. The four options vary a combination of the thickness, concrete strength, and the number of reinforcing bars.

Table 4 Shear Capacity using Aslan 100 GFRP

Option	Thickness (mm)	f'_c (MPa)	# Bars	ϕV_n (kN)	V_u (kN)	$V_u / \phi V_n$
1	70	40	16	28.8	17.6	.588
2	70	40	22	33.4	17.6	.507
3	70	50	19	33.0	17.6	.513
4	75	45	17	32.83	17.7	.518

Note: All other design calculations were based on option #1, which is conservative. Option #4 is probably the most economical.

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 dead load moment plus live load moment.

Table 5 Sustained Stresses

M_s (kN-m)	4.44
$f_{f,s}$ (MPa)	63.0
$f_{f,s}$ (Allow) (MPa)	96.5

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 .5 millimeters for exterior exposure and .7 millimeters for interior exposed members. The crack width can be calculated by EQ (8-9) shown below.

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

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.

Table 6 Crack Widths Using Aslan 100 GFRP

w (mm)	.47
w _{allowable} (mm)	.51

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.

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

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 1/360, the results are shown in Table 7 below.

Table 7 Deflections Using Aslan 100 GFRP

δ (mm)	1.09
$\delta_{allowable}$ (mm)	3.15

C.9. Shrinkage and Temperature Reinforcement

Horizontal reinforcement will be provided to control both crack widths and shrinkage of the concrete. The roof slab and plain concrete footings will require shrinkage and temperature reinforcement. ACI 440.1R-06 EQ (10-1)

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

sets the minimum reinforcement ratio for shrinkage and temperature reinforcing. ACI allows a cap of .0036 to be placed on this ratio. Table 8 below summarizes the required number of bars to achieve this ratio

Table 8 Shrinkage and Temperature Reinforcement

Size	Number of Bars	ρ
3	5	.0036

C.10. Reinforcement Summary

Table 9 below shows the required dimensions and bar details for the panels detailed in Figure 4 shown below. Figure 5 shows the individual bar details used in the panels.

Table 9 Figure 4 Reinforcing Detail details

Option	h (mm)	f'_c (MPa)	(a) RB4-58	(b) RSN4-58-x2	RB3-53
1	70	40	5	3	5
2	70	40	8	4	5
3	70	50	6	4	5
4	75	45	6	3	5

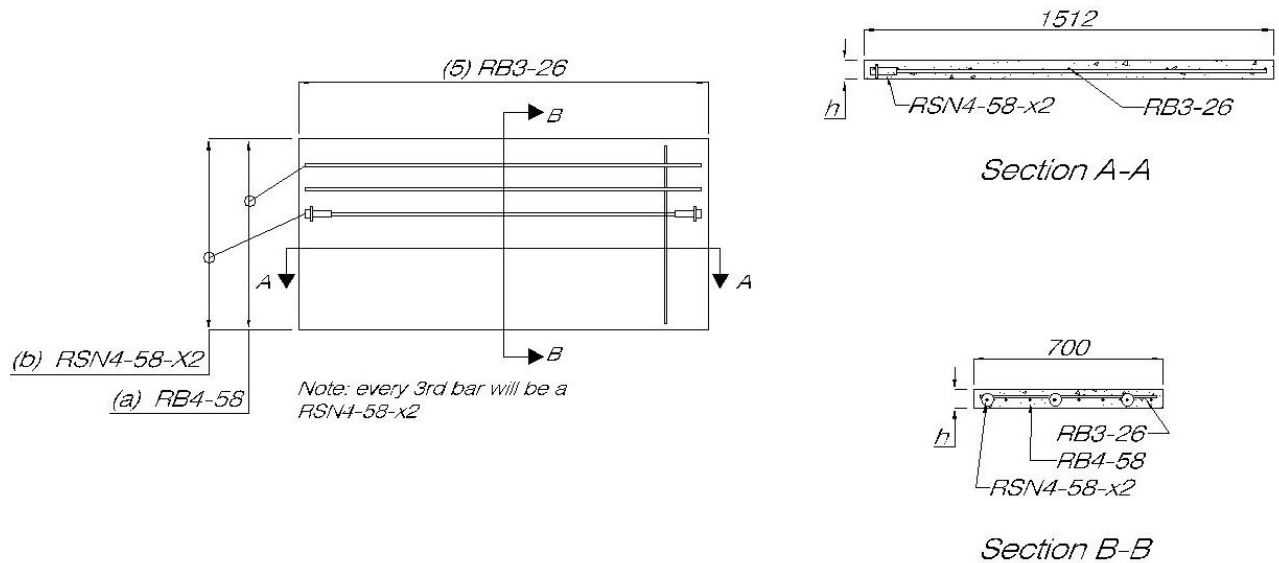


Figure 4 Reinforcing Detail

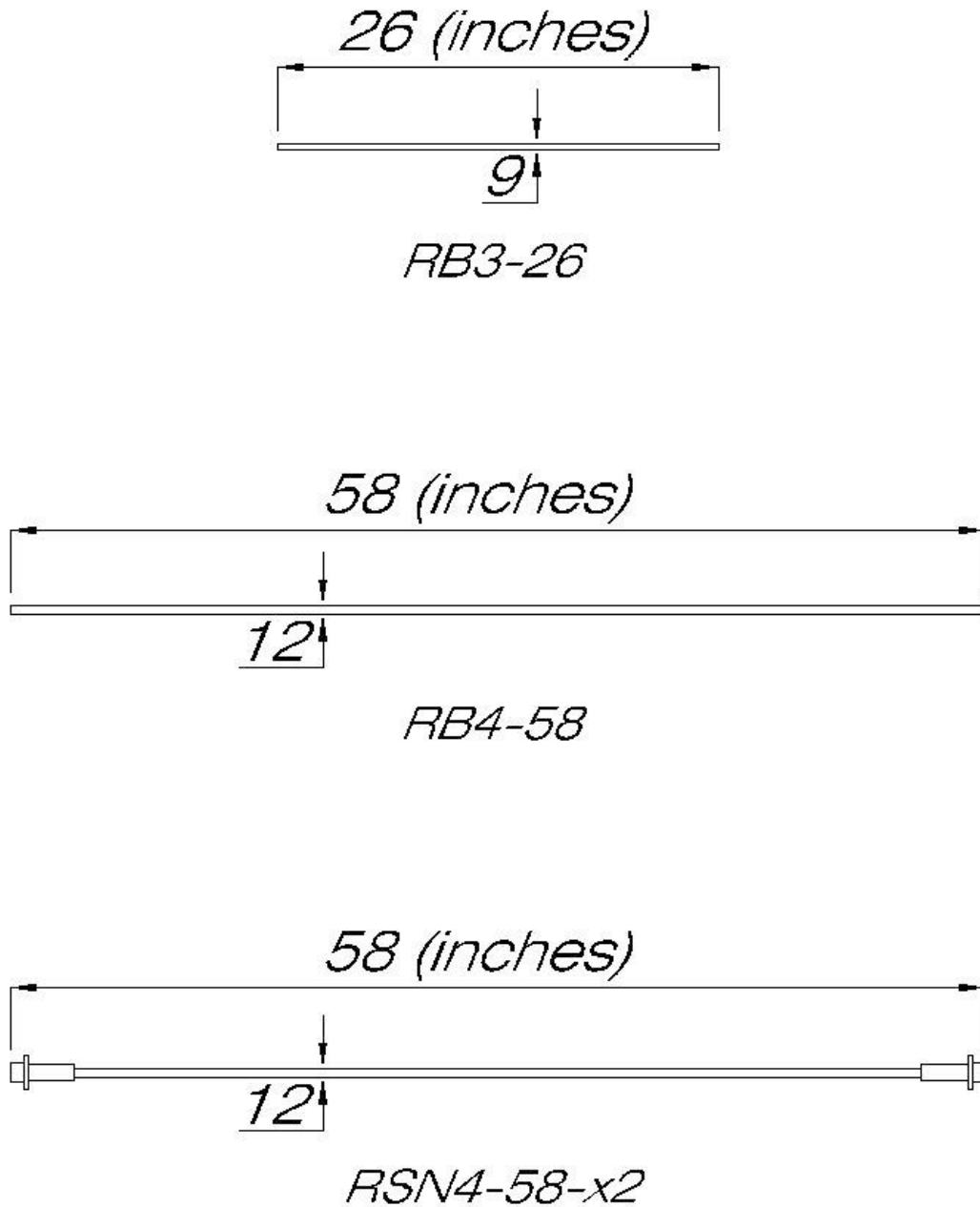


Figure 5 Bar Details

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.