Aslan FRP
Hughes Brothers
210 N. 13th Street Seward,NE 68434
Ph: 800-869-0359 Fax: 402-643-2149
Direct Ph: 402-646-6211 www.hughesbros.com

MS Kettering MRI

New York, NY

Prepared for:
Don Van Gerve, PE

4-10-07

Table of Contents

List of Tables

List of Figures

A. INTRODUCTION

This report discusses the flexural and shear capacities of a floor slab reinforced with Aslan 100 rebar related to the Memorial Sloan Kettering Hospital MRI room in New York, New York. Figure 1 shows the geometry and loading conditions. 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.

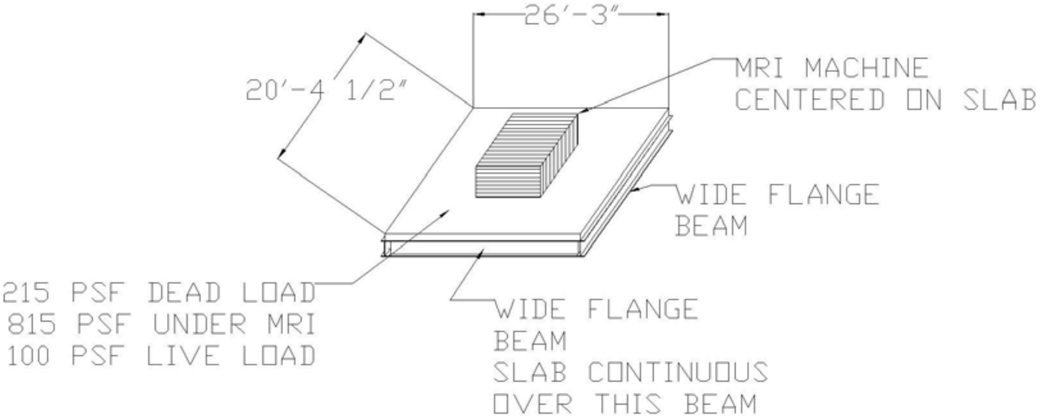


Figure 1 Geometry and Loading Conditions

B. STRUCTRUAL ANALYSIS

Moment and shear forces were provided by Robert Silman Associates, P.C. and are summarized in Table 1 below. Hughes Brothers, Inc. has not performed any structural analysis and assumes no responsibility as such.

Table 1 Moments and Shears

V_u (kips/ft)	M_u (kip-ft/ft)	$M_{serviceDL}$ (kip-ft/ft)	$M_{serviceLL}$ (kip-ft/ft)
10	58.2	33.5	2.5

C. GFRP RC DESIGN

C.1. 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}*
10	$5.9*10^6$	70,000	.01203
4	$5.9*10^6$	100,000	.01695

C.2. 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)

$$f_{fu} = C_E f_{fu}^* \tag{7-1}$$

$$\varepsilon_{fu} = C_E \varepsilon_{fu}^* \tag{7-2}$$

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 FRP 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. As per 7.1 the environmental reduction factor, C_E, should be taken as .8 (concrete not exposed to earth and water).

C.3. Slab Geometry

The slab has spans ranging from 17' to 20'-4 ½" in the longitudinal direction and 26'-3" in the transverse direction. The slabs are supported by wide flange steel beams on all sides. The slab is continuous in the longitudinal direction and simply supported in the transverse direction. The slab is 12 inches thick and has an ultimate concrete strength (f'_c) of 4500 pounds per square inch. It was assumed that the clear cover to was .75 inches, which would result in a depth to the flexural reinforcement (d) equal to 10.63 inches.

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 have a lower strength reduction factor (ϕ). The slab was analyzed as a unit strip and treating it like a beam and using the provisions of ACI 440 chapter 8. Table 3 shows the flexural capacity, ϕM_n of a 12-inch slab reinforced with #10 Aslan 100 GFRP spaced at 4".

Table 3 Flexural Strength of #10 Aslan 100 GFRP

ϕM_n (k-ft/ft)	M_u (k-ft/ft)
66.44	58.2

C.5. Shear Design

The design of FRP shear reinforcement is based on the strength design method of ACI 318. The concrete shear capacity, V_c, is slightly different for FRP reinforced members to take into account the relatively low modulus of elasticity and less dowel action. ACI 440.1R-06 section 9.4 discusses the concrete shear contribution for a two-way slab. The contribution of the concrete is expressed in EQ (9-8).

$$V_c = 10\sqrt{f'_c}\, b_o c \tag{9-8}$$

where b_o, for a unit strip, is equal to b_w or 12 inches. Table 4 shows the shear capacity and the factored shear demand. In section 9.2.2 of ACI 440.1R-06 requires a minimum amount of shear reinforcing where the factored capacity is less than 2 times the demand. It is tough to place shear reinforcing in the slab so a haunch will be provided to increase the shear capacity of the slab until the demand is less than ½ of the capacity. According to Robert Silman and Associates the shear will be 8.3 kips at a distance of 14” out from the support.

Table 4 Shear Capacity of #3 Aslan 100 GFRP

h (in)	ϕV_C (kips/ft)	V_u (kips/ft)
12	16.66	8.3

C.6. Deflections

Deflections were checked using a finite element program. To account for reduced moment of inertia of the cracked section, the slab was modeled as 7.67” thick rather than 12”. The reduced thickness has a moment of inertia that is similar to that of a 12” cracked cross-section. The immediate short-term deflection was multiplied by the factors stated in equation 8-15 of ACI. It was assumed that total long-term deflection limit of l/360 was acceptable. The deflections and the allowable deflections are shown in Table 5 below. The model results are shown in Figure 2 (full size picture can be seen in the Appendix).

Table 5 FEM Model of Deflections

I_{cr} (in^4)	$I_{7.67}$ (in^4)	Initial Deflection	Long Term Deflection	Allowable Deflection
451.98	451.22	.4961	.5953	.67

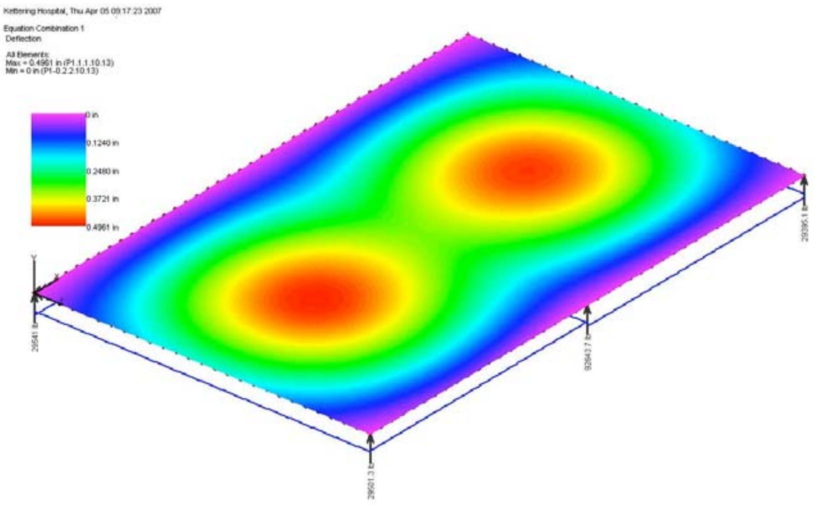


Figure 2 Deflection Results

C.7. 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 6 summarizes the results of this check. The sustained load was equal to the dead load plus 20% of the live load.

Table 6 Sustained Stresses

M_s (k-ft/ft)	$f_{f,s}$ (psi)	$f_{f,s\ (Allowable)}$ (psi)
34	11199	11200

C.8. Development Length and Lap Splices

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

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

where f_{fr} is the required stress in the bar C is the clear and α is a top bar modification factor. For this project the required development will be governed by the minimum development length of 20 bar diameters or 25 inches. Section 11.4 recommends that the lap splice length be 1.3 times the required development length. The required development and lap splice lengths are summarized below in Table 7

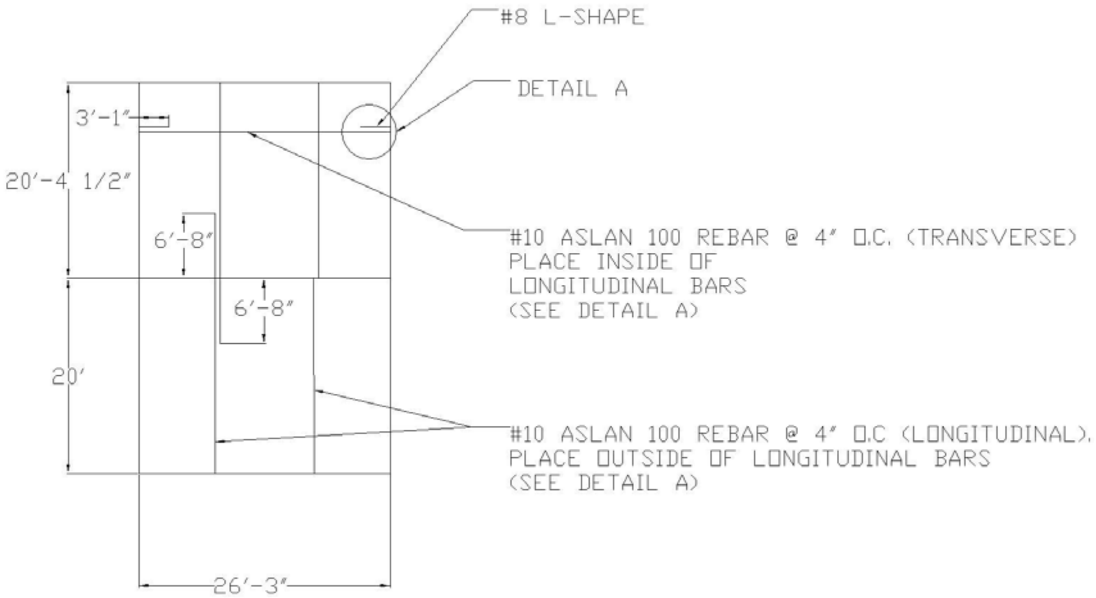
Table 7 Development and Lap Splice Length

l_d (in)	Lap Splice Length (in)
25	33

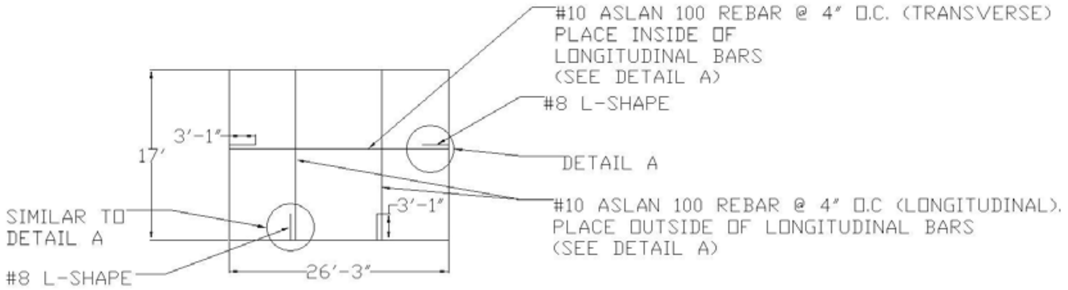
ACI requires that 1/3 of the positive moment reinforcing extend into the support. This is not possible as the supporting beams are in the way. As an alternative a middle layer will be placed to help accommodate this provision. Taking into account the lower depth to reinforcing (d), ½ of the bars will be used in the middle layer rather than 1/3.

C.9. Reinforcement Summary

Figure 3 to Figure 6 show the suggested reinforcement details to achieve the capacities stated in Table 3 and Table 4

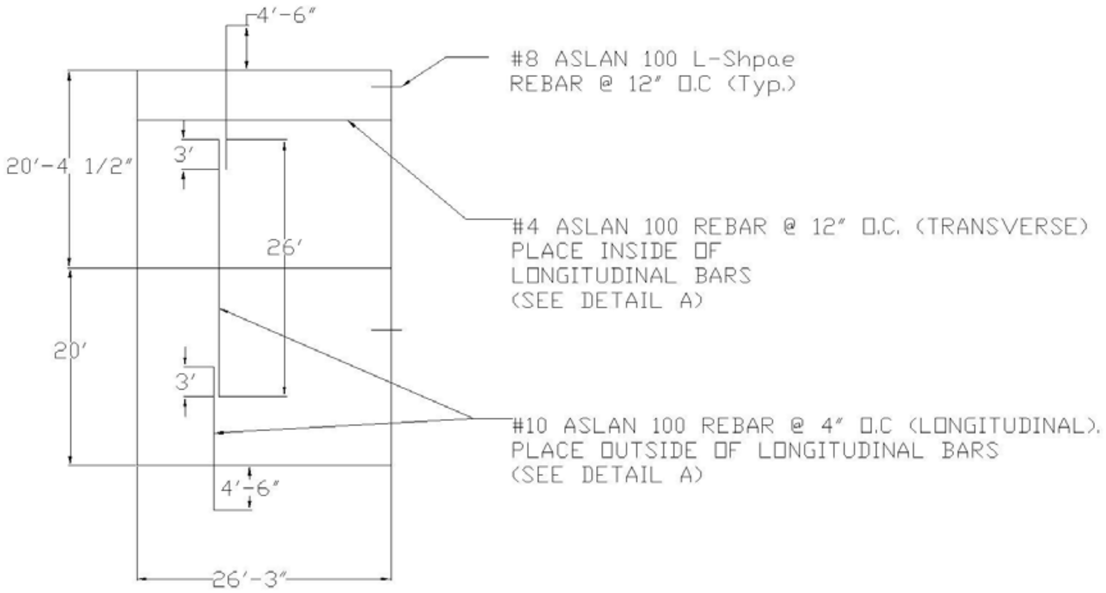


BOTTOM REINOFRCING
BOTTOM REINFORCING FOR
MRI SLABS BETWEEN
GRIDLINES A AND C



BOTTOM REINFORCING FOR
MRI SLAB BETWEEN
GRIDLINES D AND E

Figure 3 Reinforcing Detail (Plan View Bottom Mat)

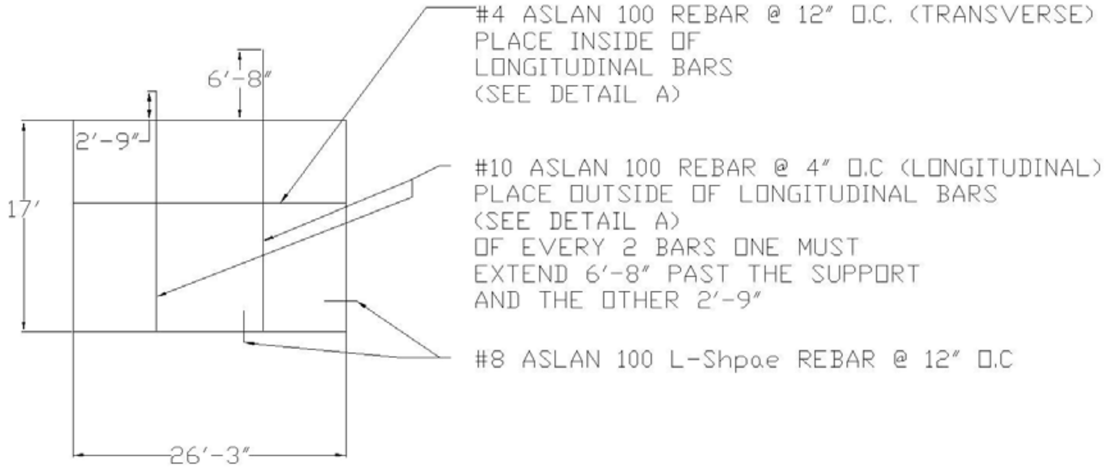


#8 ASLAN 100 L-Shpae REBAR @ 12″ O.C (Typ.)

#4 ASLAN 100 REBAR @ 12″ O.C. (TRANSVERSE) PLACE INSIDE OF LONGITUDINAL BARS (SEE DETAIL A)

#10 ASLAN 100 REBAR @ 4″ O.C (LONGITUDINAL). PLACE OUTSIDE OF LONGITUDINAL BARS (SEE DETAIL A)

TOP REINFORCING FOR
MRI SLABS BETWEEN
GRIDLINES A AND C



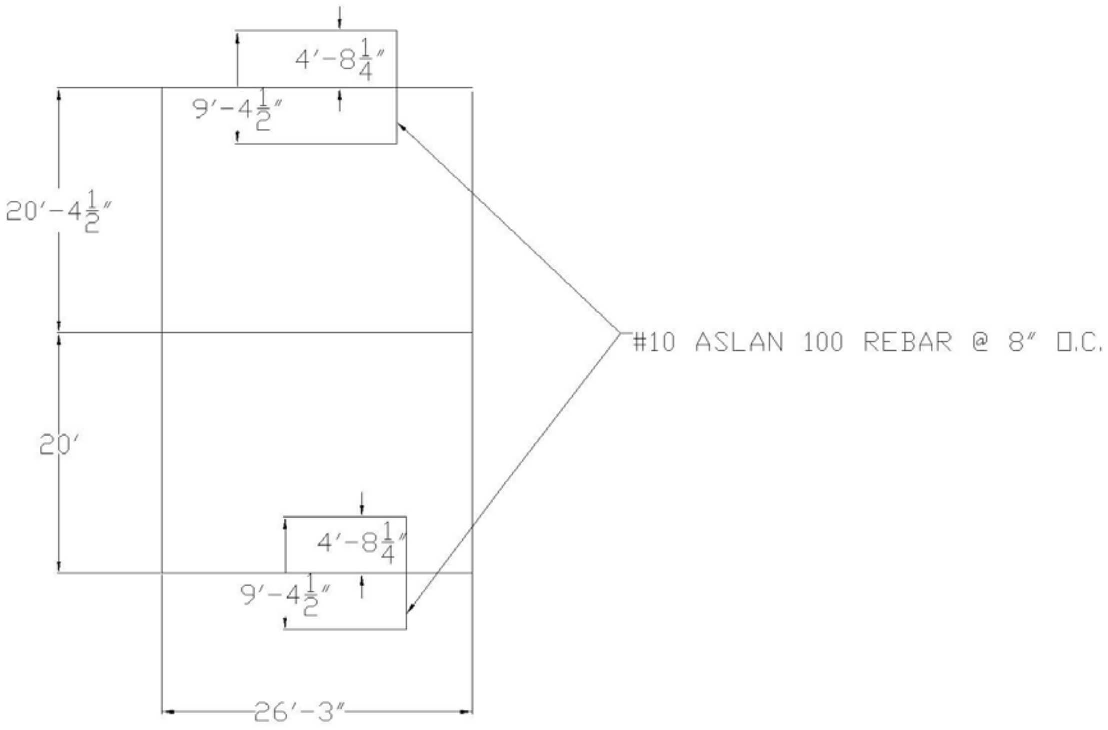
#4 ASLAN 100 REBAR @ 12″ O.C. (TRANSVERSE) PLACE INSIDE OF LONGITUDINAL BARS (SEE DETAIL A)

#10 ASLAN 100 REBAR @ 4″ O.C (LONGITUDINAL) PLACE OUTSIDE OF LONGITUDINAL BARS (SEE DETAIL A) OF EVERY 2 BARS ONE MUST EXTEND 6′-8″ PAST THE SUPPORT AND THE OTHER 2′-9″

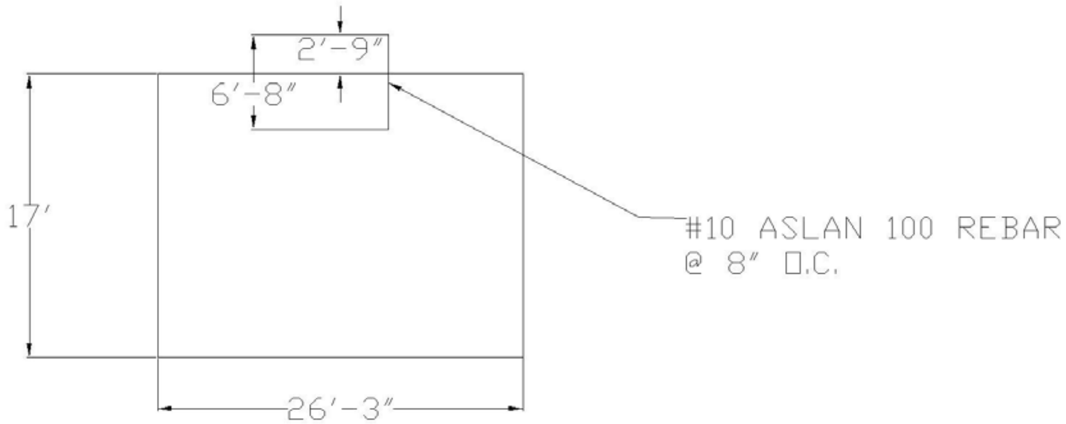
#8 ASLAN 100 L-Shpae REBAR @ 12″ O.C

TOP REINFORCING FOR
MRI SLAB BETWEEN
GRIDLINES D AND E

Figure 4 Reinforcing Detail (Plan View Top Mat)



MIDDLE REINFORCING FOR
MRI SLABS BETWEEN
GRIDLINES A AND C



MIDDLE REINFORCING FOR
MRI SLAB BETWEEN
GRIDLINES D AND E

Figure 5 Reinforcing Detail (Plan View Middle Mat)

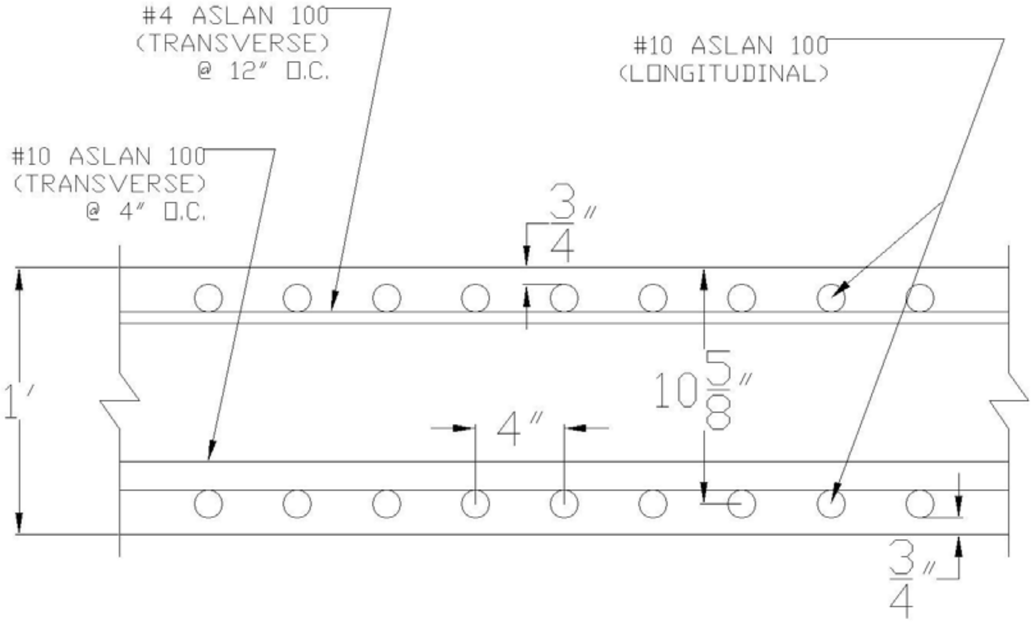


Figure 6 GFRP Reinforcing Detail

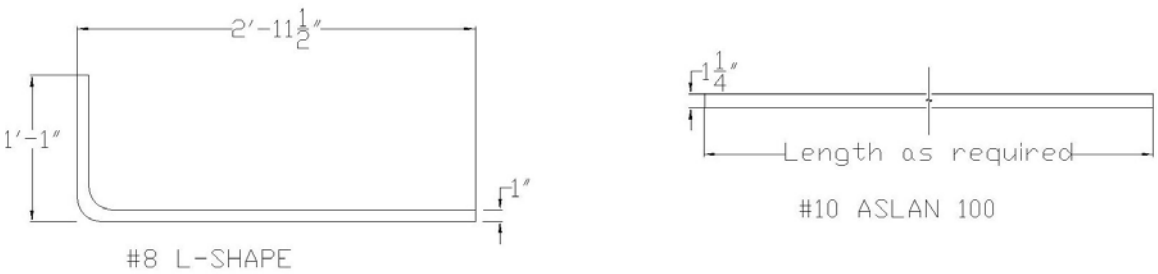


Figure 7 Bar List

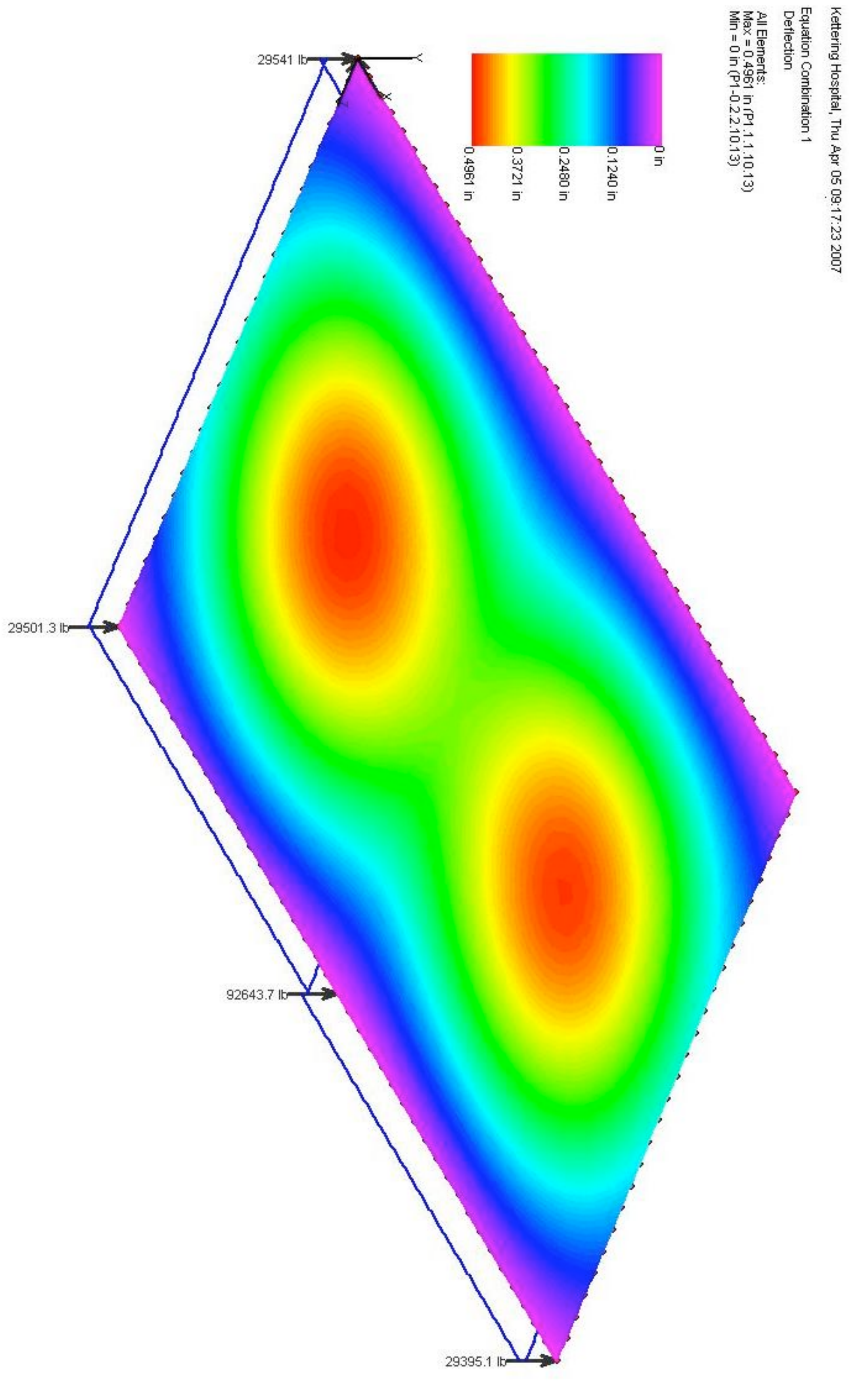
Table 8 Bar Quantities

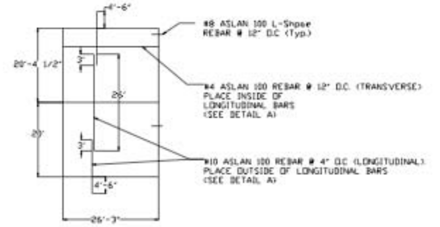
Shape	L	Straight	Straight	Straight	Straight	Straight	Straight
Size	#8	#10	#4	#10	#10	#10	#10
Length	13”x35.5”	26’	26’	29’-9”	29’-5”	19’-9”	23’-8”
Qty	430	175	60	160	160	80	80

E. REFERENCES

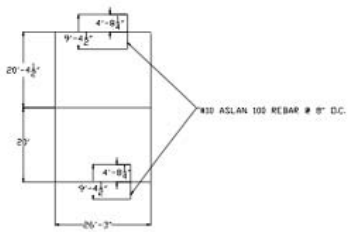
ACI 440.1R-06 “Guide for the Design and Construction of Concrete Reinforced with FRP Bars”, Published by the American Concrete Institute, Farmington Hills, MI.
ACI 318-02 “Building Code Requirements for Structural Concrete and Commentary”, Published by the American Concrete Institute, Farmington Hills,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

APPENDIX

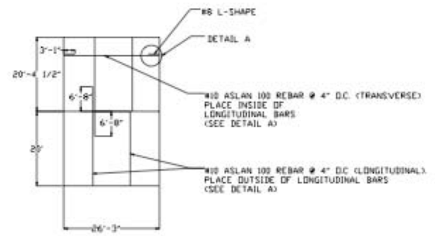

Kettering Hospital, Thu Apr 05 09:17:23 2007
Equation Combination 1
Deflection
All Elements:
Max = 0.4961 in (P1.1.1.10.13)
Min = 0 in (P1-0.2.2.10.13)
0 in
0.1240 in
0.2480 in
0.3721 in
0.4961 in
29541 lb
29501.3 lb
92643.7 lb
29395.1 lb



TOP REINFORCING FOR
MRI SLABS BETWEEN
GRIDLINES A AND C

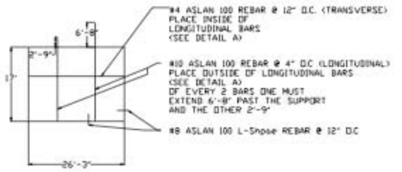


MIDDLE REINFORCING FOR
MRI SLABS BETWEEN
GRIDLINES A AND C

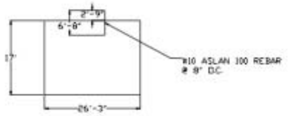


BOTTOM REINFORCING

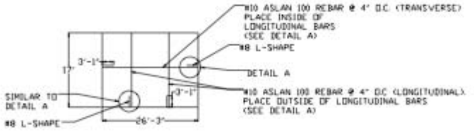
BOTTOM REINFORCING FOR
MRI SLABS BETWEEN
GRIDLINES A AND C



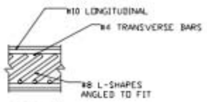
TOP REINFORCING FOR
MRI SLAB BETWEEN
GRIDLINES D AND E



MIDDLE REINFORCING FOR
MRI SLAB BETWEEN
GRIDLINES D AND E



BOTTOM REINFORCING FOR
MRI SLAB BETWEEN
GRIDLINES D AND E



DETAIL A
(END VIEW)

CONFIDENTIAL
This document includes information that is proprietary to Hughes Brothers, Inc., and shall not be disclosed or used except as expressly authorized.

Revision

Current Revision

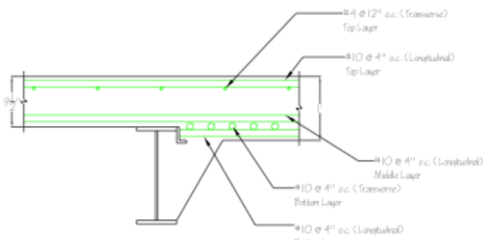
Aslan FRP
Hughes Brothers

Drawn RK

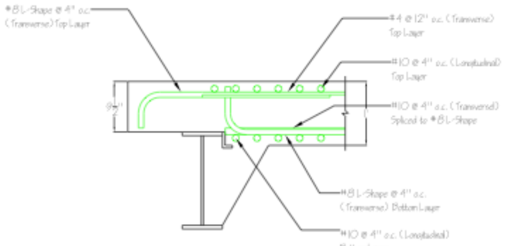
Date © 9-27-2007 HBI

Date Printed

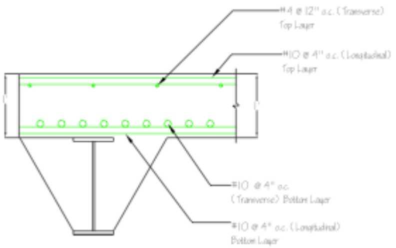
MS Kettering



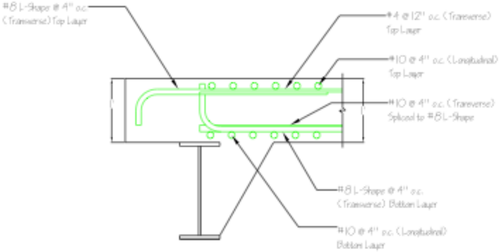
Detail for Gridlines A.3, C and D



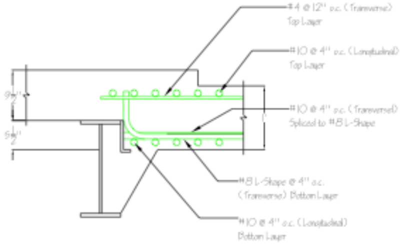
Detail for Gridline 1 Between A and B



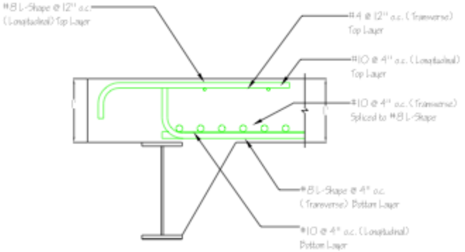
Detail for Gridline B



Detail for Gridline 1 Between B and C And Between D and E



Detail for Gridline 2



Detail for Gridline E

CONFIDENTIAL

This document includes information that is proprietary to Hughes Brothers, Inc., and shall not be disclosed or used except as expressly authorized.

Revision

Aslan FRP

Hughes Brothers

Drawn Name

Date 04-10-07 HBI

Date Printed 04-10-07

MS Kettering