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VALIDATION OF FRP COMPOSITE TECHNOLOGY THROUGH FIELD TESTING

Strengthening of Bridge P-0962
Dallas County, MO

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Strengthening of Bridge P-0962

DALLAS COUNTY, MODOT DISTRICT 8

EXECUTIVE SUMMARY

This report presents the materials and construction for flexural strengthening of the reinforced concrete (RC) bridge P-0962, Dallas County, Missouri, using externally bonded reinforcements. The report makes reference to two other documents: a) Master Materials and Construction Specifications, written in AASHTO language, and b) Manufacturer's Literature, that contains the tech data sheets for the materials used in this research program. This document explains the concrete repairs, surface preparation, materials specification, storage, handling, etc, for the five different technologies used in this research program, namely: manual lay-up carbon FRP laminates; near surface mounted (NSM) carbon FRP bars; adhered pre-cured carbon FRP laminates; steel reinforced polymer (SRP) laminates; and mechanically fastened carbon FRP laminates.

Bridge P-0962 is one of five existing RC bridges, located in three districts, which were strengthened using composite materials. Five different strengthening techniques were used in the entire program but only three were used for bridge P-0962: manual lay-up CFRP laminates, NSM CFRP Bars and SRP laminates.

This project was conducted under a joint MoDOT – UMR University Transportation Center – Private Sector funding initiative. The five existing concrete bridges will be monitored twice a year over five years, including repeated load tests. The data, information, and understanding from this validation are used in the drafting of design and construction specifications to be written in AASHTO language for future FRP-related bridge-strengthening projects.

The strengthening schemes were designed in compliance with the ACI 440.2R-02 Design Guide for Externally Bonded FRP Materials where applicable. Both FRP and SRP strengthening techniques were easily implemented and showed satisfactory initial performance. The strengthening of this bridge was carried out during seven weeks in September to October of 2003. The structure has three spans (42.5 ft = 12.95 m each), each with three RC girders monolithically cast with a 6 in (15 cm) slab. The FRP system consisted of manual lay-up and NSM bars for spans 1 and 2, numbered south to north. FRP laminates were U-wrapped on all longitudinal girders to anchor the flexural reinforcement and increase the shear capacity. Span 3 was reinforced using SRP laminates for flexural reinforcement and also SRP laminates were U-wrapped along the girders to anchor the flexural reinforcement.

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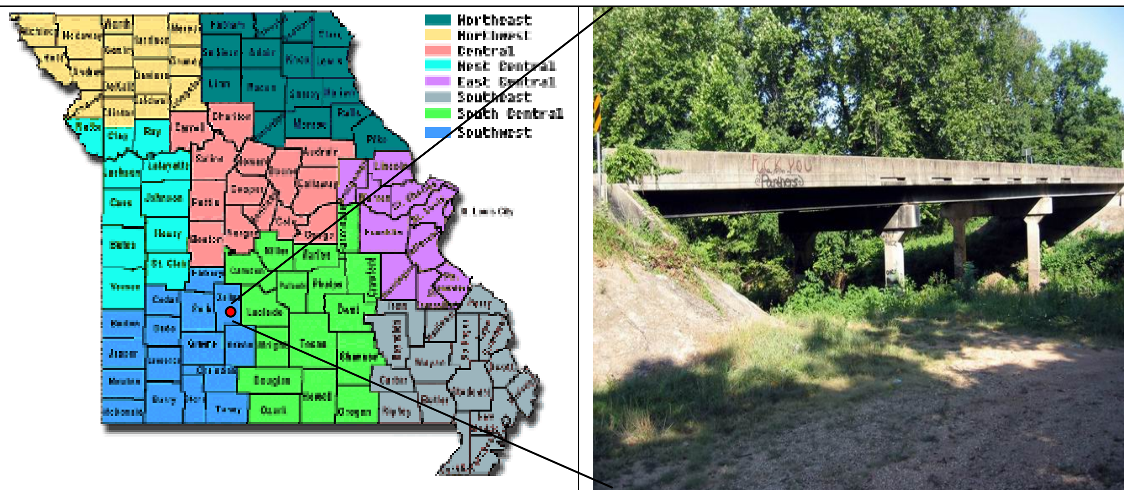
1. INTRODUCTION

1.1 General description

Bridge P-0962 is located in Dallas County, MoDOT District 8. The structure has three equally-spaced spans (42.5 ft = 12.95 m), each with three RC girders monolithically cast on a 6 in (15 cm) slab (see Table 1, Figure 1, Figure 2 and Figure 3). The total bridge length is *127.5 ft* (38.86 m) and the total width of the deck is *23.75 ft* (7.24 m). Each span has one transversal beam with the same depth as the main girders (Figure 3). Three FRP system technologies were used for the flexural strengthening of this bridge.

Table 1- Summary Information

BRIDGE P-0962	
	
District: 8	**County:** Dallas
Year Built: 1956	**Feature Intersected:** Creek
Main Spans Construction: RC T-Beam	**Number of Main Spans:** 3
Total Length: 127 ft (38.71 m)	**Rating (Deck/Sup/Sub):** 7/6/6
Load Posting: Trucks over 18 ton (16.33 tons in SI units), 15 mph (24.14 km/h) on the bridge	
BRIDGE FEATURES	
Geometry • Height of the bridge is 18 ft (5.49 m). Total width of deck is 23 ft (7 m). • Deck consists of three RC T-beams spaced 9 ft (2.74m) on centers. All spans have three transverse beams. • The thickness of the slab is 6 in (15 cm)	
Concrete Condition before Strengthening • In general, concrete is in good condition. No spalling detected. • Abutments are not in good condition. Some repairs are needed for the deck.	

The FRP systems consist of FRP manual lay-up laminates and NSM bars for reinforcement of the deck, girders and bent of spans 1 and 2 (numbered from south to north), and Steel-Reinforced Polymers (SRP) for span 3. U-wrapped FRP laminates were installed on all the main longitudinal girders using manual lay-up to hold the flexural reinforcement in place.

Figure 1. Approach to the bridge

Figure 2. Condition of bent

Figure 3. Condition of deck

2. MATERIALS

2.1 Material Properties

Three commercially-available external composite systems were adopted: (1) externally bonded CFRP laminates installed by manual wet lay-up, (2) NSM bars bonded in place with an epoxy-based paste, and (3) SRP installed by manual wet lay-up. The main difference between these three techniques is the preparation necessary before the application of the strengthening, that in turn depends upon the condition of the concrete substrate on which the fiber sheet, bars and steel sheets are bonded. FRP and SRP have been applied following the Master Materials and Construction Specifications.

The properties of the composite materials used in the design are summarized in Table 2, 3 and 4, as reported by the manufacturers (see Manufacturer's Literature).

Table 2 – Properties of CFRP Laminate Constituent Materials

Material	Ultimate tensile strength f^*_{fu} ksi [MPa]	Ultimate strain ε^*_{fu} in/in [mm/mm]	Tensile modulus E_f ksi [GPa]	Nominal thickness t_f in [mm]
Primer	2.5 [17.2]	0.03	104 [0.7]	-
Putty	2.2 [15.2]	0.07	260 [1.8]	-
Saturant	8.0 [55.2]	0.035	440 [3.0]	-
High Strength Carbon Fiber	550 [3790]	0.017	33,000 [228]	0.0065 [0.1651]

Table 3– Properties of NSM CFRP Bars Constituent Materials.

Material	Ultimate tensile strength f^*_{fu} ksi [MPa]	Ultimate Strain ε^*_{fu} [in/in]	Tensile modulus E_f ksi [GPa]	Cross Sectional Area in^2 [mm^2]	Dimensions in×in [mm×mm]
Epoxy Adhesive	4.5 [31]	0.04	-	-	-
NSM Bars	300 [2,068]	0.017	18,000 [124]	0.1679 [108.3]	4/8 bar size

Table 4– Properties of SRP Constituent Materials

Material	Ultimate tensile strength f^*_{fu} ksi [MPa]	Ultimate Strain ε^*_{fu} [in/in]	Tensile modulus E_f ksi [GPa]	Net Area per Width in^2 /in [mm^2/m]
Coating Resin	4.4 [30]	0.015	-	-
SRP Type-1	460 [3,170]	0.016	28,750 [206]	0.0173 [0.44]
SRP Type-2	345 [2390]	0.017	20,300 [206]	0.0104 [0.26]

2.2 Summary Bill of Material (As Built)

Table 5 and Table 6 presents a summary of materials as used. Table 5 shows the break up for the various reinforcement types.

Table 5– Summary of Bill of Reinforcement as Built

FRP Type	Reinforcement	Member Location	Span	Quantity	
NSM Bars	Flexural	Interior Girder	1 & 2	392 *ft*	119 m
		Total		**392 *ft***	**119 m**
Manual Lay-up Laminates	Flexural	Slab	1 & 2	448 *ft*^{2}	42 m^2
		Total		**448 *ft*^{2}**	**42** m^2
	Flexural	Interior Girder	1 & 2	462 *ft*^{2}	43 m^2
		Exterior Girder	1 & 2	419 *ft*^{2}	39 m^2
		Total		**881 *ft*^{2}**	**82** m^2
	Shear	Interior Girder	1 & 2	658 *ft*^{2}	61 m^2
		Exterior Girder	1 & 2	435 *ft*^{2}	40 m^2
		Total		**1,311 *ft*^{2}**	**122** m^2
	Flexural	Bent		170 *ft*^{2}	16 m^2
	Shear	Bent		184 *ft*^{2}	17 m^2
		Total		**354 *ft*^{2}**	**33** m^2
SRP Type-1	Flexural	Slab	3	101 *ft*^{2}	9 m^2
		Total		**101 *ft*^{2}**	**9** m^2
		Interior Girder	3	77 *ft*^{2}	7 m^2
		Exterior Girder	3	126 *ft*^{2}	12 m^2
		Total		**203 *ft*^{2}**	**19** m^2
SRP Type-2	Shear			283 *ft*^{2}	26 m^2
				220 *ft*^{2}	20 m^2
		Total		**503 *ft*^{2}**	**47** m^2

Table 6– Summary of Bill of All Material as Built

NSM Bars	Bar	**392** ft	**119** m
	Adhesive	**392** ft	**119** m
Manual Lay-up Laminates	Sheet	**2,994** ft^2	**278** m^2
	Primer	**1643** ft^2	**153** m^2
	Putty	**1643** ft^2	**153** m^2
	Saturant	**4377** ft^2	**407** m^2
	Coating	**1643** ft^2	**153** m^2
SRP	Hardwire 3X2	**203** ft^2	**19** m^2
	Hardwire 3SX	**503** ft^2	**47** m^2
	Saturant	**1395** ft^2	**130** m^2
	Coating	**632** ft^2	**59** m^2

The detailed compilation for the bill of materials reported in the Tables above is given at the end of this report as Appendix 1.

3. STRENGTHENING

3.1 Substrate Repair

The performance of a composite system depends not only on the quality and strength of the concrete substrate but also on the bond between the composite and substrate. A clean and sound substrate is essential for composite repair systems. Unsound concrete, concrete which emits a relatively dead or hollow sound when its surface is tapped with a metal tool, was removed and patched. Holes through the deck were filled; all concrete surfaces to be strengthened were thoroughly prepared according to the minimum requirement defined in the Master Materials and Construction Specification.

The concrete repair work consisted of the following parts:

- Partial-depth repairs of deteriorated concrete on deck and bents
- Removal of sound concrete along the deck, bents and girders to establish a suitable surface profile

In order to place CFRP and SRP on the underside of the bent system, repair work was done by removing 20 cubic feet (0.57 m^3) of concrete from the deteriorate areas, cleaning the area, installing repair materials, finishing and texturing (Figure 4).

Figure 4. Repair of deteriorated areas on one bent. Bent after repair

3.2 Surface Preparation

To promote continuous intimate contact between concrete and FRP, several important issues had to addressed in the surface preparation: concrete surface irregularities, fins, and/or sharp angles that may result in separation and delamination of carbon laminate from the concrete and/or in localized stress concentration. Concrete surface irregularities were removed and smoothed to less than 1 mm.

Rounding of corners using grinders reduces stress concentration and results in improved bond between the FRP and concrete surface. The concrete angles were rounded to no less than 1/2-inch (12.7 mm) (see Figure 5)

Figure 5. Rounding of corners on girder

Abrasive sandblasting was used to clean the concrete surfaces of dust, dirt, laitance, oil and any curing substance. Concrete surface roughness was equivalent to CSP 3 (Concrete Surface Profile number 3) as defined by the International Concrete Repair Institute. The sandblasting must be applied prior to CFRP and SRP installation. All loose particles, oil, dust, cement, paint and other contaminants were contained in accordance with State regulation (Figure 6)

Figure 6. Preparation of appropriate roughness by sandblasting

3.3 Externally Bonded Composite Reinforcement

Spans 1 and 2, numbered from South to North, were strengthened with manual lay-up laminates and NSM bars. Span 3 was reinforced with SRP laminates. The installation process for each technology will be described in the following sections.

3.3.1 Manual Lay-up CFRP Laminates

The carbon fabric for the manual lay-up system consists of uni-axial carbon fiber sheets for strengthening the positive moment and shear region of reinforced concrete. In this instance, a high strength carbon fiber was used (Table 2)

3.3.1.1 Primer Application to Fill Voids

Two-component epoxy primer (Table 2) was used to fill voids in the concrete surface. All surfaces to receive the carbon fiber fabric were primed with the penetrating primer (Figure 7)

Primer was mixed in accordance with the manufacturer’s recommendations (See Manufacturer’s Literature) using brushes and rollers. The volume of primer to be prepared at one time was such that could be applied within its pot life. Primer was thoroughly mixed with a hardener at the manufacturer’s specified ratio.

Application was uniform in a sufficient quantity to fully penetrate the concrete and produce a non-porous film in the surface after full penetration. A four-way method, application in all four direction, was used. When necessary, a second coat was applied after the first coat penetrated into the concrete.

Figure 7. Filling of voids and defects by primer and putty collocation

3.3.1.2 Epoxy Filler/Surfacer

Remaining minor surface irregularities and defects were corrected using epoxy filler/surfacer or putty. It is not desirable that the epoxy putty filler cover the entire concrete surface.

A trowel was used to apply the putty in order to fill any surface defect (Figure 7). The material properties of the primer and putty that were used are listed in Table 2.

3.3.1.3 Application of Carbon Fiber Sheets

The carbon fiber sheets were cut beforehand into prescribed sizes using scissors and a simple made-in-place device (Figure 8).

A saturant coating (Table 2) was applied with a medium nap roller after application of the primer and putty (Figure 9). Afterward, the pre-cut fiber sheets were attached according to Contract drawings.

Figure 8. Cutting process of CFRP sheet

The carbon fiber sheets were installed by manual lay-up method (Figure 10). The sheets were properly aligned and set into the surface saturant. The fiber plies were aligned on the structural member according to the Contract Documents. Any deviation in the alignment more than 5˚ (approximately 87 mm/m or 1 in/ft) was not acceptable. The sheets were saturated by rolling out the external surface. This operation also removed excess of saturant and bubbles (Figure 11). After appropriate time (10 minutes), a second saturant application over the carbon fiber sheets were applied to a complete impregnation (Figure 11).The saturant was applied in strict accordance with the manufacturer’s recommendations (Manufacturers Literature).

Figure 9. Saturant application

Figure 10 Manual lay-up CFRP sheet installation.

Figure 11. Squeezing of air bubbles and saturation over laminates

The process must allow sufficient working time for the rolling of the carbon fiber sheet and saturant to produce a uniform system that is completely free of voids and trapped air. It must be completed within the limits of saturant pot-life.

Because saturant is susceptible to temperature, special care shall be taken to minimize the elapsed time between mixing and application of the saturant. This must be applied to the sheet at least 15 minutes prior to any thickening.

In order to avoid vibrations during the installation, traffic control was used (see Figure 12). Speed of the car was limited to 15 mph (24.14 km/hr). Finally, a topcoat was applied to the sheet to provide a cosmetic finish and environmental protection (see Figure 12)

Figure 12. Traffic control and topcoat protection

3.3.2 Near Surface Mounted (NSM) Bars.

The carbon/epoxy CFRP Bars are pultruded carbon fiber reinforced epoxy. These bars are reinforcing elements for positive moments. The material properties of the bars and epoxy paste used are listed in Table 3.

Installation of the bars was achieved first by grooving the concrete surface. The grooves have square cross section, 5/8 inch (15.9 mm) per side, to allow embedment. This value is equivalent to the diameter of the bar plus one eighth of an inch per side). Concrete was grooved making parallel saw cuts of 5/8 in depth and spaced at 5/8 in. The groove is created by chipping out the concrete between the two cuts (see Figure 13). The system included a primer/sealer for the concrete surface (see Figure 14)

Figure 13. Grooving of girder surface for the NSM bars

Figure 14. Epoxy resin and epoxy adhesive in slot cut in the concrete surface

A high modulus, high strength and high viscosity epoxy adhesive was used (Table 3). This epoxy paste is chemically compatible with the individual properties of the primer and bars, so a solid bonding can be developed (see Figure 14)

Figure 15. Bar installation

Figure 16. Installed NSM bars

The NSM bars were then placed into the grooves and lightly pressed to force the paste to flow around the bar. The bars are sometime placed with the help of wedges. Excess material was removed manually and the surface was leveled (Figure 15 and Figure 16).

The NSM FRP technique does not require any surface preparation work and requires minimal installation time compared to FRP laminates. Nevertheless, the grooving work can take more time and cost more than the normal surface preparation of in-place-cured or pre-cured laminates.

3.3.3 Steel Reinforced Polymers (SRP)

The Steel Reinforced Polymers (SRP) tape consists of steel cord tape and epoxy resin (see Table 4). Two types of high strength SRP tape were used: a type-1 SRP cord tape of 0.0173 in^2/in (0.44 mm^2/mm) of net area per width, used for flexural reinforcement; and a type-2 SRP cord tape of 0.0104 in^2/in (0.26 mm^2/mm) of net area per width, U-wrapped on the longitudinal girders.

Installation of SRP systems is generally similar to single ply wet lay-up but the material is more rigid. Repair of concrete substrate and surface preparation to provide an open roughened texture are procedure similar as described in sections 3.1 and 3.2 of this report. Nevertheless, because the steel cord is typically bent with mechanical equipment that makes 90^o sharp bents, it is not recommended to round the corners in the concrete section as is typically done for FRP installation.

SRP system strips were cleaned and cut in length specified in the contractor drawings (see Figure 17) using commercial quality handheld electric shears or other appropriate shearing cutters. The number of sheets cut was limited to the number to be installed that day.

Figure 17. Cutting of SRP laminates and epoxy adhesive application to the surface

A coating resin was roller-applied to the concrete to prime and seal the surface (Figure 17). The steel sheet was then installed and properly aligned by the manual lay-up method. The laminates were mechanically pressed onto the concrete with enough force to impregnate them and to squeeze out the extra resin (Figure 18)


Figure 18. SRP installation and full impregnation by rolling

The process was carefully planned to allow sufficient working time for the rolling of the carbon fiber sheet and resin to produce a uniform system that is completely free of voids and trapped air and to be completed within the time limits of the resin pot life.

Sheets were then completely impregnated with an application of a second roller-applied epoxy resin to the external surface (Figure 19)


Figure 19. Full impregnation by a second epoxy application

Flexural and shear reinforcement was originally designed to be installed in alternating ways. Nevertheless, for construction reasons, all the flexural reinforcement was collocated first (see Figure 20). Additionally, all U-Wraps collocated after that were divided in two L-shape parts (see Figure 20), fully overlapped in the bottom of the girders (see Figure 21). Finally, a topcoat was applied to the sheet to provide a cosmetic finish and environmental protection.

Figure 20. Installation of flexural reinforcement. U-Wrap formed by two L-Shapes

Figure 21. Overlapping to form a U-Wrap

4. ACCEPTANCE TESTING.

A direct pull-off test based on ASTM D 4541-93 was used by the contractor in this project. This test allows to check the quality of the installation of the FRP. It consists in gluing an aluminum square plate on the strengthened part to be checked; afterwards, a core is drilled close to the aluminum plate through the laminate strip into the concrete substrate, providing an isolated test location for attachment of the pull-off tester (Figure 27). The tester records the force causing the failure, which, if divided by the core cross sectional area, will result in tensile strength (psi). Upon failure of the core specimen, a visual examination of the failure plane location reveals whether the failure occurred at the bond line or within the substrate. Failure of the concrete and not at the bond line was the only acceptable failure. The tensile bond strength must be more than 200 psi (1.4 MPa)

One pull-off test was performed every 200 ft^2 (20 m^2) of area strengthened with carbon fiber strip system or once every deck span.

Figure 22. Pull-off test

The results of single tests made on spans 1 and 2 are summarized in table 7. They show values of tensile bond strength bigger than the minimum required. Based on these results and that all failures occurs in the concrete and not at the bond line, installation of FRP was considered successful.

Table 7. Results of direct pull-off test for Dallas County bridge P-0962

Test #	Test Results psi [MPa]	Description	Work Area
1	400 [2.8]	Carbon Fiber-U Wrap sheet	Bent A
2	300 [2.1]	carbon Fiber	Deck Span 2
3	650 [4.55]	Carbon Fiber-U Wrap sheet	Internal girder-Span 2
4	700 [4.9]	Carbon Fiber-U Wrap sheet	Bent B

APPENDIX 1

Detailed Bills of Materials (as Built)

1 NSM Bars

1.1 FLEXURAL REINFORCEMENT

1.1.1 Interior Girder. All Spans

$$(2)(2)\cdot(2\cdot 2\cdot 10\text{ft} + 2\cdot 2\cdot 14.5\text{ft}) = 392\text{ft}$$

2 Manual Lay-up Laminates

2.1 FLEXURAL REINFORCEMENT

2.1.1 Slab

2.1.1.1 Span 1 & 2

$$(2)(2)\cdot(15 + 17)\cdot(6\text{in})\cdot(7.0\text{ft}) = 448\text{ft}^2$$

2.1.2 Interior Girder

2.1.2.1 Span 1 & 2

$$(2)(2\cdot 19.9\text{ft} + 2\cdot 2\cdot 17.2\text{ft} + 2\cdot 2\cdot 16.2\text{ft})\cdot(16\text{in}) = 462\text{ft}^2$$

2.1.3 Exterior Girder

2.1.3.1 Span 1 & 2

$$(2)\cdot(2)(2\cdot 16.25\text{ft} + 2\cdot 11.75\text{ft} + 2\cdot 11.25\text{ft})\cdot(16\text{in}) = 419\text{ft}^2$$

2.1.4 Bent

$$(2)(2)(3.5\text{ft} + 4.0\text{ft} + 4.5\text{ft} + 5.0\text{ft})\cdot(30\text{in}) = 170\text{ft}^2$$

2.2 SHEAR REINFORCEMENT

2.2.1 Interior Girder

2.2.1.1 Span 1 & 2

$$(2)(2)(22\text{in} + 17\text{in} + 22\text{in})(4\cdot 2.9\text{ft} + 3\cdot 1.25\text{ft} + 2\cdot 4.5\text{ft} + 1\cdot 6.0\text{ft} + 1\cdot 2\cdot 1.0\text{ft}) = 658\text{ft}^2$$

2.2.2 Exterior Girder

2.2.2.1 Span 1 & 2

$$(2)(2)(2)(22\text{in} + 17\text{in} + 22\text{in})(2\cdot 1.0\text{ft} + 8.7\text{ft}) = 435\text{ft}^2$$

2.2.3 Bent

$$(2)(2)(30\text{in} + 32\text{in} + 30\text{in})(2\cdot 3\cdot 1.0\text{ft}) = 184\text{ft}^2$$

3 SRP Type-1

3.1 FLEXURAL REINFORCEMENT

3.1.1 Slab

3.1.1.1 Span 3

$$(2)\cdot(10+12)\cdot(4\text{in})\cdot(6.0\text{ft}+11\text{in}) = 101\text{ft}^2$$

3.1.2 Interior Girder

3.1.2.1 Span 3

$$(2)(17.25\text{ft}+12.25\text{ft}+9.25\text{ft})\cdot(12\text{in}) = 77\text{ft}^2$$

3.1.3 Exterior Girder

3.1.3.1 Span 3

$$(2)(2)(13.25\text{ft}\cdot 1\text{ft}+13.75\text{ft}\cdot 1\text{ft}+6.5\text{ft}\cdot 4\text{in}+7\text{ft}\cdot 4\text{in}) = 126\text{ft}^2$$

4 SRP Type-2

4.1 SHEAR REINFORCEMENT

4.1.1 Interior Girder

4.1.1.1 Span 3

$$(2)(21.5\text{in}+17\text{in}+21.5\text{in})(3\cdot 3\text{ft}+2\cdot 5.67\text{ft}+1\cdot 6.0\text{ft}+1\cdot 2\cdot 1.0\text{ft}) = 283\text{ft}^2$$

4.1.2 Exterior Girder

4.1.2.1 Span 3

$$(2)(2)(21.5\text{in}+17\text{in}+21.5\text{in})(3\text{ft}+8\cdot 1\text{ft}) = 220\text{ft}^2$$

5 SATURANT APPLICATION

5.1 FLEXURAL REINFORCEMENT

5.1.1 Slab

5.1.1.1 Spans 1 & 2

$$(2)(2)(2)\cdot(15+17)\cdot(6\text{in})\cdot(7.0\text{ft}) = 896\text{ft}^2$$

5.1.1.2 Span 3

$$(2)(2)\cdot(10+12)\cdot(4\text{in})\cdot(6.0\text{ft}+11\text{in}) = 203\text{ft}^2$$

5.1.2 Interior Girder

5.1.2.1 Spans 1 & 2

$$(2)(2)(2\cdot 19.9\text{ft}+2\cdot 17.2\text{ft}+2\cdot 16.2\text{ft})\cdot(16\text{in}) = 569\text{ft}^2$$

5.1.2.2 Spans 3

$$(2)(2)(17.25\text{ft}+12.25\text{ft}+9.25\text{ft})\cdot(12\text{in}) = 155\text{ft}^2$$

5.1.3 Exterior Girder

5.1.3.1 Spans 1 $ 2

$$(2\cdot2)(2)(2\cdot16.25ft + 11.75ft + 11.25ft)\cdot(16in) = 592ft^2$$

5.1.3.2 Span 3

$$(2)(2)(13.25ft\cdot1ft + 2\cdot13.75ft\cdot1ft + 6.5ft\cdot4in + 2\cdot7ft\cdot4in) = 190ft^2$$

5.1.4 Bent

$$(2)(2)(2\cdot5.0ft + 4.5ft + 4.0ft + 3.5ft)\cdot(30in) = 220ft^2$$

5.2 SHEAR REINFORCEMENT

5.2.1 Interior Girder

5.2.1.1 Spans 1 & 2

$$(2)(2)(22in + 17in + 22in)(5\cdot2.9ft + 4\cdot1.25ft + 3\cdot4.5ft + 2\cdot6.0ft + 2\cdot1.0ft) = 956ft^2$$

5.2.1.2 Span 3

$$(2)(21.5in + 17in + 21.5in)(4\cdot3ft + 3\cdot5.67ft + 2\cdot6.0ft + 2\cdot2\cdot1.0ft) = 450ft^2$$

5.2.2 Exterior Girder

5.2.2.1 Spans 1 & 2

$$(2\cdot2)(2)(22in + 17in + 22in)(2\cdot2\cdot1.0ft + 2\cdot8.67ft) = 868ft^2$$

5.2.2.2 Spans 3

$$(2)(2)(21.5in + 17in + 21.5in)(2\cdot8\cdot1ft + 2\cdot3ft) = 440ft^2$$

5.2.3 Bent

$$(2)(2)(30in + 32in + 30in)\cdot(3\cdot3\cdot1.0ft) = 276ft^2$$

6 PRIMER AND PUTTY APPLICATION

6.1 FLEXURAL REINFORCEMENT

6.1.1 Slab

6.1.1.1 Spans 1 & 2

$$(2)(2)\cdot(15 + 17)\cdot(6in)\cdot(7.0ft) = 448ft^2$$

6.1.1.2 Span 3

$$(2)\cdot(10 + 12)\cdot(4in)\cdot(6.0ft + 11in) = 101ft^2$$

6.1.2 Interior Girder

6.1.2.1 Span 1 & 2

$$(2)(2\cdot 19.9\text{ft})\cdot(16\text{in}) = 106\text{ft}^2$$

6.1.2.2 Span 3

$$(2)(17.25\text{ft} + 12.25\text{ft} + 9.25\text{ft})\cdot(12\text{in}) = 77\text{ft}^2$$

6.1.3 Exterior Girder

6.1.3.1 Spans 1 & 2

$$(2\cdot 2)(2\cdot 16.25\text{ft})\cdot(16\text{in}) = 173\text{ft}^2$$

6.1.3.2 Span 3

$$(2)(2)(13.25\text{ft}\cdot 1\text{ft} + 13.75\text{ft}\cdot 1\text{ft} + 6.5\text{ft}\cdot 4\text{in} + 7\text{ft}\cdot 4\text{in}) = 126\text{ft}^2$$

6.1.4 Bent

$$(2)(2\cdot 5.0\text{ft})\cdot(30\text{in}) = 50\text{ft}^2$$

6.2 SHEAR REINFORCEMENT

6.2.1 Interior Girder

6.2.1.1 Spans 1 & 2

$$(2)(2)(22\text{in} + 17\text{in} + 22\text{in})(14.7\text{ft} + 2\cdot 1.0\text{ft}) = 340\text{ft}^2$$

6.2.1.2 Spans 3

$$(2)(21.5\text{in} + 17\text{in} + 21.5\text{in})(3\text{ft} + 5.67\text{ft} + 1\cdot 6.0\text{ft} + 2\cdot 1.0\text{ft}) = 167\text{ft}^2$$

6.2.2 Exterior Girder

4.2.2.1 Spans 1 & 2

$$(2\cdot 2)(2)(22\text{in} + 17\text{in} + 22\text{in})(2\cdot 1.0\text{ft} + 8.67\text{ft}) = 434\text{ft}^2$$

6.2.2.2 Spans 3

$$(2)(2)(21.5\text{in} + 17\text{in} + 21.5\text{in})(3\text{ft} + 8\cdot 1\text{ft}) = 220\text{ft}^2$$

6.2.3 Bent

$$(2)(2)(30\text{in} + 32\text{in} + 30\text{in})\cdot(3\cdot 1.0\text{ft}) = 92\text{ft}^2$$