COMPARISON OF CONSTRUCTION COSTS BETWEEN GRS-IBS AND CONVENTIONAL BRIDGES IN OKLAHOMA

FINAL REPORT

ODOT TASK ORDER NUMBER 2160-20-05

Submitted to:

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Submitted by:

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OKLAHOMA
Transportation

May 2021

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

EXECUTIVE SUMMARY

Several pilot GRS-IBS projects have been constructed in Oklahoma over the past years (i.e. since 2014) following the FHWA's multi-year EDC initiatives, and efforts made by the ODOT Local Government division, the BIA Office in Anadarko, OK, and several counties in Oklahoma. The PI's research team has also completed ODOT-sponsored, full-scale laboratory and field studies in which GRS abutments have shown satisfactory structural performance. Meanwhile, a set of 34 GRS-IBS projects are scheduled for construction in Grant County in the near future, which is a significant advancement in the use of GRS-IBS to replace structurally deficient and functionally obsolete bridges in Oklahoma.

In this study, comparisons have been made between the cost of GRS vs. conventional bridge abutments to provide some insight into possible cost advantages that the newer GRS abutments could have in future like projects in Oklahoma. Different offices and individuals were contacted to obtain information on construction costs, and possibly, construction speed of the GRS and select conventional bridges. However, collection of cost information on both the GRS and conventional bridge alternatives proved to be significantly more challenging than had been anticipated for a variety of reasons that are discussed in this report. Additionally, except for the bridges in Kay County, no construction speed information was available on any other bridges for comparison purposes.

The cost information that was possible to collect and compile has been analyzed and presented separately for different counties where GRS abutments have been built as pilot projects. Additionally, the cost data on each bridge was itemized separately relative to its abutments and its superstructure in order to provide a reliable comparison between different choices of abutment, if both alternatives (i.e. deep foundation vs. GRS) would be equally feasible for a given project.

The latest elevation surveys of bridges in Caddo County (i.e. the GRS bridges that were built most recently) had been obtained through Mr. Scott Garland, PE. Additionally, Mr. Bryan Cooper had supplied our team with the latest photographs that showed the conditions of different GRS bridges across the state. The above information indicated that all GRS bridges have been performing well with no report of any structural problems to date.

Results of this study show that construction costs of the few GRS bridges that have been constructed in Oklahoma, have been overall either comparable to, or less than those of conventional bridges of comparable size. Additionally, bundling of projects and increased experience with GRS abutment construction by contractors and local forces throughout the state could improve their cost advantages over conventional alternatives. Among major advantages of GRS abutments over conventional alternatives are that they can help eliminate the bump-at-the-end-of-the-bridge problem, and their construction requires equipment that is commonly available to many contractors and local forces. Therefore, more widespread familiarity with their construction technique can lead to a larger pool of potential contractors and local forces for their construction, resulting in lower costs, especially for smaller bridge abutments.

During the course of this study, it was observed that there is a paucity of well-documented, cost and construction speed information on both the GRS and conventional bridges on local roads in different counties. Developing a centralized system to record and maintain such data would provide a valuable reference database for different stakeholders, which can help ensure more cost-effective bridge projects across the state in the future. This is an area that this research team can help with, and would be worth considering in the continuation of this study.

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1. INTRODUCTION

In this study, cost data and other related information (size, location, etc.) on the existing and ongoing GRS-IBS projects were gathered and compiled in order to compare against those on select conventional bridges in Oklahoma as much as it was found available from different parties, as explained in this report.

Different offices and individuals were contacted for information on GRS- and conventional-abutment bridges relative to their cost and construction speed, per the objective of the study. This included ODOT Local Government, Bridge and Construction Divisions, the BIA, contractors, County Commissioners, and engineers at several Field District Offices (i.e. those in Districts 1, 3, 4 and 7, corresponding to the existing GRS bridge locations). However, obtaining such information turned out to be much more challenging than we had anticipated due to various reasons. For instance, the information had not been necessarily recorded and archived completely, or kept in one central place for future access. There have been changes in personnel and in office locations, and even occurrences of office damage, which made access to such data even more challenging. Some county commissioners who were closely involved with the construction of GRS bridges in their counties were no longer in office. Even some GRS bridge contractors were no longer in business. Pandemic-related challenges had also exacerbated the situation and made access to any construction records more complicated.

It was ultimately possible to gather cost data on most of the GRS bridges and a few conventional bridges for comparison purposes, as presented in this report. However, little information could be found on their construction speed that could lead to any meaningful comparisons between these alternative construction techniques. Evidently, this is because these local bridges are either built e.g., using county forces for whom logging the details of a bridge construction time/speed may not serve any particular purpose, or by contractors who may be involved with several construction projects at a time, and therefore, recording the construction time of any particular local bridge at hand would not be practical or purposeful either.

As a starting point, we reached out to Mr. Walt Peters, PE at the ODOT Bridge Division and received a list of conventional bridges that included information such as their location (county and geographical coordinates), identifying numbers and construction year, among others. **Figure 1** shows a snapshot of such information in tabulated form. In communications with Mr. Bryan Cooper (LTAP Manager), we received the geographical coordinates of the existing GRS bridges in Oklahoma in addition to snapshots of their existing conditions, which indicated that they were all in good operating conditions. Mr. Tom Simpson, PE (BIA) was instrumental in providing construction cost data on several GRS and conventional bridges in Caddo, Kay and Lincoln Counties.

Figure 2 shows a map indicating the locations of existing GRS bridges in Oklahoma (in orange) and possible conventional bridges that we had originally identified for comparison purposes (in blue). **Table 1** shows the locations of existing GRS-IBS projects in Oklahoma based on the information provided by Mr. Tom Simpson and Mr. Bryan Cooper. Cost-related data that were sought and collected on GRS and conventional bridges in different counties are described separately in the following sections. The only exceptions are the single GRS bridges in Haskell and Ottawa counties for which cost information was not available during the period of this project. On the other hand, a significant amount of information was obtained on the upcoming GRS bridges in Grant County, which is discussed in a separate section as well. In this report, the terms GRS-IBS, GRS-abutment bridges and GRS bridges are used interchangeably.

Layout: L11 Year Built, Etc.

NBI No.	Structure No.	Local No.	Status	District	County	Facility Carried	Year Built	Year Reconst.	Year Load Rated	Year Overlayed	Year Painted
000010000000000	37N2860E0770007	231	I	04	KINGFISHER	N2860	1932	1975	7/16/2018 12:00:00 AM		1932
000020000000000	61N4075E1442000	025-MC	I	02	PITTSBURG	N4075 (7 ST.)	1946		10/14/2013 12:00:00 AM	9/27/2005 12:00:00 AM	
000040000000000	05E1160N2020008	2	I	05	BECKHAM	E1160	1989	-1	7/3/2012 12:00:00 AM	1/1/1901 12:00:00 AM	-1
000060000000000	45E2080N4430003	041A 3	I	02	MCCURTAIN	E2080	1900	1960	6/14/2019 12:00:00 AM	1/1/1901 12:00:00 AM	2019
000080000000000	25E1580N3200009	095 2	I	03	GARVIN	E1580	1990	0	6/14/2016 12:00:00 AM	5/11/2010 12:00:00 AM	-1
000100000000000	52N3150E0360003	121	I	04	NOBLE	N3150	1990	-1	8/24/2016 12:00:00 AM	1/1/1901 12:00:00 AM	1990
000130000000000	56N4080E0910008	109 02	I	01	OKMULGEE	N4080	1989	-1	11/5/2014 12:00:00 AM	1/1/1901 12:00:00 AM	
000140000000000	25N3330E1570003	254 3	I	03	GARVIN	N3330	1989	0	3/12/2004 12:00:00 AM	1/1/1901 12:00:00 AM	-1
000150000000000	62E1520N3530009	031-D2	I	03	PONTOTOC	6214C	1990	-1	2/10/2011 12:00:00 AM	1/1/1901 12:00:00 AM	-1
000240000000000	24E0360N3080007	075	I	04	GARFIELD	E0360	1904	-1	12/13/2004 12:00:00 AM	1/1/1901 12:00:00 AM	-1
000280000000000	05E1250N1700001	3	I	05	BECKHAM	E1250	1905		7/10/2014 12:00:00 AM	5/22/2014 12:00:00 AM	-1
000320000000000	63N3410E1180003	033	I	03	POTTAWATOMIE	RANGELINE RD.	1917	-1	11/11/2010 12:00:00 AM	1/1/1901 12:00:00 AM	-1
000390000000000	24N2950E0570006	341	I	04	GARFIELD	N2950	1905	-1	3/12/2019 12:00:00 AM	1/1/1901 12:00:00 AM	9201
000420000000000	51E0871N4290000	11 M	I	01	MUSKOGEE	FAU 6784 CALLAHAN	1905	2005	11/11/2016 12:00:00 AM	1/1/1901 12:00:00 AM	2001
000440000000000	07N3651E2198000	081C 2	I	02	BRYAN	N3651 (0716C)	1906	-1	7/12/2016 12:00:00 AM	1/1/1901 12:00:00 AM	-1
000470000000000	24N2960E0520005	346	I	04	GARFIELD	N2960	1906	-1	10/21/1996 12:00:00 AM	1/1/1901 12:00:00 AM	0601
000550000000000	16E1590N2700008	1059	I	07	COMANCHE	IRR E1590	1906		1/19/2010 12:00:00 AM	1/1/1906 12:00:00 AM	
000590000000000	07N3651E2197000	081B 2	I	02	BRYAN	UP R.R.	1908		1/1/1901 12:00:00 AM	1/1/1901 12:00:00 AM	-1
000600000000000	16E1570N2710001	1047	I	07	COMANCHE	E1570	1906	-1	3/30/2010 12:00:00 AM	1/1/1906 12:00:00 AM	
000680000000000	16E1579N2510005	3048A	I	07	COMANCHE	E1579 (CITY ST.)	1906		11/25/2019 12:00:00 AM	1/1/1901 12:00:00 AM	1906
000700000000000	63D3342E1446000	001-D2	I	03	POTTAWATOMIE	D3342 (6374C)	1906	1993	1/6/2010 12:00:00 AM	1/5/2010 12:00:00 AM	
000740000000000	41E0760N3420003	020-D1	I	03	LINCOLN	E0760	1907		1/5/1998 12:00:00 AM	1/1/1901 12:00:00 AM	0701

BrM_Grid_Export (9)

Figure 1. Tabulated information on local bridges in Oklahoma
(Courtesy of Mr. Walt Peters, PE)

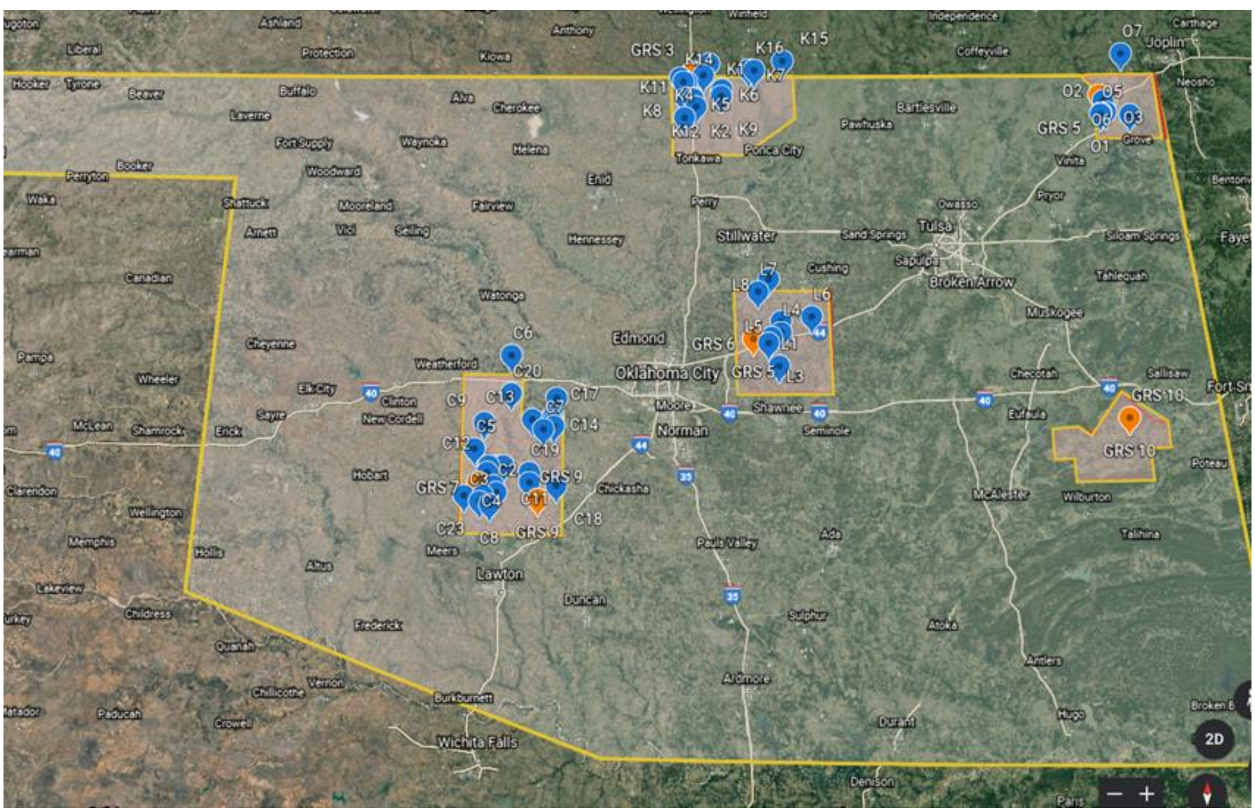
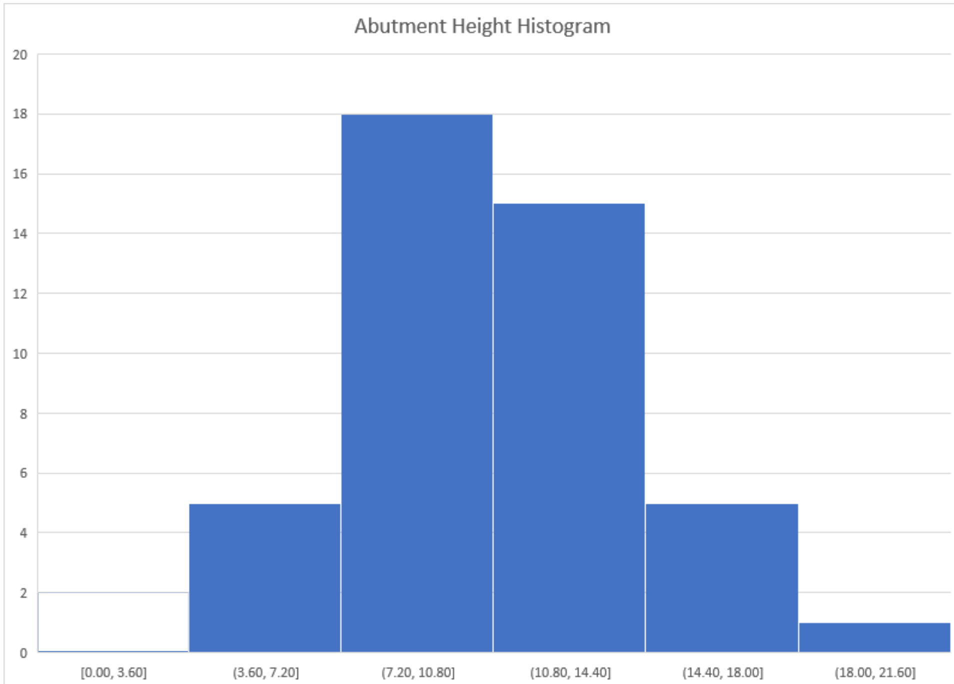


Figure 2. Map of GRS-abutment bridge locations in Oklahoma together with those of candidate conventional bridges for cost comparison purposes

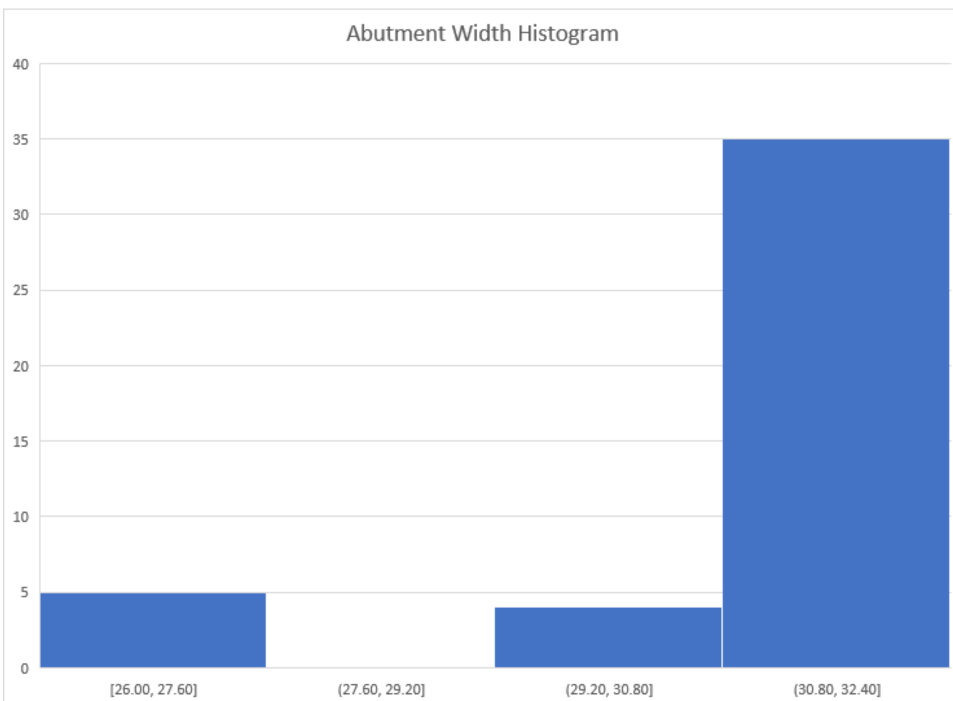
Table 1. Inventory of GRS-abutment bridges in Oklahoma

Bridge No.	County	Location/Vicinity	Geographical Coordinates	Notes
1	Ottawa	EW-160 Road, .18 Mi. West of NS-510 Road	$36^0$47′12.06″ N 94^0 57′59.77″ W	CMU facing
2	Kay	NS-3180 Road / 44th Street, North of Blackwell, South of Braman	36^0 54′ 50.56″ N 97^0 20′ 12.83″ W	CMU facing
3			36^0 54′ 44.02″ N 97^0 20′ 12.81″ W	Sheet pile facing
4			36^0 54′ 21.38″ N 97^0 20′ 12.64″ W	Sheet pile facing
5			36^0 54′ 13.29″ N 97^0 20′ 12.58″ W	CMU facing
6	Lincoln	EW-9960 Road, 2.57 Mi. West of US-177, 3.97 Mi. South of SH-66	35^0 37′ 22.93″ N 97^0 02′ 44.11″ W	Largest GRS abutments in OK
7	Caddo	EW-1400 Road over East Cache Creek, 4.4 Mi. East of SH-58	34^0 59′ 08.10″ N 98^0 31′ 30.74″ W	CMU facing
8		EW-1350 Road over Two Hatchet Creek, .75 Mi. West of SH-9	35^0 03′ 29.30″ N 98^0 25′ 04.47″ W	CMU facing
9		EW-1450 Road, .63 Mi. West of SH-8	34^0 54′ 47.01″ N 98^0 12′ 34.38″ W	Large-Block facing
10	Haskell	EW-1220 Road, 1.0 Mi. South of SH-9, 5.0 Mi. East of Stigler	35^0 14′ 46.58″ N 95^0 01′ 59.70″ W	CMU facing

Figure 3 shows histograms of abutment height and width for the GRS-abutment bridges built, or planned for construction, in different Oklahoma counties to date. Data in these figures show that the vast majority of the bridge abutment heights (i.e. 75%) is within the 7-14 ft range. Germane to their width, all existing GRA abutments in Kay and Caddo counties are 30′-wide or narrower, whereas the upcoming Grant County bridges are all designed with 30±2 ft-wide abutments.



(a)



(b)

Figure 3. Histograms of GRS Bridges in Oklahoma relative to: (a) abutment height in ft. (b) bridge width in ft. (vertical axis: number of occurrences)

2. CADDO COUNTY

Despite several challenges that were mentioned in the previous section, Caddo County offices (Districts 2 and 3) courteously made attempts to search for construction information on GRS and comparable conventional bridges. The staff at the District 2 office were able to find documents on two GRS bridges that were analyzed as shown in **Fig. 4**, which indicates that bid prices from different contractors can vary significantly. An important factor could be the familiarity of the contractor with the GRS-IBS construction guidelines and requirements. In the particular example shown in **Fig. 4**, Contractor A had built several GRS bridges in different counties in Oklahoma, which seems to have helped this contractor submit significantly lower bids for the two GRS-IBS projects in Caddo County. The importance of familiarity with the GRS construction process, and how it could result in cost-effective and rapid construction practice is also discussed later in this report on field-scale model construction and testing at OU. Additional related discussion can also be found in a recent FHWA publication (Nicks 2019).

Fig. 5 shows example list of candidate conventional bridges in different counties (in this case, Caddo County) that were communicated to different offices to obtain construction cost information and compare with the corresponding data on GRS bridges. A map showing the locations of these bridges is given in **Fig. 6**. We ultimately were able to receive cost data on only two conventional bridges in Caddo County from Mr. Tom Simpson that could be used for direct comparison of abutment alternatives. The data on a couple of other conventional bridges were available in the form of total costs only (as opposed to separately on abutments). Cost information on two other conventional bridges in Kay County was also available, which was used for a broader comparison of the abutment types relative to their costs. The costs of the two conventional bridges in Kay County were practically the same and equal to $60,000 (see **Section 4**).

Abutment type	GRS-IBS	NBI	
Structure No.	08E1400N2500004	32146	
Height (ft)	10		
Span Legth (ft)	70		
Width	27.2		
Superstructure type	STEEL I-BEAM SPAN		
ADT-2015	50		
ADT-2035	0		
V	0		

Summary		
Plan Area of Superstructure	1,904.00	ft^2
Cost of superstructure per ft^2	$117.03	$/ft^2
Cost of abutment per LF of height		$/LF
Cost of abutment per LF of height	-	$/LF

				Bid A		Bid B		Bid C		
Item No	Description	Units	Qty	Unit Price	Total	Unit Price	Total	Unit Price	Total	
501(A) 1307	Substructure Excavation Comon	CY	1000	$20.00	$20,000.00	$10.00	$10,000.00	$14.00	$14,000.00	
506(A) 1322	Structural steel	LB	69,822.00	$1.30	$90,768.60	$2.00	$139,644.00	$2.40	$167,572.80	
509(A) 1326	Class AA Concrete	CY	50	$225.00	$11,250.00	$400.00	$20,000.00	$600.00	$30,000.00	
511(A) 1332	Reinforcing Steel	LB	9,663.00	$0.90	$8,696.70	$1.00	$9,663.00	$2.50	$24,157.50	
602(A) 1351	Type I-A Plain Riprap	TON	265	$35.00	$9,275.00	$50.00	$13,250.00	$80.00	$21,200.00	
880() 8905	Construction Traffic Control	LSUM	1	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$10,000.00	$10,000.00	
SP	W-Beam Guard Rail	LF	400	$11.00	$4,400.00	$20.00	$8,000.00	$20.00	$8,000.00	Abutment Costs
SP	Geosynthetic Reinforcement	SY	3490	$5.00	$17,450.00	$1.25	$4,362.50	$6.00	$20,940.00	
SP	CMU Block-Hollow	EA	2075	$6.00	$12,450.00	$20.00	$41,500.00	$25.00	$51,875.00	
SP	CMU Block-Solid	EA	670	$8.00	$5,360.00	$20.00	$13,400.00	$26.00	$17,420.00	
SP	GRS Backfill	CY	835	$35.00	$29,225.00	$70.00	$58,450.00	$70.00	$58,450.00	
SP	RSF Backfill	CY	155	$30.00	$4,650.00	$70.00	$10,850.00	$110.00	$17,050.00	
SP	Foam Board (4" Thick)	SF	36	$12.00	$432.00	$50.00	$1,800.00	$10.00	$360.00	
SP	Road Base Aggregate	CY	130	$45.00	$5,850.00	$76.00	$9,880.00	$95.00	$12,350.00	
SP	Concrete Block Wall Fill	CY	4.5	$225.00	$1,012.50	$800.00	$3,600.00	$200.00	$900.00	
SP										
				Abutment	$180,873.10	Abutment	$304,736.50	Abutment	$376,117.80	
				Total	$222,819.80	Total	$346,399.50	Total	$454,275.30	

Abutment type	GRS-IBS
Structure No.	08E1350N2560006
Height (ft)	10
Span Legth (ft)	55.4
Width	27.5
Superstructure type	48FT I BEAM SPAN WITH CONCRETE DECK
ADT-2015	50
ADT-2035	0
V	0

Summary		
Plan Area of Superstructure	1,523.50	ft^2
Cost of superstructure per ft^2	$101.55	$/ft^2
Cost of abutment per LF of height		$/LF
Cost of abutment per LF of height	-	$/LF

				Bid A		Bid B		Bid C		
Item No	Description	Units	Qty	Unit Price	Total	Unit Price	Total	Unit Price	Total	
501(A) 1307	Substructure Excavation Comon	CY	1260	$20.00	$25,200.00	$10.00	$12,600.00	$14.00	$17,640.00	
506(A) 1322	Structural steel	LB	43,985.00	$1.30	$57,180.50	$2.00	$87,970.00	$2.40	$105,564.00	
509(A) 1326	Class AA Concrete	CY	37	$350.00	$12,950.00	$400.00	$14,800.00	$600.00	$22,200.00	
511(A) 1332	Reinforcing Steel	LB	7,633.00	$0.90	$6,869.70	$1.00	$7,633.00	$2.50	$19,082.50	
602(A) 1351	Type I-A Plain Riprap	TON	280	$35.00	$9,800.00	$50.00	$14,000.00	$80.00	$22,400.00	
880() 8905	Construction Traffic Control	LSUM	1	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$10,000.00	$10,000.00	
SP	W-Beam Guard Rail	LF	375	$11.00	$4,125.00	$20.00	$7,500.00	$20.00	$7,500.00	Abutment Costs
SP	Geosynthetic Reinforcement	SY	4725	$3.25	$15,356.25	$1.25	$5,906.25	$6.00	$28,350.00	
SP	CMU Block-Hollow	EA	2675	$6.00	$16,050.00	$20.00	$53,500.00	$25.00	$66,875.00	
SP	CMU Block-Solid	EA	700	$8.00	$5,600.00	$20.00	$14,000.00	$26.00	$18,200.00	
SP	GRS Backfill	CY	1140	$30.00	$34,200.00	$70.00	$79,800.00	$70.00	$79,800.00	
SP	RSF Backfill	CY	215	$30.00	$6,450.00	$70.00	$15,050.00	$110.00	$23,650.00	
SP	Foam Board (4" Thick)	SF	36	$12.00	$432.00	$50.00	$1,800.00	$10.00	$360.00	
SP	Road Base Aggregate	CY	150	$30.00	$4,500.00	$76.00	$11,400.00	$95.00	$14,250.00	
SP	Concrete Block Wall Fill	CY	4.5	$225.00	$1,012.50	$800.00	$3,600.00	$200.00	$900.00	
				Abutment	$154,706.25	Abutment	$294,526.25	Abutment	$367,849.00	
				Total	$201,725.95	Total	$331,559.25	Total	$436,771.50	

Figure 4. Bid prices for two GRS-IBS projects in Caddo County based on data provided by Ms. Andrea Wall (Office of the Caddo County Commissioner, District 2)

Figure 7 shows cost comparisons between GRS bridges in Caddo County and the said conventional bridges. The cost data are plotted both as a function of the abutment height and facing area, which has also been used as a parameter in cost comparison studies (e.g. Nicks 2019). Data in **Fig. 7** indicate that GRS bridge costs are somewhat higher (i.e. up to 11%) than those of conventional bridges of the same height or facing area for the cases examined. This could be attributed to the fact that the GRS-IBS is a newer construction technology and as a result, contractors and county forces are not as familiar with them as they are with conventional bridges, which in comparison, have been built routinely across the state for several decades.

GRS 7:

NBI	Bridge #
26799	C1
32147	C2
30072	C3
30128	C4
32143	C5

GRS 8:

NBI	Bridge #
30816	C6
26464	C7
26972	C8
26996	C9
26997	C10
27663	C11
32145	C12

GRS 9:

NBI	Bridge #
27623	C13
27783	C14
27918	C15
29424	C16
29024	C17
29025	C18
26935	C19
28841	C20
29316	C21
29655	C22
26971	C23

Figure 5. Candidate conventional bridges identified for cost comparisons with GRS bridges in Caddo County (Table 1)

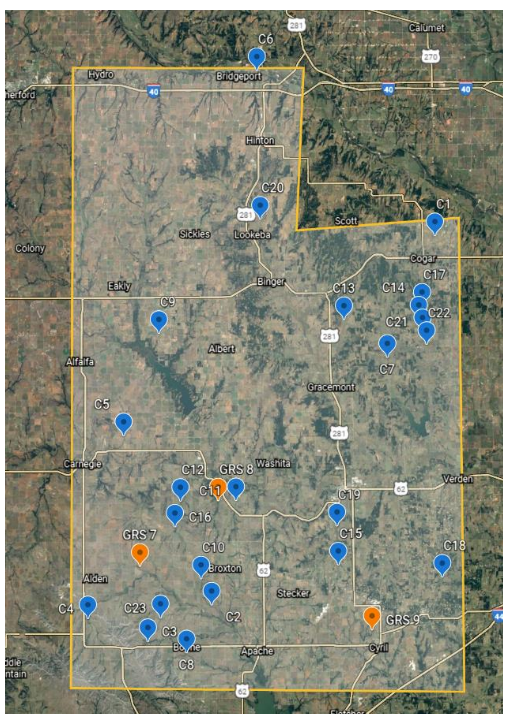
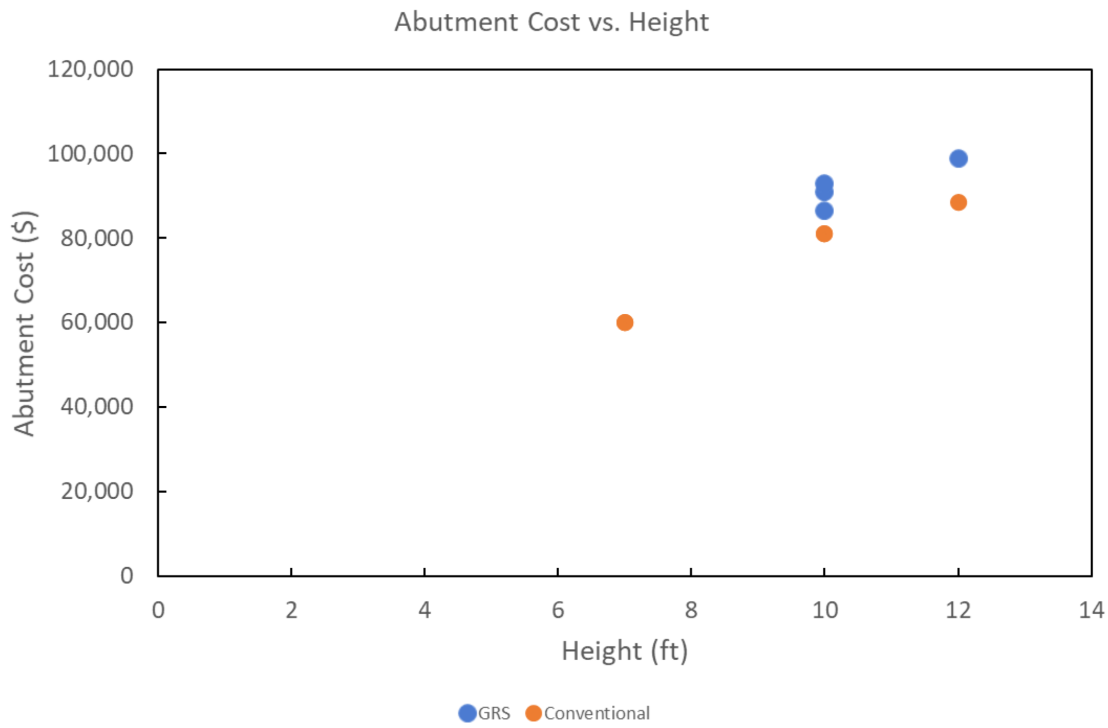


Figure 6. Map of GRS bridge locations in Caddo County (orange) together with those of candidate conventional bridges (blue) for comparison purposes



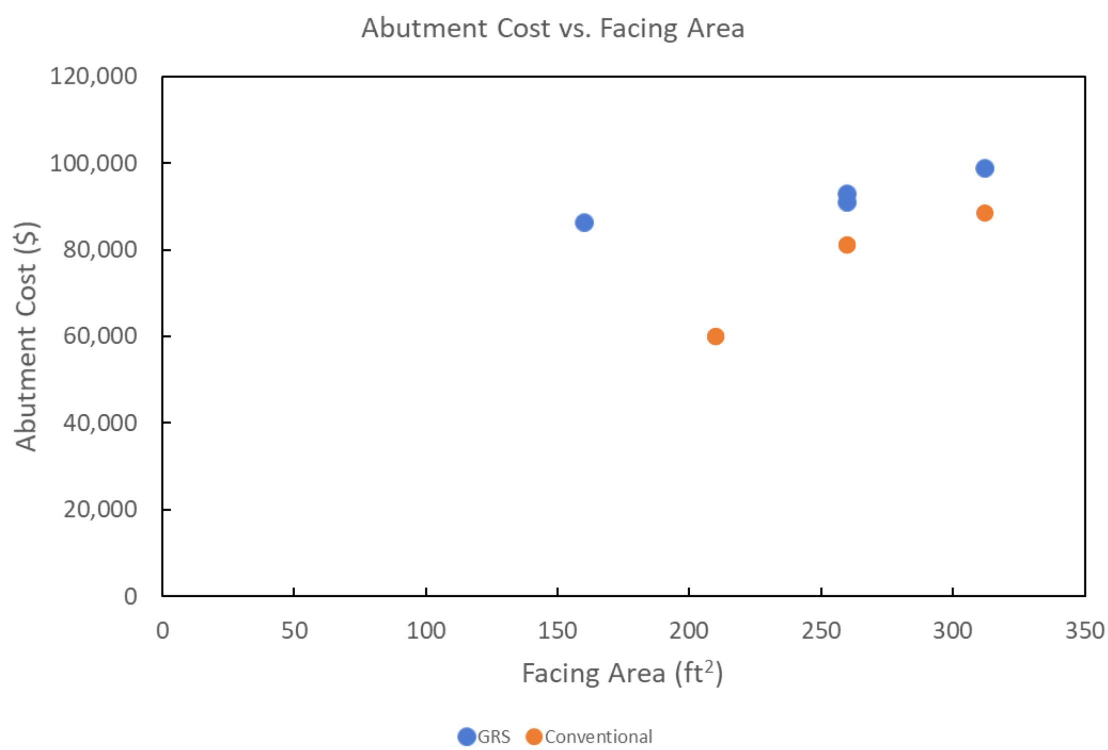


Figure 7. Comparison of abutment costs between GRS bridges in Caddo County and conventional bridges (with available cost data) as a function of abutment height and facing area

3. GRANT COUNTY

In 2019, ODOT was awarded a total of $3.47 million to help replace 34 bridges in Grant County through the Competitive Highway Bridge Program (CHBP). The project requirements included innovative technology, financing, and project delivery aspects (Williams 2019). The innovative technology aspect of the project included precast concrete beams that included prestressed elements. Innovative financing included securing funding from different stakeholders as shown in **Table 2**. Innovative project delivery included a unified set of plans and standardized designs for a bundle of 34 bridges, which helped reduce the workload and make the entire project cost effective through the economy of scale. It also involved a streamlined environmental study and approval process (**Table 3**; Williams 2019).

Table 2. Different sources of funding for the upcoming GRS bridges in Grant County (Williams 2019)

CIRB/STP	County	ODOT	CHBP Grant
$2,751,000	$720,000	$2,038,800	$3,468,000

Table 3. Timeline of GRS bridges in Grant County (Williams 2019)

Survey	March 2020
Hydraulics	May 2020
Environmental	TBD
PS&E	May 2021
Federal Authorization - Bid Letting	August 2021

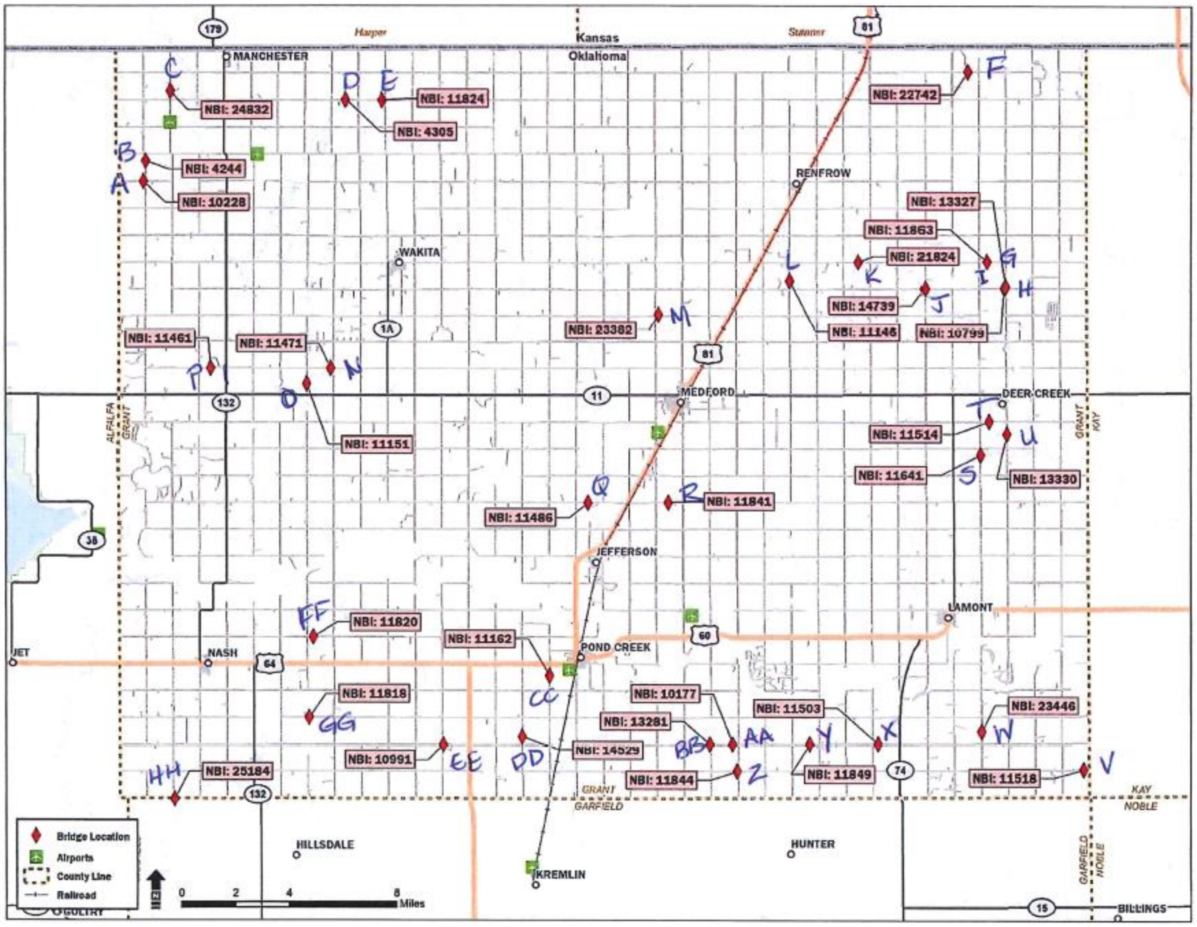


Figure 8. Location map of bridges in Grant County that will be replaced with GRS-IBS (from Ms. Shelly Williams, PE)

The GRS-abutment bridges in Grant County are expected to reduce the structurally deficient bridges in the county by 20%, boost the local economy, and improve traffic safety for the local communities (Williams 2019). A map of different GRS bridge locations across the county is shown in **Fig. 8**, and example bridges that are slated for replacement with GRS-IBS are shown in **Fig. 9**.

Figure 10 shows cost estimates for bundled GRS-IBS projects in Grant County as provided by Ms. Shelly Williams, PE. Data in **Fig. 10** indicate that the estimated cost of these GRS abutments, regardless of their bridge span, is ~$71K, which is significantly lower than the bid amounts in **Fig. 4**. Comparison of data in **Figs. 4 and 9** indicates that bundling of GRS-IBS construction, as has been adopted by ODOT for Grant County projects, could indeed lead to significant cost savings relative to the occasional and case-based construction of these bridges.

Figure 9. Example bridges/crossings in Grant County that will be replaced with GRS-IBS

Meanwhile, the large number of GRS projects that are planned in Grant County provides an opportunity to explore the possible benefit of developing correlations between select attributes of GRS bridges (e.g. bridge span or plan area, abutment height, etc.) and the anticipated construction costs in a future study. For instance, **Fig. 11** shows a comparison between estimated costs based on actual contractor's bid amounts on one of the GRS bridges in Caddo County, and estimated amounts (90% AWP) directly reported for one of the GRS bridges in Grant County (labeled as A-A in **Fig. 8**). The bid amounts on the Caddo County GRS bridge were prorated based on the difference between the sizes of plan areas of the two bridges.

LENGTH		ITEM	Unit	Total	Unit $	Estimated Cost
Span (ft)	Beam (ft)	Substructure Excavation Common	CY	346	$ 22.00	$ 7,612.00
30	37.17	Aggregate Base Type A	CY	385	$ 65.00	$ 25,025.00
		Geosynthetic Reinforcement	SY	1600	$ 4.00	$ 6,400.00
		Type 1-A Plain Rip Rap	TONS	128	$ 55.00	$ 7,040.00
		Filter Fabric	SY	125	$ 3.00	$ 375.00
		Precast Concrete Block (8" x 12" x 18")	EA	616	$ 40.00	$ 24,640.00
		Prestressed Concrete Beam	LF	**260.19**	$ 230.00	$ 59,843.70
		Structural Steel	LB	265	$ 5.00	$ 1,325.00
		Bridge Traffic Rail	LF	**74.34**	$ 35.00	$ 2,601.90
		Sub-Total Bridge Estimate				***$ 134,862.60***
		Traffic Estimate		1	$ 1,500.00	$ 1,500.00
		Staking	LSUM	1	$ 1,500.00	$ 1,500.00
		Mobilization	LSUM	1	$ 16,000.00	$ 16,000.00
		Total Estimate				***$ 152,362.60***

LENGTH		ITEM	Unit	Total	Unit $	Estimated Cost
Span (ft)	Beam (ft)	Substructure Excavation Common	CY	346	$ 22.00	$ 7,612.00
40	47.17	Aggregate Base Type A	CY	385	$ 65.00	$ 25,025.00
		Geosynthetic Reinforcement	SY	1600	$ 4.00	$ 6,400.00
		Type 1-A Plain Rip Rap	TONS	128	$ 55.00	$ 7,040.00
		Filter Fabric	SY	125	$ 3.00	$ 375.00
		Precast Concrete Block (8" x 12" x 18")	EA	616	$ 40.00	$ 24,640.00
		Prestressed Concrete Beam	LF	**330.19**	$ 230.00	$ 75,943.70
		Structural Steel	LB	265	$ 5.00	$ 1,325.00
		Bridge Traffic Rail	LF	**94.34**	$ 50.00	$ 4,717.00
		Sub-Total Bridge Estimate				***$ 153,077.70***
		Traffic Estimate		1	$ 1,500.00	$ 1,500.00
		Staking	LSUM	1	$ 1,500.00	$ 1,500.00
		Mobilization	LSUM	1	$ 16,000.00	$ 16,000.00
		Total Estimate				***$ 170,577.70***

Figure 10. Cost estimates for bundled GRS-IBS projects in Grant County (Courtesy of Ms. Shelly Williams, PE)

Results in **Fig. 11** show a good agreement between the two estimated amounts relative to the overall abutment cost (i.e. $69,028.00 vs. $70,385.00). They also indicate that the estimated total cost of $183,263.60 (i.e. prorated cost of the Caddo County bridge) is within the ballpark of the two estimates directly obtained on the Grant County bridge (i.e. $167,734.00 and $204,095.25) after cost adjustments were made for the actual type of the superstructure used (e.g. steel vs. prestressed concrete beams).

			Estimated from Caddo 7 (GRS)		
Item No	Description	Units	Qty	Unit Price	Total
501(A) 1307	Substructure Excavation Comon	CY	739	$20.00	$14,780.00
506(A) 1322	Structural steel	LB	51,623.00	$1.30	$67,109.90
509(A) 1326	Class AA Concrete	CY	37	$350.00	$12,950.00
511(A) 1332	Reinforcing Steel	LB	7,144.00	$0.90	$6,429.60
602(A) 1351	Type I-A Plain Riprap	TON	196	$35.00	$6,860.00
880() 8905	Construction Traffic Control	LSUM	1	$1,000.00	$1,000.00
SP	W-Beam Guard Rail	LF	296	$11.00	$3,256.00
SP	Geosynthetic Reinforcement	SY	2580	$3.25	$8,385.00
SP	CMU Block-Hollow	EA	1534	$6.00	$9,204.00
SP	CMU Block-Solid	EA	495	$8.00	$3,960.00
SP	GRS Backfill	CY	617	$30.00	$18,510.00
SP	RSF Backfill	CY	115	$30.00	$3,450.00
SP	Foam Board (4" Thick)	SF	27	$12.00	$324.00
SP	Road Base Aggregate	CY	96	$30.00	$2,880.00
SP	Concrete Block Wall Fill	CY	3	$225.00	$675.00
				Abutment	**$69,028.00**
				Total	$159,773.50
			Adjusted for superstructure type		**$183,263.60**

Estimated abutment cost for A-A Bridge in Grant County		
Source 1: File '90% AWP Estimate 34557(04) for 34 Bridges + 4 Extra.pdf'		
AGGREGATE BASE TYPE A	$38,475.00	
GEOTEXTILE REINFORCEMENT	$13,840.00	
SUBSTRUCTURE EXCAVATION COMMON	$2,500.00	
TYPE I-A PLAIN RIPRAP	$14,400.00	
FILTER FABRIC (RIPRAP)	$1,170.00	
Total Abutment	**$70,385.00**	<-- Source 1: File '90% AWP Estimate 34557(04) for 34 Bridges + 4 Extra.pdf'
Total Bridge (Source 1):	**$204,095.25**	<-- Source 1: File '90% AWP Estimate 34557(04) for 34 Bridges + 4 Extra.pdf'
Total Bridge (Source 2) - Adjusted for superstructure type:		
	$167,734.00	<-- Source 2: File 'CHBP ConstEst_30ft_40ft_2020-02-12.pdf' (Adjusted)
		Original estimate: $153,078

Figure 11. Comparison between estimated costs of Bridge A-A in Grant County using different sources

It is understood that the accuracy of such estimates can depend on a wide range of variables including abutment height, bridge span, site conditions, bundled vs. unbundled estimates (i.e. economy of scale) and construction-related factors. However, correlations developed using larger databases could serve as a preliminary cost-estimate and decision-making tool for interested parties in similar projects in the future. For instance, if both a conventional and a GRS-abutment bridge alternative are determined to be equally feasible for a given site, these correlation-based cost estimates could shed some light on possible cost-differences that would be anticipated between the two systems. **Table 4** shows a summary comparison of selected GRS and conventional bridges in several other states based on various sources. Results show that cost-savings between 16%-63% have indeed been achieved.

The '90% AWP estimate' cost data on GRS bridges from Ms. Melissa Davis (Grant County project manager) was further analyzed as shown in **Fig. 12**, which indicates an interesting trend with the abutment height and facing. Results in **Fig. 12** show that:

1. Estimated abutment costs for Grant County bridges indicate a clear and consistent dependence on abutment height. They also show a very good agreement with the actual costs of GRS bridges of comparable height in Lincoln County (1 bridge) and Kay County (4 bridges). The design widths of Grant County bridges varied within a fairly narrow range of 30±2 ft and therefore, bridge width was considered a distant secondary variable in this analysis. Another cost datapoint from a GRS bridge project in Missouri is also provided for comparison purposes (LCBH Solutions 2018), which shows very good agreement with other datapoints.
2. For abutment heights of up to 12 ft, abutment cost effectively increases linearly (i.e. proportionally) with height. However, the cost starts to increase at a higher rate for taller abutments. This observation confirms our expectation that the cost-effectiveness of GRS abutments relative to conventional abutments could diminish in the case of taller abutments. The use of large-block-facing abutments could help speed up abutment construction to some extent, leading to some cost savings in such cases (Hatami *et al.* 2020, Redi-Rock 2020 - **Fig. 13**). However, it would require local availability of approved large blocks and experienced contractors, and

therefore, confirmation of such savings awaits additional large-bock abutment construction projects in the future.

Table 4. Cost comparisons between GRS and conventional bridges in several other states

Cost Item Reported	GRS-IBS Alternative	Conventional Alternative	Savings	% Savings
FL – Blackrock Road Bridge				
Total Cost	$512,009	$612,009	$100,000	16%
OH -Bowman Road Bridge (GRS vs. Pile Cap Abutment)				
Superstructure	$95,000	$105,000	$10,000	10%
Abutment	$171,000	$233,000	$62,000	27%
Total cost	$266,000	$338,000	$72,000	21%
PA – Mount Pleasant Road Bridge (GRS vs. Precast Box Culvert)				
Abutment	$40,000	$56,000	$16,000	40%
Total cost	$101,893	$150,000	$48,000	32%
LA – Cutoff Creek, Cecil Creek, Big Lake 2 Bridges (GRS vs. Pile Support)				
Total cost	NR	NR	NR	40%
MA – Route 7A over Housatonic RR (GRS vs. Micropile support)				
Total cost	$1,163,000	$2,299,000	$1,136,000	49%
NM – White Swan Bridge				
Labor	$52,897	$105,000	$52,897	50%
Total cost	$419,331	$1,000,000	$580,669	58%
IA – Olympic Ave & 250th Street Bridge				
Total cost	$49,000	$105,000-$130,000	$56,000-$81,000	53-62%
NY – CR12 Project Bridge				
Material	$160,000	$300,000	$140,000	47%
Labor	$50,000	$150,000	$100,000	67%
Equipment	$30,000	$200,000	$170,000	85%
Total cost	$240,000	$650,000	$410,000	63%
NY – CR38 over Plum Brook Bridge				
Superstructure	$95,000	$180,000	$85,000	47%
Abutment	$65,000	$125,000	$60,000	48%
Total cost	$308,000	$453,000	$145,000	32%
Range of Savings in Total Bridge Cost: 16-63%				

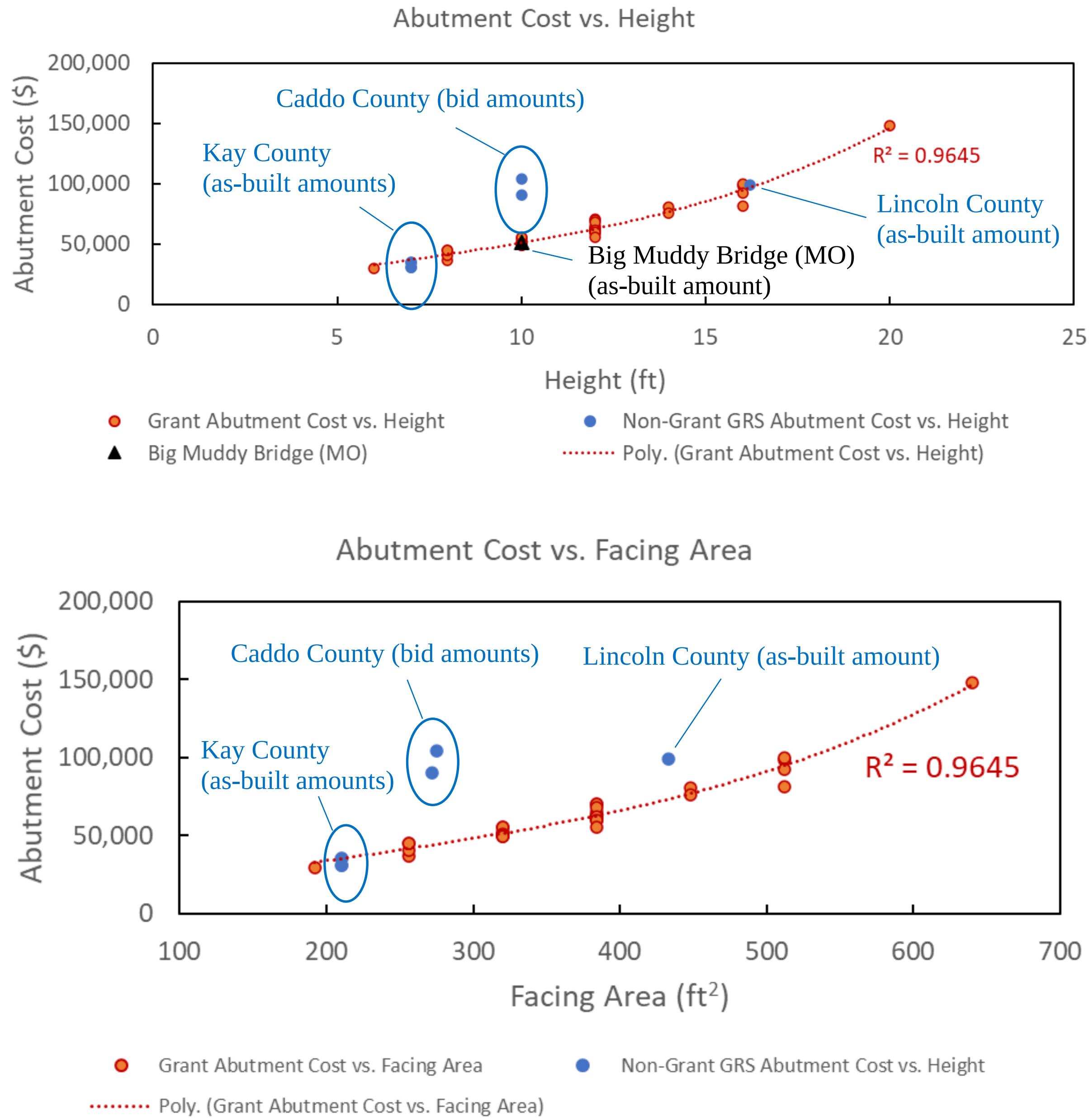


Figure 12. Cost estimates for Grant County GRS bridges (abutment cost only) as compared to the cost data available on GRS bridges in other counties as a function of (a) abutment height, (b) abutment facing

Furthermore, the sheer volume of tall GRS abutments requiring significant amounts of select aggregate, reinforcement material and labor could erode their otherwise, demonstrated cost advantages to some extent for very tall bridge abutments.

3. Results in **Fig. 12** could be considered as preliminary guidance to estimate the possible cost of GRS abutments in an Oklahoma county relative to comparable conventional abutments. However, further improvement in the accuracy and reliability of the results in **Fig. 12** awaits additional cost data on similar projects in the future.

   Furthermore, the accuracy of cost estimates can highly depend on several other factors such as: site conditions and scale of excavations necessary for the abutments, any stream or traffic rerouting provisions required, source and availability of materials (i.e. fill aggregate, reinforcement and blocks), construction of the bridge by local force vs. contractors, and familiarity of the construction crew with GRS abutment construction techniques, among others. Therefore, results of the type shown in **Fig. 12** should be used with caution and having these limitations in mind.
4. The bid amounts obtained from the Caddo County District 2 office (**Fig. 4**) are higher than the predicted amounts based on other projects in **Fig. 12**. We sought to obtain the as-built costs of these GRS bridges to determine if such difference indeed existed with as-built values. However, such information has not become available as of the date of this report.

   An example case study for a significantly higher contractor bid amount than the actual project cost (and the engineer’s estimate) is provided in **Fig. 14** (highlighted in yellow), which also shows significant cost savings on the actual cost of a GRS-IBS ($137/sqft deck area) relative to a typical conventional bridge ($250/sqft deck area). Additional case-study evidence for significant cost-savings in GRS bridge projects relative to conventional abutments is shown in **Fig. 15**, which is based on the cost analysis of more than 12 GRS bridges in Pennsylvania.

Figure 13. Large-bock bridge abutments in Hamilton County, OH that resulted in $40,000 cost savings (Redi-Rock 2020)

5. Another factor contributing to cost-savings in the bridge projects in Grant County and Kay County is the bundling of the projects in those counties, which would generally lead to more cost-effective projects. Other state DOTs and counties have also recognized the value of bundling their bridge construction projects and incorporating GRS abutments in replacing structurally deficient bridges. For instance, a case study by Valmont™ Structures on their Con-Struct® bridge units in Midland County, MI stated that:

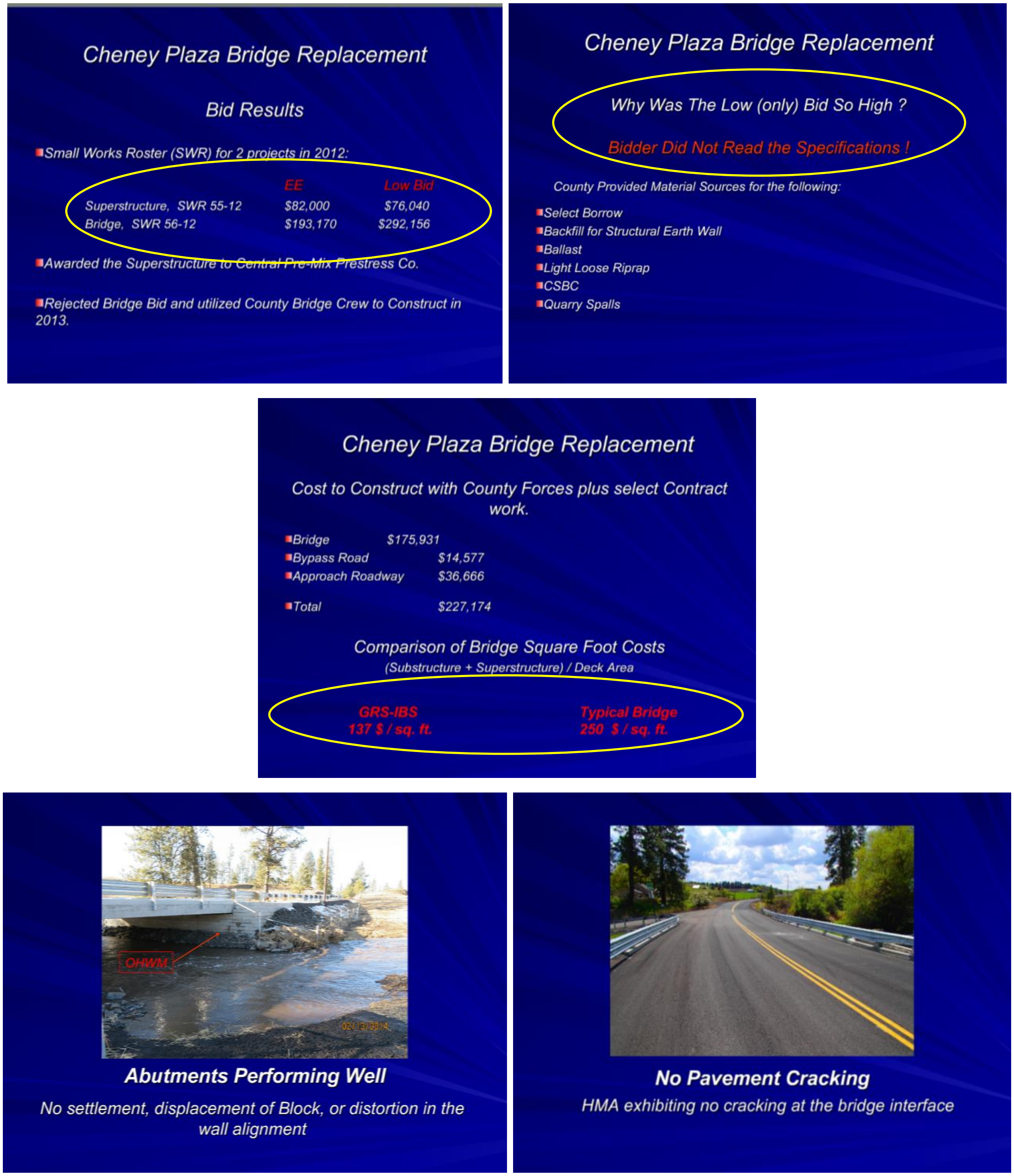


Figure 14. (top) Example high bid on a GRS-IBS, highlighting the importance of contractor training and pre-bid conference to obtain reasonable bids; also, cost comparison with a typical conventional bridge; (bottom) Reported performance of the same GRS bridge (Source: Neil Carroll, FHWA 2015)

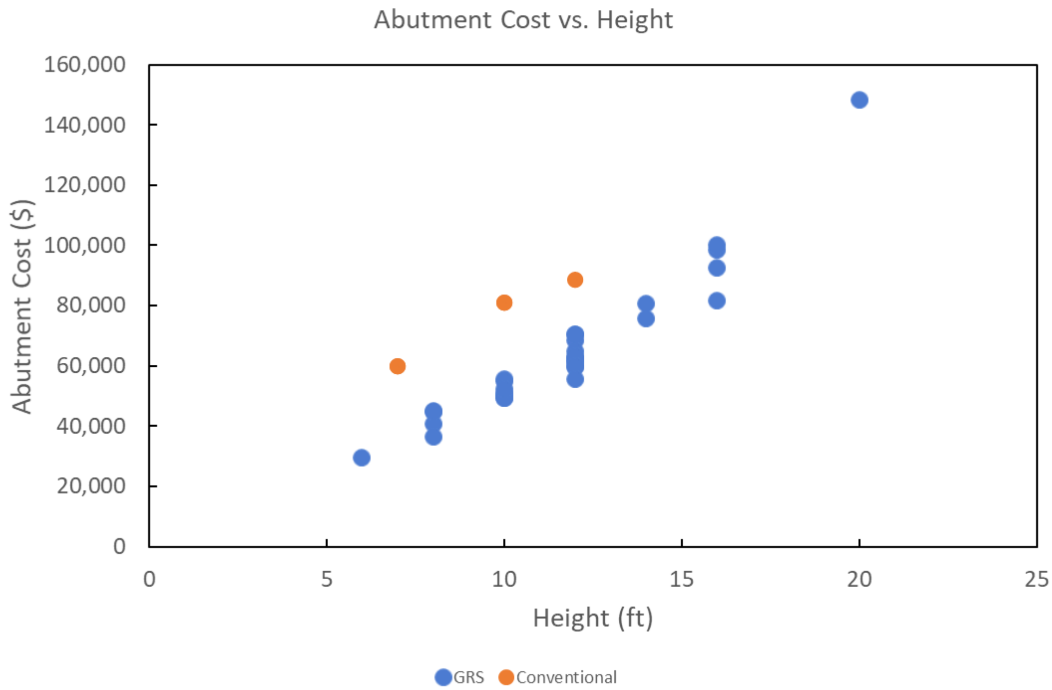
"These bridge systems, that can be bundled and self-installed, were the answer when Midland County Road Commission and their structural consultant, OHM Advisors, were looking for an economical method to replace two structurally deficient bridges, the Orr Road bridge over Weaks Drain and the Grey Road bridge over Bullock Creek. To get the most bang for their buck, Midland County chose to combine multiple innovative cost-cutting measures:

- *Bundling the bridges into a single package*
- *Pre-ordering the bridge superstructures to be manufactured at the same time*
- *Incorporating Geosynthetic Reinforced Soil (GRS) abutments (**Fig. 16**)*
- *Utilizing the Con-Struct Galvanized Steel Press-Brake-Formed Tub Girder Bridge System."*

Figure 15. Cost comparison between GRS and conventional bridges in PA
(Source: Randy Albert, FHWA 2015)

Figure 16. Example ABC on Geosynthetic Reinforced Abutments in Midland County, MI (Valmont™ Structures 2021)

Figures 17 shows cost comparisons between GRS bridges planned for construction (i.e. projected costs) in Grant County and conventional bridges in Caddo and Kay counties (data from Mr. Tom Simpson (BIA). In contrast to the results in **Fig. 7**, data in **Fig. 17** indicate that projected costs of bundled GRS bridges in Grant County are less than those of conventional bridges for the cases examined. These cost data indicate that GRS abutments could indeed be cost effective relative to comparable conventional solutions.



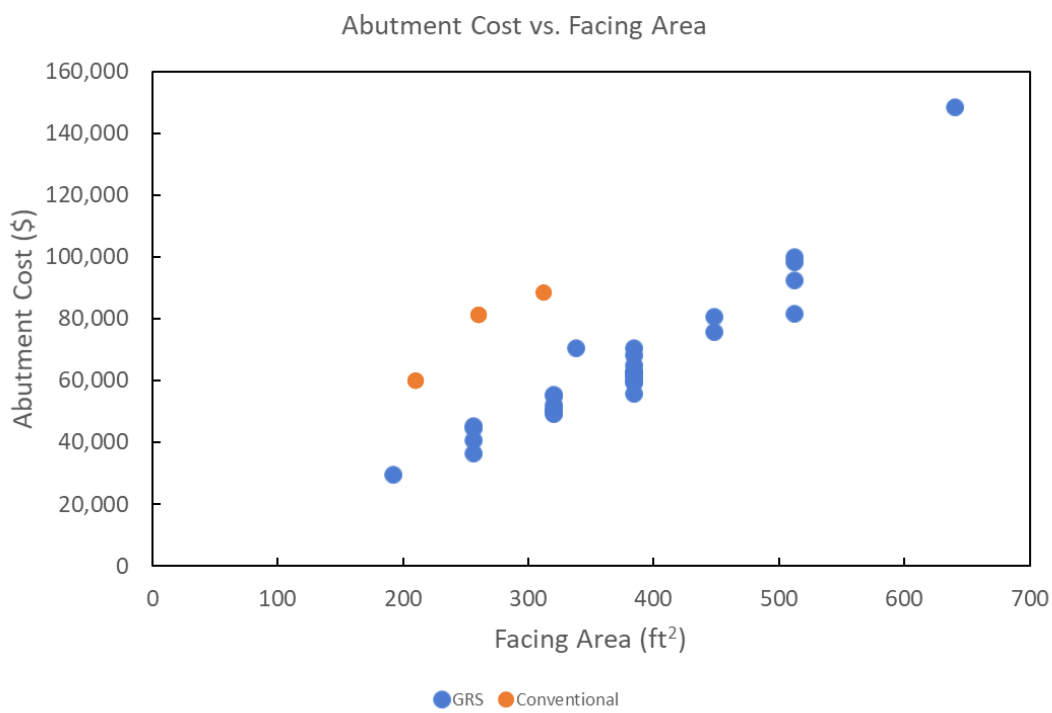


Figure 17. Comparison of abutment costs between GRS bridges in Grant County and selected conventional bridges (with available cost data) as a function of abutment height and facing area

Following a series of communications with Mr. Max Hess (Grant County Commissioner, District 1), we also received cost documents on several conventional bridges in their district, an example of which is provided in **Fig. 18**. Through subsequent communications with Mr. Hess, we were able to determine the portion of the total costs that was on the abutments only, which is highlighted in **Fig. 18** and the legend provided in the figure. Cost analysis for all conventional bridges with available data in that district is summarized in **Table 5**.

Table 5. Cost data on selected conventional bridges in Grant County with total cost for the superstructure and the abutments listed as separate categories

Local ID	Cost		
	Abutment	Superstructure	Total
38	$33,032.44	$33,843.01	$66,875.45
51	$35,541.86	$64,908.96	$100,450.82
52	$43,576.86	$75,893.47	$119,470.33
53	$47,276.58	$66,023.89	$113,300.47
57	$46,978.11	$49,554.02	$96,532.13
58	$29,184.32	$39,282.55	$68,466.87
63	$29,479.04	$62,660.88	$92,139.92
64	$32,327.50	$46,407.43	$78,734.93
94	$28,325.57	$35,298.43	$63,624.00
273	$43,305.88	$72,626.28	$115,932.16
318	$41,809.85	$63,659.88	$105,469.73
361	$30,377.86	$19,650.28	$50,028.14
125A	$22,742.74	$17,618.39	$40,361.13
39A	$36,548.17	$32,844.67	$69,392.84
39B	$27,013.49	$25,595.12	$52,608.61
56A	$24,513.39	$19,341.88	$43,855.27

55' Long 26'8" Wide

DISTRICT 1 BRIDGE PROJECT MATERIAL LIST BRIDGE # 53

12" H-Beam	$1,065.30
9 5/8 Piling	$3,407.50
9 5/8 Piling	$2,912.76
7 5/8 Piling	$1,200.42
7 5/8 Piling	$865.98
1/2X6 Flat	$133.92
6" Channel	$928.16
6" Channel	$84.38
3X3X1/4 Angle	$811.77
7" Channel	$712.99
3X5X1/4 Angle	$373.53
10" Channel	$348.23
1/2" Rebar	$1,120.81
Welded Studs	$200.34
Endwings	$180.00
Guardrail	$110.00
6X20 H-Beam	$1,254.07
21.7X20 Sheeting	$8,159.41
3X14 Decking	$1,979.04
2 1/2" Chairs	$11.39
4" Chairs	$27.57
6" Wire Ties	$73.65
Concrete & Finishing	$5,224.00
Total	$31,172.47
DIETZ WELDING	$26,320.00
TOTAL	$57,492.47
E7-N289-005	
Leflore &890 Intersection Then 1/2 Mile East	

33 1/4" x 11 3/8" x 130 lb. 7 Beams

$24 274.25 New

$15 015.00 Used

Labor $16,500.00

LEGEND

Not Included in abutment costs
Angles: 25% included in abutment costs
Welding: 2/3 included in abutment costs
Labor: 60% included in abutment costs
Included in abutment Costs

Figure 18. Cost data on an example conventional bridge in Grant County with cost items for the superstructure and the abutments identified separately

We have also been in communication with Mr. Hess' and CED 8 offices to see if the corresponding abutment size information would also be available for direct comparison of the cost data with those on GRS bridges. However, as of the date of this report such information has not been available. Meanwhile, inspection of data in **Table 5** indicates that the conventional bridges in Grant County District 1 were very cost-effective, which is attributed to the use of experienced local force and efficient procurement of construction materials (e.g. recycled beams, etc.) on the part of the commissioner's office.

4. KAY COUNTY

Four (4) GRS-IBS bridges were built over Dry Creek near Blackwell in Kay County during the period April 2014-February 2015, which provided a unique opportunity for a side-by-side comparison of their cost and performance with one another and with two additional conventional bridges (i.e. a total of six bridges were constructed over the said period). The bridges are numbered as shown in **Fig. 19**, and their construction-related information is presented in **Table 6**. **Figure 20** shows before and after photographs of an example GRS bridge from this ensemble.

Figure 21 shows cost comparisons between GRS bridges in Kay County and conventional bridges in Caddo and Kay counties. Similar to the results shown in **Fig. 17**, data in **Fig. 21** indicate that GRS abutments could indeed be cost effective relative to comparable conventional solutions.

Figure 19. Locations of GRS bridges in Kay County

Figure 20. Before and after pictures of the GRS Bridge No. 3 in Kay County
(Photographs Courtesy of Mr. Tom Simpson, PE)

Table 6. Summary data on GRS and conventional bridges in Kay County, OK (includes information from Mr. Tom Simpson, PE)

Bridge	Span Length m (ft)	Abutment Height m (ft)	Bridge Width m (ft)	Abutment Cost	Total Cost	Construction Time (days)	Completion Year
Conventional Bridge 1	15.3 (50.0)	2.2 (7.0)	9.2 (30)	$60,000	$105,000	30 - 40	2014
GRS-IBS Bridge 2				$31,000	$79,000	30	2014
GRS-IBS Bridge 3				$35,000	$82,000	30	2015
GRS-IBS Bridge 4				$35,000	$82,000	30	2015
GRS-IBS Bridge 5				$31,000	$142,000	21	2014
Conventional Bridge 6				$60,000	$165,000	24	2014

Bridge	Facing	GRS fill	Reinforcement	Foundation type	Scour protection
Conventional Bridge 1	Sheet piling	N/A	N/A	H-Piles driven to bedrock	No rip-rap
GRS-IBS Bridge 2	CMU	No. 89 stone in abutment, No. 57 gravel in road base and RSF	TerraTex HPG-57 woven geotextile, 70 kN/m tensile strength in MD and XD	RSF	Rip-rap
GRS-IBS Bridge 3	5-m (15-foot)-high sheet piling				No rip-rap
GRS-IBS Bridge 4	5-m (15-foot)-high sheet piling				
GRS-IBS Bridge 5	CMU				Rip-rap
Conventional Bridge 6	Sheet piling	N/A	N/A	H-Piles driven to bedrock	No Riprap

N/A: Not Applicable

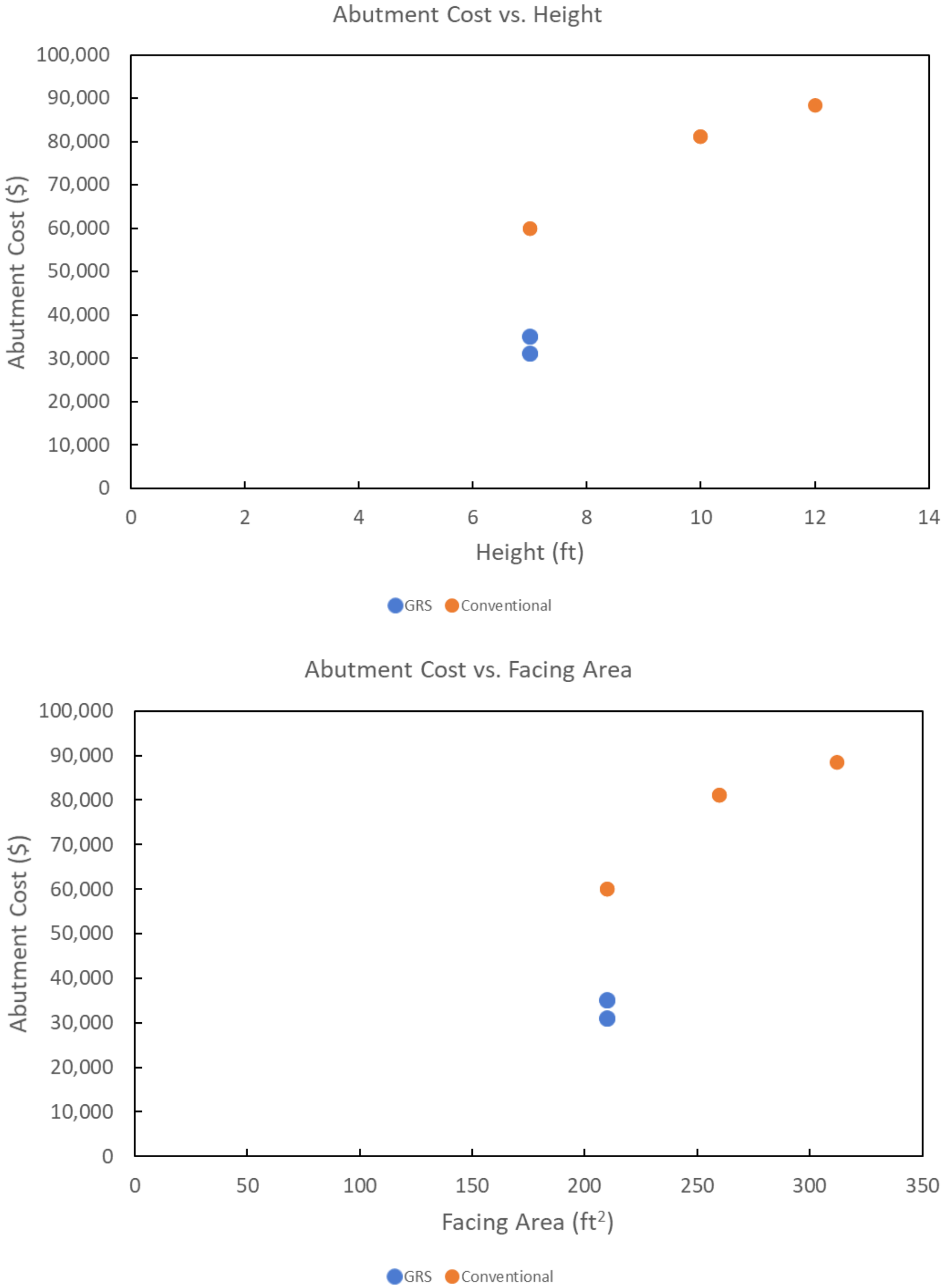


Figure 21. Comparison of abutment costs between GRS bridges in Kay County and selected conventional bridges (with available cost data) as a function of abutment height and facing area

5. LINCOLN COUNTY

Project costs of the only GRS-abutment bridge constructed to date in Lincoln County (Yates Bridge over Spring Creek) are compared with those of a conventional bridge (i.e. Guilliam Bridge) that had been considered at the time, using the data provided by Mr. Tom Simpson, PE. The GRS abutment was the only alternative considered for this project. However, the bidding results of October 19, 2015 for a pile-supported abutment bridge with comparable bridge dimensions were also obtained. **Figure 22** shows selected information on the two bridges including some design specifications and bill of quantities.

Figure 23 shows bid tables for both bridges, which include comparisons between different contractor bids and engineer's estimate. The GRS and the conventional bridges were comparable with respect to factors such as their width, abutment height, span length, ADT and superstructure. Contractors' quotes on the two projects were quite different; but after ignoring the highest unit prices, it can be observed that the unit cost of the superstructure ($/ft^2) for the conventional bridge is higher than that of the GRS-IBS bridge (i.e. $39.03/ft^2 vs. $31.27/ft^2). However, this difference seems to be counterbalanced by a somewhat higher cost of the GRS abutment relative to the pile support. Even though these prices are only estimates, the data in **Fig. 23** indicate that the cost-effectiveness of GRS-IBS relative to conventional bridges could be eroded for taller abutments. In addition, since the back-slope of the GRS abutments had to be changed from 1:1 to a milder 2:1 for added stability, there were additional quantities of excavation and aggregate that were involved in order to complete the abutments. Per the estimate provided by Mr. Simpson, the actual (total) cost of the GRS bridge was approximately $170,000, which was comparable to the engineer's estimated amount.

DESIGN DATA

CLASS AA CONCRETE f'c = 4 KSI
REINFORCING STEEL fy = 60 KSI
STRUCTURAL STEEL (GRADE 36) Fy = 36 KSI

OPERATING RATING HS 89.4

DA = 4.18 SQ MI
S = 31.1 FT/MI
P = 38.49 IN/YR
PK2 = 526
PK5 = 1090
PK10=1640
PK25=2570
PK50=3220
PK100=4030
PK500=6250

LINCOLN COUNTY YATES BRIDGE (41-162)			
SUPERSTRUCTURE A36 STEEL			
MEMBER	NO.	LENGTH (FT.)	TOTAL WEIGHT (LBS)
C10 X 15.3	2	26'-11"	824
L3 x 3 x 1/4		559'	2739
W6 x 20	20	5'-8"	2,268
8"x1/4" Plate	2	56'	224
		TOTAL	6055
MATERIAL		QUANTITY	
Guard Rail on the Bridge			112.5 L.F.
24 Ga. Tensile Form			1512 S.F.
Concrete			36.3 C.Y.
Reinf. Steel	#4 Bars	3120 L.F.	2090 LBS.
	#5 Bars	4040 L.F.	4220 LBS.
5/8" Dia. x 4" Welded Studs			164 Studs

LINCOLN COUNTY YATES BRIDGE (41-162)			
SUBSTRUCTURE (2 ABUTMENTS)			
MATERIAL		UNITS	QUANTITY
Geosynthetic Reinforcement		SY	5400
CMU Block - Hollow		EA	2910
CMU Block - Solid		EA	778
Reinf. Steel	#4 Bars	LB	1532
GRS Backfill		CY	1310
RSF Fill		CY	246
Foam Board (4" Thick)		SF	36
Road Base Aggregate		CY	186
Concrete Block Wall Fill		CY	3.4

NOTE: ABUTMENT DIMENSIONS & QUANTITIES ARE BASED ON POOR SOIL CONDITIONS AND A HEIGHT OF 16.22'

CONST. 56'–2" STEEL BEAM BRIDGE W/ GRS–IBS ABUTMENTS W/ 26–0" CL. RDY

YATES BR 41–162 LINCOLN CO

DESIGN DATA

CLASS AA CONCRETE f'c = 4 KSI
REINFORCING STEEL fy = 60 KSI
STRUCTURAL STEEL (GRADE 36) Fy = 36 KSI

MAXIMUM FACTORED PILE LOAD –
ABUTMENTS: 19.3 TONS / PILE

DA = 2.33 SQ MI
S = 48.2 FT/MI
P = 38.75 IN/YR
PK2 = 389
PK5 = 813
PK10=1240
PK25=1950
PK50=2420
PK100=3040
PK500=4700

LINCOLN COUNTY BRIDGE A (41–280) 59.00' Long			
A36 STEEL			
MEMBER	NO.	LENGTH (FT.)	TOTAL WEIGHT (LBS)
HP12x53	2	33'–0"	3,498
C10x15.3	2	30'–0"	918
C8x11.5		248'	2,852
L4x3x1/4		100'	580
L3x3x1/4		291'	1,426
W6x20	20	5'–8"	2268
1/2" Plate	36	5 3/4" X 10 7/8"	352
8"x1/4" Plate	2	59'	236
		TOTAL	12,130
MATERIAL		QUANTITY	
Guard Rail			225 L.F.
Driven Guard Rail Posts (W6x8.5)			28 Ea.
Type 1 End Section (Elephant Ear)			4 Ea.
24 Ga. Tensile Form			1512 S.F.
Piles HP 10x42			240 L.F.
Piles HP 12x53			480 L.F.
12 Ga. Sheet Piling			2,400 S.F.
Concrete			38.2 CY
Reinf. Steel	#4 Bars	3480 L.F.	2325 LBS.
	#5 Bars	4240 L.F.	4420 LBS.
5/8" Dia. x 4" Welded Studs			170 Studs

59'–0" STEEL BEAM BRIDGE W/ 26–0" CL. RDY

BR 41–280 LINCOLN CO

Figure 22. Side-by-side comparisons between Yates Bridge over Spring Creek (GRS-IBS; Left) and pile-supported Guilliam Bridge over Kickapoo Creek (Right) in Lincoln County, OK, relative to their design data and bill of quantities

Bid Tabulation

Lincoln County

Bid No. 16-01
Yates Bridge w/ GRS Abutments
Bids Received May 2, 2016

EST, Inc.
615 N. Hudson, 3rd Floor
Oklahoma City, OK 7301[illegible]
(405)815-3600

BR A - YATES BRIDGE 56' I-BEAM W/ CONCRETE DECK ON GRS ABUTMENTS

ITEM NO.		DESCRIPTION	UNITS	QUANTITY	Engineer's Estimate		Contractor A		Contractor B	
501(B)	1307	SUBSTRUCURE EXCAVATION COMMON	CY	681.00	20.00	$ 13,620.00	12.00	$ 8,172.00	8.00	$ 5,448.00
506(A)	1322	STRUCTURAL STEEL	LB	6055.00	2.50	$ 15,137.50	5.22	$ 31,607.10	6.00	$ 36,330.00
509(A)	1326	CLASS AA CONC.	CY	37.00	350.00	$ 12,950.00	229.00	$ 8,473.00	400.00	$ 14,800.00
511(A)	1332	REINFORCING STEEL	LB	8692.00	1.00	$ 8,692.00	0.60	$ 5,215.20	1.20	$ 10,430.40
601(B)	1353	TYPE 1-A PLAIN RIPRAP	TON	510.00	35.00	$ 17,850.00	44.25	$ 22,567.50	55.00	$ 28,050.00
880(J)	8905	CONSTRUCTION TRAFFIC CONTROL	LSUM	1.00	2000.00	$ 2,000.00	2500.00	$ 2,500.00	2000.00	$ 2,000.00
SP	0	BEAM GUARD RAIL ON THE BRIDGE	LF	125.00	11.00	$ 1,375.00	30.00	$ 3,750.00	50.00	$ 6,250.00
SP	0	GEOSYNTHETIC REINFORCEMENT	SY	5400.00	3.25	$ 17,550.00	2.75	$ 14,850.00	6.00	$ 32,400.00
SP	0	CMU BLOCK - HOLLOW	EA	2910.00	2.80	$ 8,148.00	4.00	$ 11,640.00	19.00	$ 55,290.00
SP	0	CMU BLOCK - SOLID	EA	778.00	3.00	$ 2,334.00	2.40	$ 1,867.20	22.00	$ 17,116.00
SP	0	GRS BACKFILL	CY	1310.00	30.00	$ 39,300.00	24.45	$ 32,029.50	95.00	$ 124,450.00
SP	0	RSF FILL	CY	246.00	30.00	$ 7,380.00	30.00	$ 7,380.00	100.00	$ 24,600.00
SP	0	FOAM BOARD (4" THICK)	SF	36.00	2.00	$ 72.00	10.00	$ 360.00	50.00	$ 1,800.00
SP	0	ROAD BASE AGGREGATE	CY	186.00	30.00	$ 5,580.00	28.00	$ 5,208.00	100.00	$ 18,600.00
SP	0	CONCRETE BLOCK WALL FILL	CY	4.00	220.00	$ 880.00	150.00	$ 600.00	900.00	$ 3,600.00
SP	0	12 GA. SHEET PILING	SF	1998.00	10.00	$ 19,980.00	0.45	$ 899.10	6.00	$ 11,988.00
			TOTAL			$ 172,848.50		$ 157,118.60		$ 393,152.40

Abutment type	GRS-IBS
Bridge Name	Yates
Height	16.22 ft
Span Legth	56.3 ft
Width	26 ft
Superstructure type	Steel Beam
ADT-2015	50
ADT-2035	75
V	45

Summary		
Area of Superstructure	1,463.80	ft^2
Cost of superstructure per ft^2	31.27	$/ft^2
Cost of abutment per LF of height	7,038.22	$/LF
Cost of abutment per LF of height	-	$/LF

					Superstructure		Abutment	
Item No		Description	Price	Units	Qty	Total	Abutment	Total
501(B)	1307	Substructure Excavation	$16.00	CY		$ -	681	$10,896.00
506(A)	1322	Structural Steel	$3.86	LB	6,055.00	$23,372		$ -
509(A)	1326	Class AA Concrete	$289.50	CY	37	$10,712		$ -
511(A)	1332	Reinforcing Steel	$0.80	LB	8,692.00	$6,954		$ -
601(B)	1353	Type 1-A Plain Riprap	$39.63	TON		$ -	510	$20,208.75
880(J)	8905	Construction Traffic Control	$2,166.67	LSUM	1	$2,167		$ -
SP	0	Beam Guard Rail	$20.50	LF	125	$2,563		$ -
SP	0	Geosynthetic Reinforcement	$3.00	SY		$ -	5,400	$16,200.00
SP	0	CMU Block- Hollow	$3.40	EA		$ -	2,910.00	$9,894
SP	0	CMU Block - Solid	$2.70	EA		$ -	778	$2,101
SP	0	GRS Backfill	$27.23	CY		$ -	1,310.00	$35,665
SP	0	RSF Fill	$30.00	CY		$ -	246	$7,380
SP	0	Foam Board (4"Thick)	$6.00	SF		$ -	36	$216
SP	0	Road Base Aggregate	$29.00	CY		$ -	186	$5,394.00
SP	0	Concrete Block Wall Fill	$185.00	CY		$ -	4	$740.00
SP	0	12 GA Sheet piling	$5.48	SF		$ -	1,998.00	$10,955.70
					Superstructure	$45,766.57	Abutment	$119,649.80

(a)

Bid Tabulation

Lincoln County

Bid No. 15-13
Guilliam Bridge
Bids Received October 19, 2015

EST, Inc.
615 N. Hudson, 3rd Floor
Oklahoma City, OK 73012
(405)815-3600

ITEM NO.		DESCRIPTION	UNITS	QUANTITY	Engineer's Estimate		Contractor A		Contractor B		Contractor C	
506(A)	1322	STRUCTURAL STEEL	LB	15008.00	1.20 $	18,009.60	2.50 $	37,520.00	5.50 $	82,544.00	9.50 $	142,576.00
509(A)	1326	CLASS AA CONC.	CY	38.20	400.00 $	15,280.00	320.00 $	12,224.00	825.00 $	31,515.00	900.00 $	34,380.00
511(A)	1332	REINFORCING STEEL	LB	6630.00	1.20 $	7,956.00	0.86 $	5,701.80	1.50 $	9,945.00	2.50 $	16,575.00
514(A)	6010	PILES, FURNISHED (HP 10x42)	LF	240.00	21.00 $	5,040.00	34.00 $	8,160.00	35.00 $	8,400.00	85.00 $	20,400.00
514(A)	6011	PILES, FURNISHED (HP 12x53)	LF	480.00	26.00 $	12,480.00	40.00 $	19,200.00	42.00 $	20,160.00	95.00 $	45,600.00
514(B)	6292	PILES, DRIVEN (HP 10x42)	LF	240.00	8.00 $	1,920.00	10.00 $	2,400.00	15.00 $	3,600.00	50.00 $	12,000.00
514(B)	6294	PILES, DRIVEN (HP 12x53)	LF	480.00	10.00 $	4,800.00	10.00 $	4,800.00	18.00 $	8,640.00	50.00 $	24,000.00
SP	0	24 GA. TENSINLE FORM	SF	1755.00	5.00 $	8,775.00	4.72 $	8,283.60	9.20 $	16,146.00	13.00 $	22,815.00
SP	0	12 GA. SHEET PILING	SF	2190.00	10.00 $	21,900.00	9.23 $	20,213.70	20.00 $	43,800.00	35.00 $	76,650.00
SP	0	BEAM GUARD RAIL ON THE BRIDGE	LF	125.00	25.00 $	3,125.00 *	11.00 $	1,375.00	35.00 $	4,375.00	75.00 $	9,375.00
880(J)	8905	CONSTRUCTION TRAFFIC CONTROL	LSUM	1.00	2000.00 $	2,000.00	2000.00 $	2,000.00	4000.00 $	4,000.00	11227.00 $	11,227.00
			TOTAL SURFACING		$	101,285.60 *	$	121,878.10	$	233,125.00	$	415,598.00

* Corrected

Abutment type	Pile Abutment
Bridge Name	Guilliam
Height	17 ft
Span Legth	59 ft
Width	26 ft
Superstructure type	Steel Beam
ADT-2015	100
ADT-2035	150
V	45 MPH

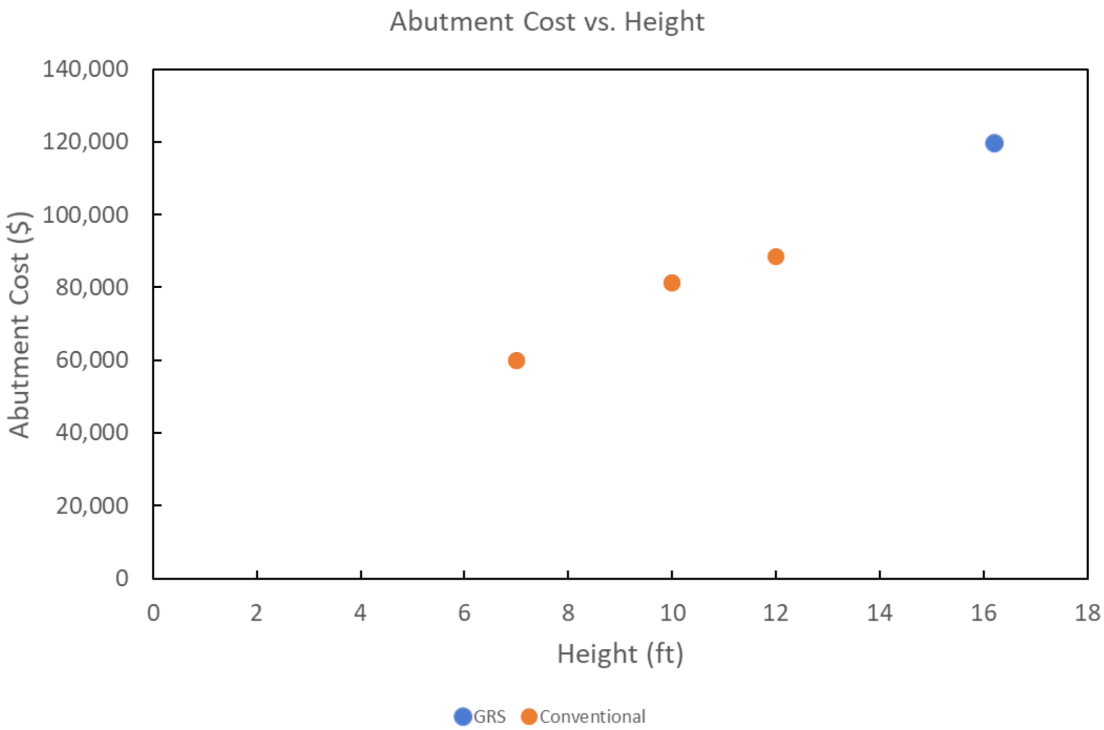
Summary		
Area of Superstructure	1,534.00	ft^2
Cost of superstructure per ft^2	39.03	$/ft^2
Cost of abutment per LF of height	3,775.65	$/LF
Cost of abutment per LF of height	2,848.59	$/LF

					Superstructure		Abutment	
Item No		Description	Price	Units	Qty	Total	Abutment	Total
506(A)	1322	Structural Steel	$3.07	LB	8,000.00	$24,533	7,008	$21,491.20
509(A)	1326	Class AA Concrete	$515.00	CY	38.2	$19,673	-	$ -
511(A)	1332	Reinforcing Steel	$1.52	LB	6,630.00	$10,044	-	$ -
514(A)	6010	Piles, Furnished (HP 10 x 42)	$30.00	LF		$ -	240	$7,200
514(A)	6011	Piles, Furnished (HP 12 x 53)	$36.00	LF		$ -	480	$17,280
514(B)	6292	Piles, Driven (HP 10 x 42)	$11.00	LF		$ -	240	$2,640
514(B)	6294	Piles, driven (HP 12 x 53)	$12.67	LF		$ -	480	$6,080
SP	0	24 GA Tensile form	$6.31	SF		$ -	1,755.00	$11,068
SP	0	12 GA Sheet Piling	$13.08	SF		$ -	2,190.00	$28,638
SP	0	Beam Guard Rail	$23.67	LF	125	$2,958		$ -
880(J)	8905	Construction Traffic control	$2,666.67	LSUM	1	$2,667		$ -
					Superstructure	$59,875.78	Abutment cost with furnished Piles	$64,186
							Abutment cost with driven Piles	$48,426

(b)

Figure 23. Cost comparisons for bridge projects in Lincoln County, OK: (a) GRS-IBS Yates Bridge over Spring Creek; (b) Pile-supported Guilliam Bridge over Kickapoo Creek

Figure 24 shows additional cost comparisons between the GRS bridge in Lincoln County (i.e. Yates Bridge) and smaller conventional bridges in Caddo and Kay counties, similar to those presented in **Figs. 7, 17 and 21**. Results in **Fig. 24** provide a somewhat different perspective on the estimated cost of the conventional abutment shown in **Fig. 23b**, and indicate that the amount in **Fig. 23b** could indeed be significantly underestimated, as it does not appear to be consistent with the trend in data in **Fig. 24**. In contrast the abutment cost of the GRS bridge appears to be consistent with the trends observed in **Fig. 24** given its abutment height.



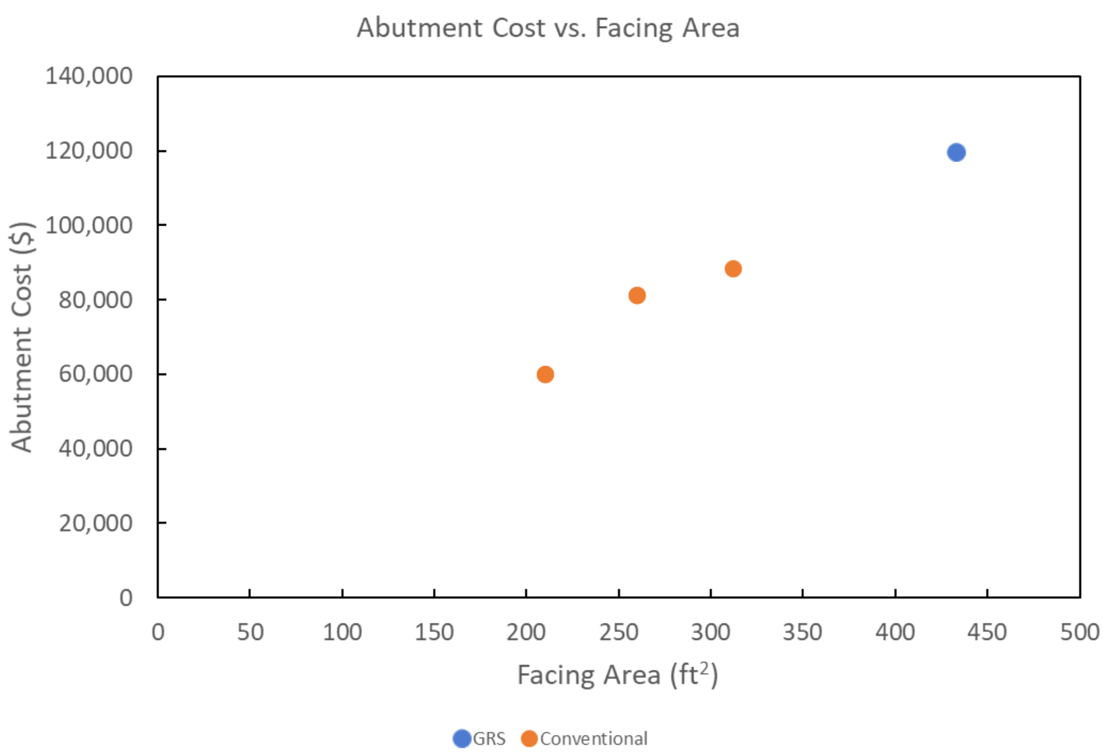


Figure 24. Comparison of abutment costs between the GRS bridge in Lincoln County and selected conventional bridges (with available cost data) as a function of abutment height and facing area

6. CONSTRUCTION AND TESTING OF FIELD-SCALE GRS ABUTMENTS AT THE UNIVERSITY OF OKLAHOMA

The importance of familiarity with the GRS construction process, and how it could result in cost-effective and rapid construction practice has also been demonstrated quantitatively by our research group through field-scale model construction and testing in our laboratory. **Figure 25** shows a comparison of cumulative person-hours our research group has spent to build seven (7) 8 ft-high GRS model abutments at the Fears Structural Laboratory. Six of these abutments had been constructed during a recently concluded research project sponsored by ODOT (Hatami *et al.* 2020). A seventh model using large blocks for the facing and a dense-graded fill was built during this study in the continuation of the previous project at no cost to ODOT. The construction effort in person-hours for this latest model abutment was also monitored and recorded for comparison purposes.

Abutment Models Nos.1-3, Nos. 4-6 and No. 7 were built by different teams of students with some overlapping crew members. A comparison of construction speeds for these model GRS abutments is presented in **Fig. 25**, which consistently shows that:

1. Collective experience gained by each team as a result of repeat construction of the GRS abutments can increase the construction speed within each team significantly (i.e. comparing construction speeds within Models Nos. 1-3, and separately, Models Nos. 4-6).
2. Maintaining any degree of continuity across construction teams even with inevitable member turnover, consistently resulted in overall reduction of construction time for each newer set of model abutments (i.e. comparing construction speeds of Models Nos. 1-3 with those of Models Nos. 4-6, and that of Model No. 7).

Implications of the above findings to field construction of GRS-IBS are discussed in the next section of this report.

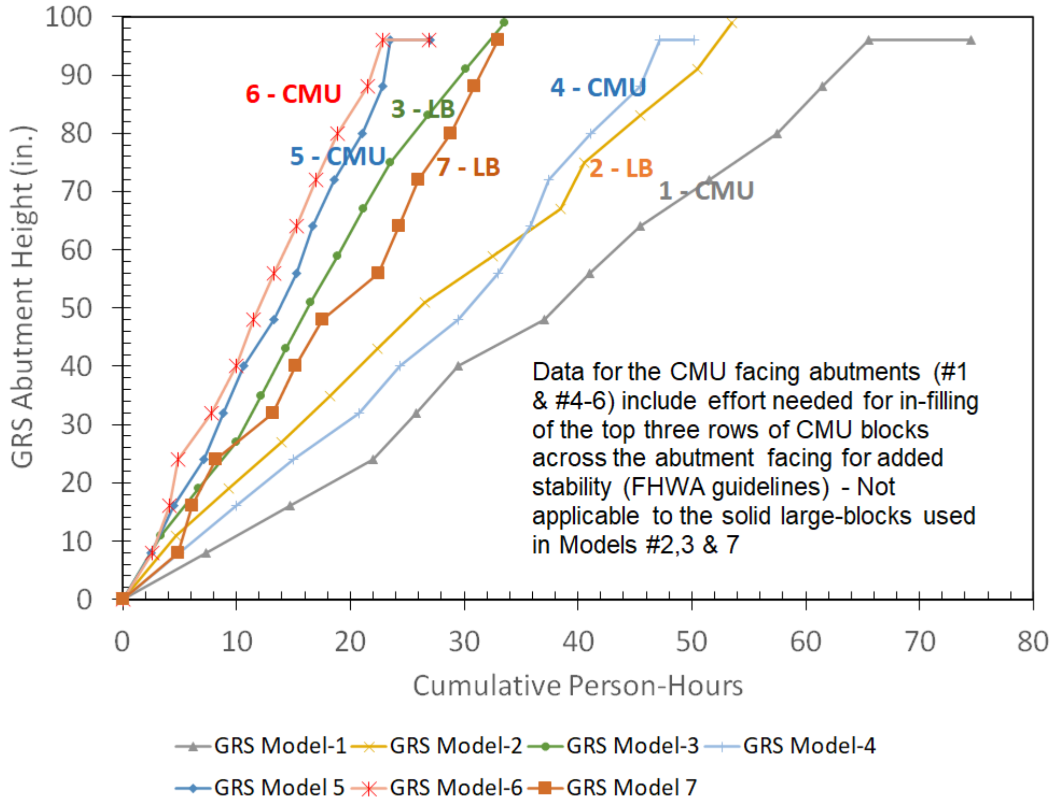


Figure 25. Construction effort (in person-hours) for field-scale GRS Abutment Models #1- #7 at OU

Key for facing type: CMU = Concrete Masonry Units; LB = Large Blocks (2′ × 2′ × 4′)

7. SUMMARY AND CONCLUSIONS

Based on the results of this study, the following conclusions are drawn:

1. Construction costs of the few GRS bridges that have been constructed in Oklahoma, have been overall either comparable to, or less than those of conventional bridges of comparable size. However, isolated cases of single GRS bridge construction that have been tried in some counties for the first time, might have posed some technical and cost-related challenges.

2. Construction time and costs of GRS abutment bridges are expected to decrease as more contractors become familiar with their construction techniques and QC/QA

requirements. Once these reduced construction time and costs for GRS-IBS are materialized, they will provide an even more accurate and meaningful basis for comparing their project cost and construction speed with those of conventional bridges of comparable size, which have been in construction and use for decades. For instance, Bid A in **Fig. 4** provided a more accurate sense of the GRS bridge cost relative to Bids B or C for the same project. Increased experience with GRS abutment construction throughout the state could lead to significant cost savings as a result of reduced construction time and traffic disruption, and earlier availability of the bridges and roadways for service to the users.

3. The cost-effectiveness of GRS abutments relative to conventional abutments could diminish significantly in the case of taller/larger abutments. For instance, the GRS bridge in Lincoln County offered a very interesting and rather unique case study due to the significant size of its abutments (i.e. over 16 ft tall). Cost estimates in **Fig. 23** indicated that GRS abutments of significant size and height can become expensive and lose their otherwise typical cost advantages over conventional solutions as compared to smaller bridges (e.g. the 7-ft-tall GRS bridge abutments in Kay County). The use of large-block-facing abutments could help speed up abutment construction to some extent, leading to some cost savings in such cases. However, significant quantities of select aggregate, reinforcement material and labor necessary to build large GRS abutments could erode their otherwise, demonstrated cost advantages to some extent for very tall bridge abutments.
4. Factors such as familiarity of the contractors with GRS abutment construction, use of local force and materials such as recycled beams, among others, could help further reduce the cost of GRS bridges, and thereby, their widespread use in county and local projects. Therefore, an initiative to build GRS bridges by experienced contractors and through bundling of projects (such as the current projects in Grant

County) could serve as a cost-saving approach to replacing structurally deficient and functionally obsolete bridges across the state.

5. During the course of this study, it was observed that there is a paucity of well-documented, cost and construction speed information on both the GRS and conventional bridges on local roads in different counties. Developing a centralized system to record and maintain such data would provide a valuable reference database for different stakeholders, which can help ensure more cost-effective bridge projects across the state in the future. This is an area that our research team can help with, and would be worth considering in the continuation of this study.

8. REFERENCES CITED

1. FHWA, 2015. *EDC Exchange GRS-IBS 61 Webinar*, September 15, 2015. https://connectdot.connectsolutions.com/p7t4uvdqg9c/?launcher=false&fcsContent=true&pbMode=normal

2. Hatami K, Doger R, Boutin J, 2020. Feasibility Study of GRS Systems for Bridge Abutments in Oklahoma: Influence of Facing and Aggregate Fill on Performance, *Final Report No. FHWA-OK-19-09*, ODOT SP&R ITEM NUMBER 2262, ODOT, Oklahoma City, OK, January 2020, 43p.

3. LCBH Solutions, 2018. Big Muddy Bridge Replacement, Boonville, MO. *Final Report*, 25 April 2018.

4. Nicks J. 2019. Geosynthetic Reinforced Soil-Integrated Bridge System: Bid Price Analysis and Cost Comparisons with Alternative Foundation Systems, *FHWA Publication No.: FHWA-HRT-19-024*, Federal Highway Administration, McLean, VA

5. Redi-Rock, 2020. https://www.redi-rock.com/Redi-Rock-XL-saves-money-over-cast-in-place-abutments.htm

6. Valmont™ Structures, 2021. *Valmont™ Con-Struct® Case Study*, Midland County, MI, valmontstructures.com

7. Williams, S, 2019. From Research to Implementation. *Oklahoma Transportation Research Day*, November 5, 2019, Midwest City, OK.