TECHNOTE

Geosynthetic Reinforced Soil–Integrated Bridge System—Bid Price Analysis and Cost Comparisons with Alternative Foundation Systems

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FHWA Contact: Jennifer Nicks, HRDI-40, (202) 493-3075, jennifer.nicks@dot.gov

Introduction

In 2009, the Federal Highway Administration (FHWA) launched the Every Day Counts (EDC) initiative to identify and deploy innovations aimed at reducing the time it takes to deliver highway projects, reducing design and construction costs, enhancing safety, and protecting the environment (McAbee 2012). Because the Geosynthetic Reinforced Soil–Integrated Bridge System (GRS-IBS) meets these criteria, it was selected for and promoted through the first three rounds of EDC. The design and construction methods for GRS-IBSs are outlined in FHWA guidance (Adams and Nicks 2018).

Based on the experience prior to EDC, the GRS-IBS was a good solution for States and counties who had limited funds and a large inventory of bridges in need of replacement. The first production GRS-IBS, termed the Bowman Road Bridge, was built in 2005 in Defiance County, OH (figure 1). The county engineer developed an engineer's estimate (EE) and performed a cost comparison between this new, innovative solution (i.e., GRS-IBS) and an alternative foundation system that was standard practice in the county (i.e., concrete-pile, capped abutments with 2:1 spill-through slopes). Findings showed that, on the first GRS-IBS bridge, the county realized a 21-percent cost savings for the project (table 1) (FHWA 2010). After constructing more than 30 GRS-IBSs to date, cost savings for Defiance County were determined to be approximately 50 percent on average due to the ease of construction and increased construction efficiency gained from improved skill and experience (Schlatter 2015).

Even greater savings were realized for a replacement project along County Road (CR) 12, with construction of one of the first GRS-IBSs built in St. Lawrence County, NY. In this case, the county decided to construct the GRS-IBS behind an existing abutment, which increased the span length of the bridge, but the technology negated the need for approach slabs, sleeper slabs, joint details, etc., which are standard practice for their bridges. To evaluate the benefits of the GRS-IBS, a cost comparison, showing more than 60-percent savings (table 2), was made by the county engineer. Data on nine bridges, summarized by Lawrence (2014), indicated an average savings of more than 30 percent for projects with site locations suitable for the technology.

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike, McLean, VA 22101-2296
www.fhwa.dot.gov/research

Figure 1. Photo. Bowman Road Bridge—the first GRS-IBS.

Source: FHWA.

Despite being proven to be cost effective, there are still many State and county project bids coming in above the EE. In this study, an independent cost analysis was performed by a third party to identify significant relationships between the many variable factors impacting competitive bid prices and understand the deviance that sometimes occurs between winning bids and expected costs for GRS-IBSs. Consultants evaluated project requirements along with the EE and winning bid and then developed an independent cost estimate (ICE) for each project. Each project examined had its respective cost drivers, but the thrust of this investigation was to identify important relationships impacting cost. In addition, a comparison was performed between ICEs for GRS-IBSs versus more traditional foundation systems. The findings and recommendations presented herein are based on that cost analysis.

This study includes a dataset of 13 projects across the country let between 2012 and 2014. Although this dataset represents a very small subset of all GRS-IBS projects, some important insights can still be gleaned. Of the 13 bridges, 9 were selected because the bid exceeded the EE; the remaining 4 were chosen because the bid was near or below the EE. The primary reasons for these selections were to establish why some projects came in higher than the EE and ensure future estimates and bids are more reasonable.

Table 1. Cost comparisons for the Bowman Road Bridge in Defiance County, OH (FHWA 2010).

Cost Item	Cost of GRS-IBS	ICE for Alternative	Difference
Abutment	$95,000	$105,000	10%
Beams and waterproofing	$171,000	$233,000	27%
Total	$266,000	$338,000	21%

ICE = independent cost estimate.

Table 2. Cost comparisons for the CR 12 Bridge in St. Lawrence County, NY (FHWA 2010).

Cost Item	Cost of GRS-IBS	ICE for Alternative	Difference
Material	$160,000	$300,000	47%
Labor	$50,000	$150,000	67%
Equipment	$30,000	$200,000	85%
Total	$240,000	$650,000	63%

ICE = independent cost estimate.

Project Details

The 13 projects selected for analysis are summarized in table 3. Wall heights ranged from approximately 8 to 28 ft, and the computed wall-face area in square feet (SF) ranged from 1,129 to 7,295 SF (wall-face area was computed as the sum of the area of the abutment wall face and the wing walls). The bridges studied were all single-span bridges with superstructure lengths between approximately 30 to 105 ft. Eight bridges were stream crossings, three were grade separations, and two were railway crossings. Each GRS-IBS was designed and constructed per FHWA's guidance (Adams et al. 2011) with some minor deviations, in some cases, based on State or project requirements.

ICEs were developed based on typical production values for site preparation and bridge construction for GRS-IBSs and conventional foundation systems. Costs for production rates and work-task risks were also incorporated into the ICEs. Using inspector daily logs and agency documentation, the actual labor and equipment hours were estimated using either local-area rates or Davis Bacon rates, plus a 30-percent fringe benefit for uniformity across all projects. Material prices were either based on agencies' historical bid averages or averages from suppliers. In general, to make ICEs comparable to EEs, the same material costs were used unless local differences were explicitly identified by the consultants preparing the ICE. Overhead and profit were assumed to equal 5 percent for all cases, although this percentage would be variable dependent upon the contractor. Note that ICEs were only prepared for GRS-IBSs and did not include the superstructure, roadwork, or other aspects of an entire project. Once prepared, ICEs were compared to the original EEs and bids. Agencies' methods of bidding out projects were then evaluated to determine the reason for any major deviations.

Table 3. Details of the selected GRS-IBS projects.

Project No.	Project State	Wall Height (ft)	Wall-Face Area (SF)	Span Length (ft)	Crossing Type	No. of Bidders
1	DE	17.1	4,425	30.3	Stream	6
2	FL	13.8	2,605	41.5	Stream	2
3	FL	15.4	3,770	57.3	Grade	2
4	MA	23.2	6,469	105.0	Rail	6
5	MI	11.0	1,725	50.0	Stream	4
6	MN	25.3	4,251	82.5	Rail	2
7	MO	13.9	2,035	53.5	Stream	4
8	SD	8.4	1,229	28.7	Stream	2
9	VA	14.5	1,847	43.1	Stream	4
10	WV	28.5	7,295	44.0	Grade	3
11	WI	10.3	1,500	37.0	Grade	2
12	CA	11.6	1,432	32.5	Stream	8
13	LA	14.5	5,996	35.0	Stream	3

No. = number.

Transportation Agency Estimates

Prior to requesting contractor bids, agencies develop a project estimate based on design plans, site conditions, and risks. The exact means of pricing the project is an agency's internal decision. The most common method used by State transportation agencies and their consultants for developing cost estimates is the historical bid–based approach (AASHTO 2013). This method uses historical pricing data from recently let contracts as the basis for determining estimated unit prices for a future project. Most transportation agencies have historical data on material costs of granular backfill and geotextiles, which comprise two of the three primary components of a GRS-IBS. The third primary component is a wall-facing unit, the type of which can vary between projects. The most common has been generic dry-cast concrete masonry units (CMUs), which are not traditionally used in conventional mechanically stabilized earth (MSE) walls, so the cost data on facing elements available for MSE walls cannot necessarily be directly applied to a GRS-IBS estimate.

Contractor Pricing

A contractor's bid proposal to construct a project represents the sum of the estimated cost to perform the work, an allowance for perceived risks, and consideration of the economic environment (primarily the number of expected bidders and alternative opportunities to employ assets). The risk component of a bid is increased when there are no bid items to accommodate work-quantity variation, such as

Table 4. Cost estimates and bids for each project.

Project No.	EE		Bid		ICE With 5% OH&P		Bid/EE	Bid/ICE	ICE/EE
	Total Cost	Cost/SF	Total Cost	Cost/SF	Total Cost	Cost/SF			
1	$263,540	$59.56	$238,701	$53.94	$277,050	$62.61	91%	86%	105%
2*	$165,540	$63.55	$334,210	$128.30	$232,713	$89.33	202%	144%	141%
3*	$256,993	$68.17	$324,074	$85.96	$203,720	$54.04	126%	159%	79%
4*	$318,910	$49.30	$420,490	$65.00	$442,285	$77.59	132%	84%	157%
5	$158,384	$91.82	$98,689	$57.21	$161,287	$97.16	62%	59%	106%
6	$204,663	$48.14	$272,145	$64.02	$322,670	$75.04	133%	85%	156%
7*	$92,500	$45.45	$102,711	$50.47	$112,145	$55.11	111%	92%	121%
8	$110,826	$90.18	$112,300	$91.38	$104,819	$85.29	101%	107%	95%
9	$292,597	$158.42	$393,675	$213.14	$364,207	$197.19	135%	108%	124%
10*	$765,975	$105.00	$729,500	$100.00	$614,210	$84.20	95%	119%	80%
11*	$65,000	$43.33	$118,000	$78.67	$124,863	$85.06	182%	92%	196%
12	$90,585	$63.26	$35,346	$24.68	$84,610	$66.21	39%	37%	105%
13*	$424,840	$70.85	$1,009,400	$168.35	$616,737	$102.86	238%	164%	145%

*GRS-IBS bid as a lump sum.
No. = number; OH&P = overhead and profit.

lump-sum items or statements in the contract documents effectively creating a lump-sum item.

Partially resolving the uncertainty of both the quantity of backfill and excavated material does not generally reduce a contractor's risk premium (Milgrom and Weber 1982). The perception of risk has a significant effect on bids. From a contractor's perspective, poor-quality bid documents are a risk indicator. For example, if the design plans noted excavation quantities that did not match the specifications for payment or the quantity of backfill for the excavation, then these slight differences would increase the contractor's perceived risk and, thus, they would increase costs. The marketplace also helps dictate bids. Contractors generally understand competition and settle on a final bid amount after considering the number of assumed bidders and the known capability of those bidders.

Cost Study Findings

After extensive analysis of EEs, bids, and ICEs, the results were compared and evaluated (table 4). Factors, such as bridge crossing type, wall-face area, wall height, span length of the bridge, and number of bidders were also evaluated to determine their impact on cost. Finally, the difference in the ICE between a typical alternative foundation system and the GRS-IBS was determined to evaluate the cost-effectiveness of the GRS-IBS.

Comparison Between the EE, Bid, and ICE

The largest difference found was for project number (No.) 13, in which the bid was 238 percent greater than the EE and 164 percent greater than the ICE. The main factor found in this case was that there were only two pay items: cofferdams and the GRS abutment. The cofferdams were bid lower than anticipated, but the GRS abutment was almost four times the EE. The design plans cited a 2:1 cut slope for the project, which may have impacted the cost of the GRS abutment from a contractor's perspective.

Additionally, of the seven projects that bid the GRS-IBS as a lump-sum item (project Nos. 2, 3, 4, 7, 10, 11, and 13), only one project had an EE greater than the bid (project No. 10). Note that project No. 10 had a prebid meeting, which may have helped mitigate any perceived risks on the part of the contractor. Also, without much historical pricing data on GRS-IBS as a lump sum, the EE may have miscalculated realistic marketplace costs. The largest savings found were for project No. 12, for which the bid was approximately 38 percent of the EE and ICE. In this case, there were four pay items: granular backfill, geosynthetic reinforcement, CMUs, and structural excavation. This finding suggests that more pay items may help ensure bids are close to the EE and that bidding the GRS abutment as a lump sum may not result in cost efficiency.

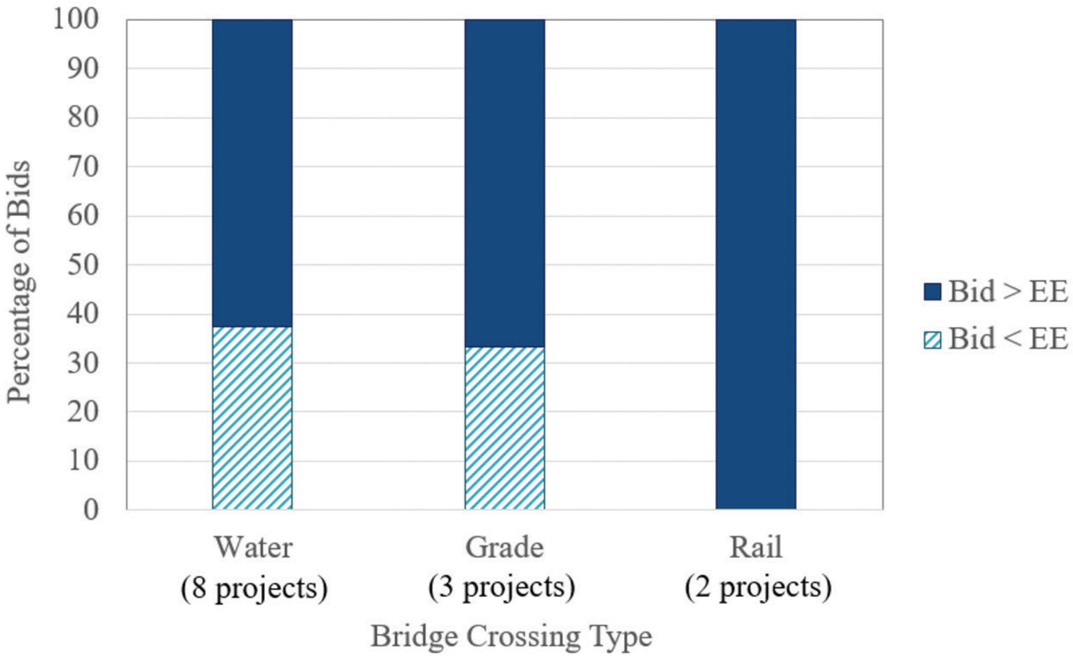
Cost Drivers

There are many factors that impact costs in bridge projects. This study evaluated five potential impacts on the EE, contractor bids, and ICE: bridge crossing type, wall-face area, wall height, span length of the bridge, and number of bidders.

Bridge Crossing Type

As previously stated, the GRS-IBSs selected included eight stream crossings, three grade separations, and two railway crossings. To date, this project distribution is a good representation of GRS-IBSs built in the United States, where most GRS-IBSs are stream crossings, followed by grade separations and then rail crossings (Daniyarov et al. 2017). For each crossing type, the bid was compared to the EE to determine whether the crossing type impacted the relative difference between the bid and EE (figure 2). Stream crossings or grade separations resulted in similar findings, with approximately 33 and 38 percent of bids being lower than the EE, respectively, indicating that the crossing type did not seem to be a major factor. With only two bids to evaluate for railway crossings, the relationship between the contractor's bid and the EE may be skewed.

Figure 2. Chart. Comparison of bids that were greater than the EE and bids that were less than the EE as a function of bridge crossing type.



Source: FHWA.

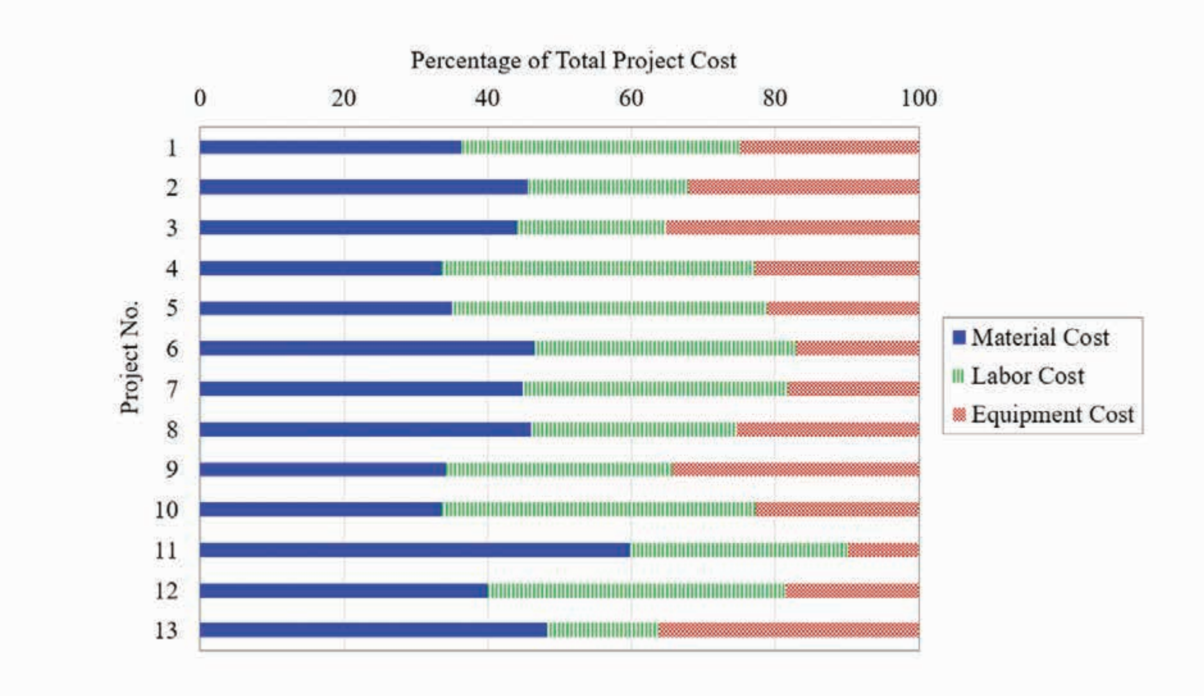
Wall-Face Area

For each project, the ICE established material, labor, and equipment costs (table 5). Although the differences between each cost category changed per project, material costs typically comprised the largest percentage of total cost, followed by labor and then equipment costs (figure 3). As expected, total costs increased for all categories as wall-face area increased. However, when projects were normalized by wall-face area, there was no trend between material, labor, and equipment costs and the SF of wall-face area (figure 4).

Table 5. ICE breakdowns for material, labor, and equipment costs.

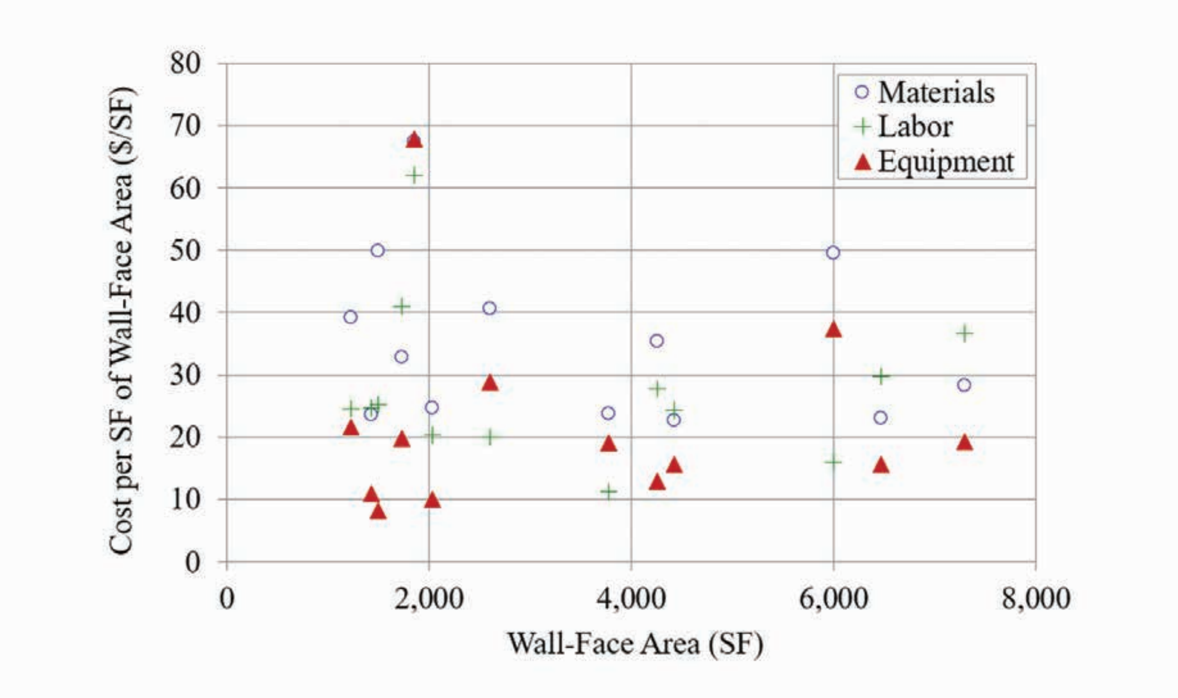
Project No.	Wall Height (ft)	Wall-Face Area (SF)	Total Cost	Material Cost			Labor			Equipment		
				Amount	Cost/SF	% of Total Cost	Amount	Cost/SF	% of Total Cost	Amount	Cost/SF	% of Total Cost
1	17.1	4,425	$277,050	$100,590	$22.73	36%	$107,379	$24.27	39%	$69,081	$15.61	25%
2	13.8	2,605	$232,713	$105,982	$40.68	46%	$51,837	$19.90	22%	$74,894	$28.75	32%
3	15.4	3,770	$203,720	$89,492	$23.74	44%	$42,660	$11.32	21%	$71,568	$18.98	35%
4	23.2	6,469	$442,285	$148,785	$23.00	34%	$192,564	$29.77	44%	$100,935	$15.60	23%
5	11.0	1,725	$161,287	$56,484	$32.74	35%	$70,763	$41.02	44%	$34,040	$19.73	21%
6	25.3	4,251	$322,670	$150,017	$35.29	46%	$117,612	$27.67	36%	$55,041	$12.95	17%
7	13.9	2,035	$112,145	$50,369	$24.75	45%	$41,299	$20.29	37%	$20,478	$10.06	18%
8	8.4	1,229	$104,819	$48,226	$39.24	46%	$30,060	$24.46	29%	$26,533	$21.59	25%
9	14.5	1,847	$364,207	$124,662	$67.49	34%	$114,392	$61.93	31%	$125,152	$67.76	34%
10	28.5	7,295	$614,210	$206,417	$28.30	34%	$267,764	$36.71	44%	$140,029	$19.20	23%
11	10.3	1,500	$124,863	$74,680	$49.79	60%	$37,945	$25.30	30%	$12,237	$8.16	10%
12	11.6	1,432	$84,610	$33,783	$23.59	40%	$35,198	$24.58	42%	$15,630	$10.91	18%
13	14.5	5,996	$616,737	$297,085	$49.55	48%	$96,098	$16.03	16%	$223,553	$37.28	36%

Figure 3. Chart. ICE material, labor, and equipment costs as a percentage of total project costs.



Source: FHWA.

Figure 4. Scatter plot. Costs per SF of wall-face area per ICE.



Source: FHWA.

Wall Height

Similar to wall-face area, wall height does not appear to influence any estimate or final project costs (figure 5). Note, however, that at the height range of 13 to 15 ft, cost per SF of wall-face area appears to exhibit a spike, depicted by more scatter in the data. This spike in costs may be due to the limited dataset or different conditions, but overall, wall height seems to have a negligible impact on total cost per SF of wall-face area.

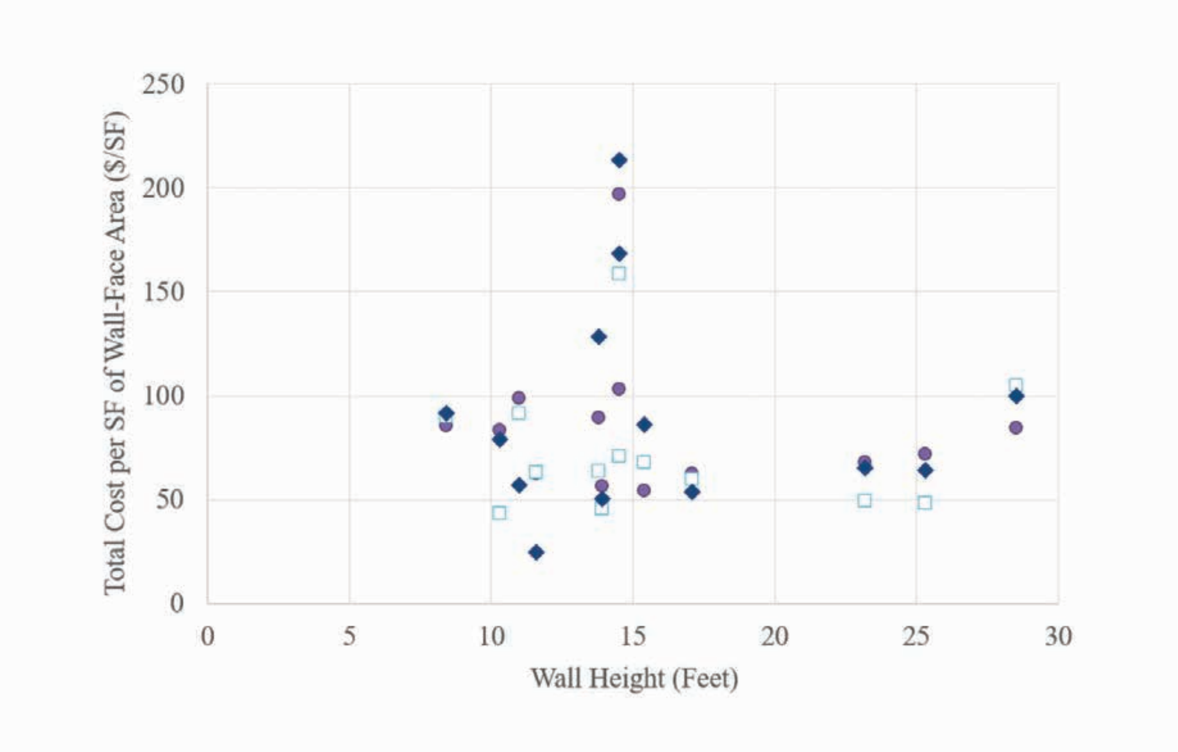
Span Length of the Bridge

The construction of a GRS-IBS is largely independent of the span length of the superstructure. The EEs, bids, and ICEs showed little impact in their estimates regarding span length (figure 6). Bids suggest that, as the span length of the superstructure increases, the bid per SF of wall-face area generally decreases; this factor, however, does not appear to have as large of an impact on the EE or ICE. Notably, at smaller span lengths, there is considerable scatter in the data, particularly in bids, with all estimates leveling out once the span is longer than 50 ft.

Number of Bidders

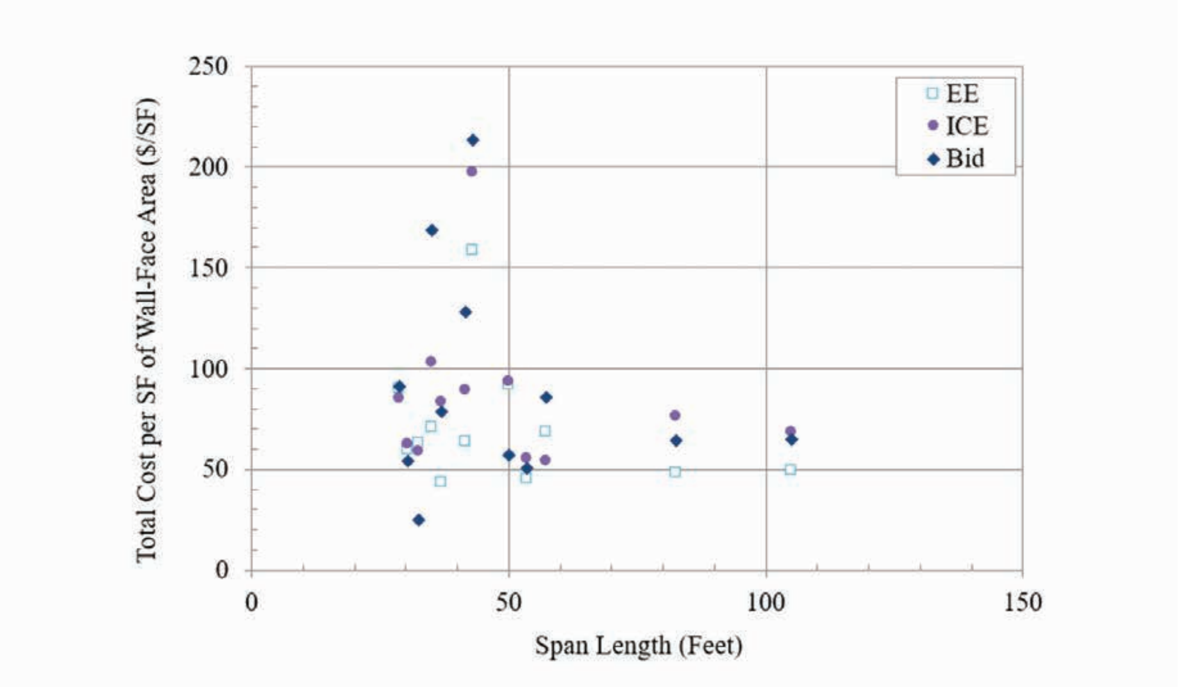
Competition helps reduce cost. In game theory, and similarly in decision theory, the term auction is often used in reference to a letting (Easly and Kleinberg 2010). A bridge owner is a buyer of a product that has no standard value, and it is the contractor (bidder) who defines the project's value based on his or her view of the marketplace. Actions by a bridge owner to increase competition tend to receive bids that are lower and more comparable to the EE (figure 7). Additionally, considering the GRS-IBS is a relatively new technology, the number of bidders can be considered an indication of perceived risk viewed by contractors.

Figure 5. Scatter plot. Total cost per SF of wall-face area as a function of wall height.



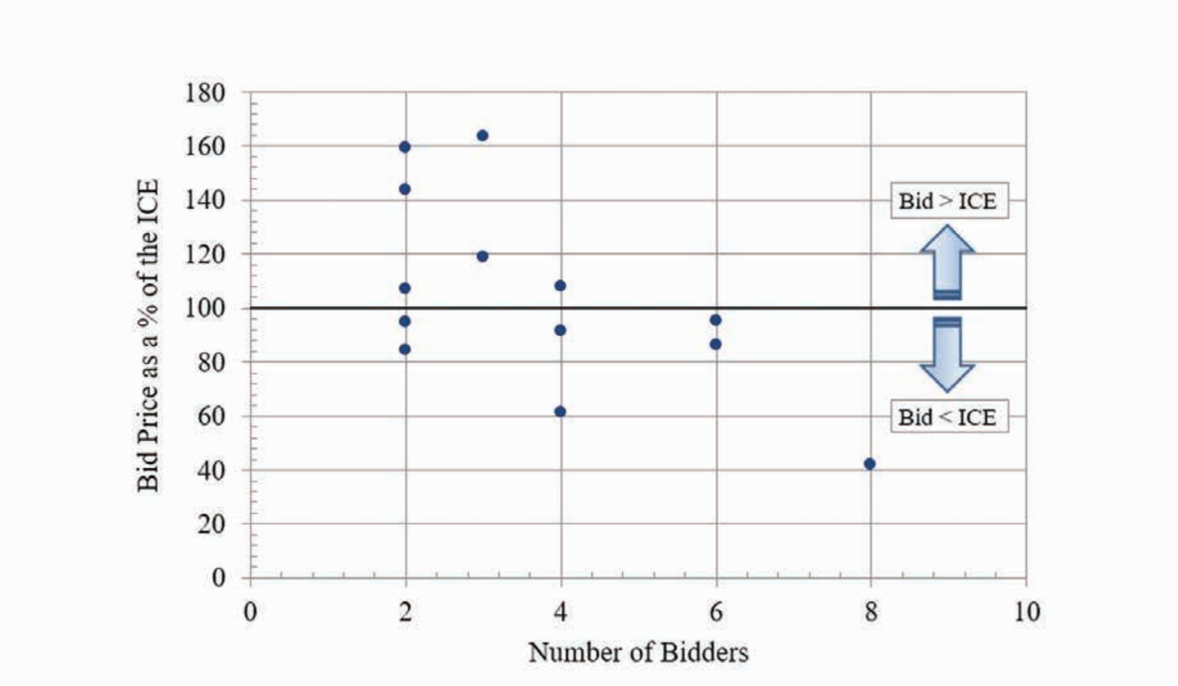
Source: FHWA.

Figure 6. Scatter plot. Total cost per SF of wall-face area as a function of span length.



Source: FHWA.

Figure 7. Scatter plot. Bid price as a percent of the ICE versus the number of bidders.



Source: FHWA.

Comparison Between GRS-IBSs and Alternative Foundation Systems

To evaluate the cost-effectiveness of a GRS-IBS, a cost comparison was performed assuming an alternative foundation system had been selected for the site. These alternative foundation systems included stub abutments on piles, culverts, integral abutments, cast-in-place concrete abutments on piles, and MSE walls with the bridge supported on piles. A request was sent to each agency of the 13 GRS-IBS projects asking for their input regarding their preferred design plans for the typical alternative foundation system they would have used. If preferences and details of an alternative foundation system were not provided, a review was made of available soil borings and geotechnical recommendations to decide a suitable alternative foundation system.

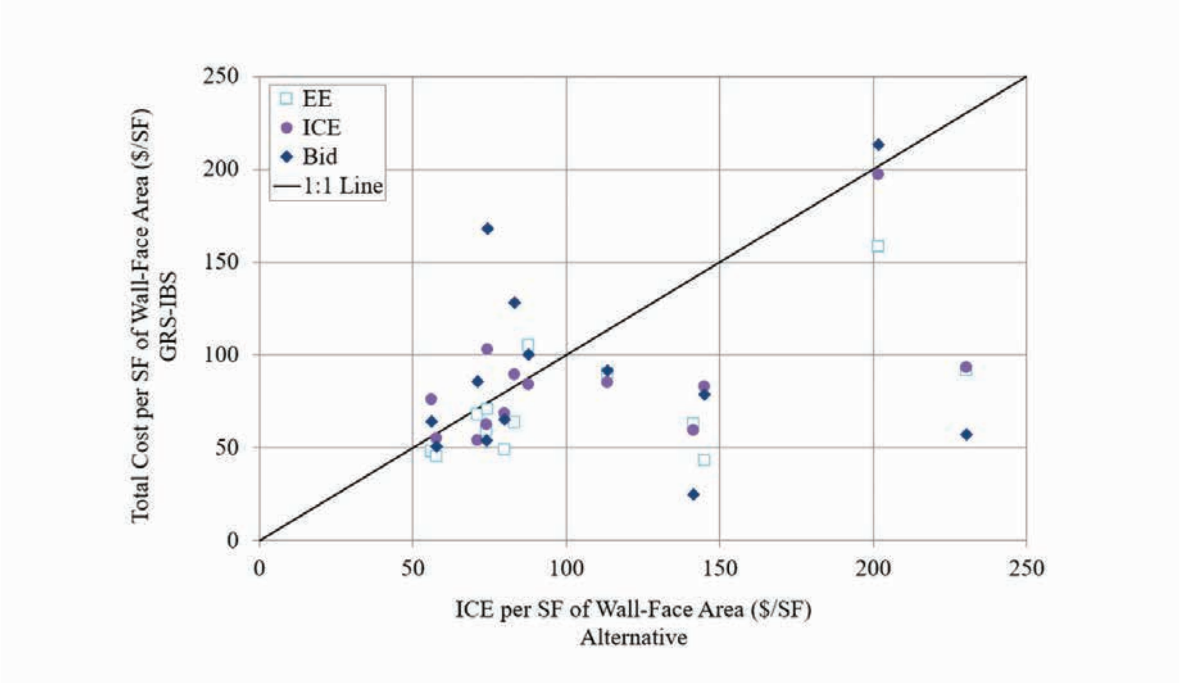
Each of the identified alternative foundation systems was developed into preliminary designs. These designs supported the development of site-specific dimensions and associated material quantities for work items associated with the foundations. Project-specific estimates were developed from the dimensions, work items, and quantities established by the design. The estimates of the alternative foundation designs had a probable accuracy range of plus or minus 20 percent. Results of the comparisons between ICEs for GRS-IBSs and alternative foundation systems are shown in table 6.

For 10 of the 13 projects, the GRS-IBS was found more cost-effective than the alternative foundation system. Out of the 13 projects, a comparison showed 12 EEs and 6 bids of the GRS-IBSs were less expensive than the ICEs of the alternative foundation systems (figure 8). It is likely that general unfamiliarity with the GRS-IBS at the time of the projects led to high bids, which had the most scatter; however, it is difficult to make that conclusion because the comparison is not made directly by the contractor but rather through this study. Overall, the data conclude that, in the right site conditions with experienced contractors in this area of GRS construction, the GRS-IBS is a good option. In some cases, however, conventional alternatives may be more appropriate. A general cost analysis should be performed for any viable foundation system to determine what system is most appropriate for a particular project.

Table 6. Comparisons between ICEs for GRS-IBSs and alternative foundation systems.

Project No.	Alternative Foundation System Considered	ICE GRS-IBS		ICE Alternative Cost		Alternative Versus GRS-IBS	
		Total Cost	Cost/SF	Total Cost	Cost/SF	Savings (Losses)	GRS-IBS/ Alternative
1	Stub abutment on piles with MSE walls	$277,050	$62.61	$328,190	$74.17	$51,140	84%
2	Double barrel box culvert	$232,713	$89.33	$216,758	$83.21	($15,955)	107%
3	Concrete integral abutments on piles	$203,720	$54.04	$267,651	$70.99	$63,931	76%
4	MSE wall abutment on micropiles	$442,285	$68.37	$454,770	$79.78	$12,485	97%
5	Precast box culvert	$161,287	$93.50	$382,387	$230.35	$221,100	42%
6	MSE wall abutment on steel piles	$322,670	$75.90	$241,991	$56.28	($80,679)	133%
7	Concrete abutment on predrilled piles	$112,145	$55.11	$117,852	$57.91	$5,707	95%
8	Concrete abutment on piles	$104,819	$85.29	$139,487	$113.50	$34,668	75%
9	Concrete abutments on spread footings	$364,207	$197.19	$372,496	$201.68	$8,289	98%
10	Cast-in-place concrete abutment	$614,210	$84.20	$640,185	$87.76	$25,975	96%
11	Concrete abutment on piles	$124,863	$83.24	$213,051	$145.13	$88,188	59%
12	Concrete abutment on spread footings	$84,610	$59.09	$180,637	$141.34	$96,027	47%
13	Concrete abutment on piles	$616,737	$102.86	$446,414	$74.45	($170,323)	138%

Figure 8. Scatter plot. Cost comparisons between GRS-IBSs and traditional bridges.



Source: FHWA.

Conclusions and Recommendations

This cost study was initiated to compare EEs to winning bids for 13 GRS-IBS projects and evaluate ICEs for GRS-IBSs and assumed alternative foundation systems. As part of this comparison, project specifications were evaluated to identify methods that may result in bids that are closer to EEs. In addition, this study aimed to determine some driving factors leading to differences in EEs and contractor bids. Although, only 13 projects were evaluated, with the majority selected because the bids seemed anomalous, some basic trends (or a lack thereof) were identified. Key findings and recommendations include the following:

- As most GRS-IBS projects are relatively small in terms of overall costs, there is no standard or best strategy to improve pricing for an individual project; transportation agencies should develop strategies adapted to each specific project and local market conditions.
- To reduce contractor risk and perception of risk, it is recommended to avoid bidding GRS-IBSs as a lump sum. To support quality estimates of GRS-IBS abutment costs, transportation agency estimators should bid item-defined quantities (not a lump sum) for (1) excavation; (2) granular backfill; (3) facing elements (CMUs, segmental retaining wall units, etc.); (4) geosynthetic(s); and (5) water control (if necessary).
- Consistency in quantities and unit-price payments between design plans and specifications should be maintained to avoid any perceived risk by a contractor.
- There is no clear trend between normalized estimates and wall-face area, wall height, or span length of the bridge.
- More competition, thus a higher number of bidders for a project, leads to lower total costs.
- The GRS-IBS is a proven, cost-effective solution compared to conventional alternative foundation systems, as indicated by more than 75 percent of GRS-IBS projects analyzed in this study resulting in lower costs based on the

ICEs. A general cost analysis should be performed for any viable foundation system to determine what system is most appropriate for a particular project.

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