Title: Rapid Replacement of a Short Span Bridge Using a Pre-Fabricated Lightweight Superstructure

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Rapid Replacement of a Short Span Bridge Using a Pre-Fabricated Lightweight Superstructure

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ABSTRACT

Transportation agencies in the U.S. routinely replace short highway bridges in the span range of 20-50 feet (~6-15m). Though fairly mundane in nature, these projects can become costly because they can take as long as six months to construct in-situ. Direct costs associated with maintaining traffic on a detour during the construction project can be substantial, but there are also other impacts that are directly proportional to the duration of the project. User delay costs, fuel consumption, air pollution, increased exposure to the possibility of construction related accidents, a field engineer’s office, inspection staff, are all increased. Though consuming a construction season to replace a small bridge was the norm in the past, current trends point to a growing intolerance for such practice.

Erie County NY’s New Oregon Road bridge replacement project provides an example of an alternative method for quickly replacing short span bridges. The County purposely selected innovative construction techniques and materials and provided an incentive to the contractor. The success of the project demonstrates that this type of bridge can be replaced in 30 days or less. The project utilized simple pre-cast concrete blocks for the substructure and lightweight, modular superstructure panels for the superstructure. The 115 psf panels were a hybrid of high strength concrete and fiber reinforced polymer (FRP) composites. The project was done in about a third the time of a similar project which was completed on the same road a year earlier using conventional construction methods and materials.

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INTRODUCTION

Erie County needed to replace two similar short span bridges on New Oregon Road. It replaced one conventionally in 2003 but decided to try accelerated construction strategies to see if intangible benefits such as user costs would justify any premium that might have to be paid for prefabricated bridge components. A year later, the County replaced the second New Oregon Road bridge in just 31 calendar days, approximately one third the time it took to replace the first one. The County’s plan successfully demonstrated that the entire short span bridge substructure and superstructure could be closed, demolished and replaced within modular substructure units and prefabricated superstructure panels with little additional cost.

The contract included special provisions that required a shorter window for completing the project than was typically allowed. It also awarded the contractor financially for reopening the bridge earlier than scheduled. During the first two weeks of the project, the bridge was closed to traffic, the substructure demolished; cast-in-place concrete footings placed on bedrock; and abutments built using a non-proprietary, pre-cast building block system. The second half of the project allowed for the placement of the superstructure (in two days) followed by the application of a thin polymer concrete wearing surface to give the stainless steel reinforced concrete deck extra longevity. Placing concrete for approach slabs, paving of approach pavement, and installing of the steel bridge and approach railing were also done before opening to traffic again. After completing the project, the superintendent reportedly said that he could have done it in half the time if he had known how easy it was going to be.

In addition to demonstrating quick project delivery, the County was interested in the longevity of the constructed facility. Fiber reinforced polymer (FRP) materials were selected to show that it is possible to build bridges that can have a service life greater than is obtained using conventional materials. Although FRP composites had been constructed in the past (O’Connor, 2008), and are known to be corrosion resistant and virtually maintenance free, their initial cost has been a hindrance to expanded use. To make them more economical, Erie County used FRP and high strength concrete together as a structurally composite section that capitalizes on the best properties and value of each material. The efficiency of this hybrid system may finally make them affordable and attractive to local bridge owners. This paper explains the use of the technology on one of several projects that have been done in a part of the U.S. that is notorious for its blizzards, the region near Buffalo, NY.

HYBRID SUPERSTRUCTURE

This design of the superstructure originated with a collaborative research project at the University of Southern Queensland, Australia. An international team of engineers refined the design for Erie County and had four superstructure panels manufactured in Toowoomba, Queensland, for delivery the job site in western New York. See figure 1.
Although glass fiber composite laminate (GFRP) can provide value because of its very strength to weight ratio and its durability, its inherently low modulus of elasticity (E) necessitates a stiffness driven design. This has restricted its use to short span bridges and also inspired the use of a dual-component structural system. The New Oregon Road superstructure has total length of 31’ (9.5m).

A 100% FRP bridge typically results in a structure that is over-designed for strength in order to meet serviceability requirements. To restrict the maximum deflection under service load conditions to the length of the span (L) divided by 800, service load stresses are often less than 10% of the ultimate strength of the FRP laminate. Such a factor of safety may be desirable on experimental bridges for a little extra peace of mind, but it is not a cost effective use of these proven materials and not necessary from a safety perspective. A hybrid system can improve the efficiency with which its materials are used.

On most past projects, a ridge surface has been adhesively bonded to the GFRP bridge decks. This provides the required skid resistance and protects the surface from UV radiation and abrasion. In some instances, this has proven to be a maintenance nuisance because of unexpected cracking and debonding. The high strength concrete (f’c = 65 MPa or 9,400psi) used on the hybrid New Oregon Road bridge serves a dual function of cost-effectively stiffening the structure, while providing a conventional wearing surface that is durable and readily accepted by owners. See figure 2.

With the use of stainless steel reinforcing in the bridge deck, a service life in excess of 100 years is expected. The bridge system as a whole provides exceptionally value because of its inherently high strength and resistance to deterioration from the elements.

Furthermore, unlike some all-FRP bridges that have been designed by finite element analysis (FEA), the design is easily understood by practicing civil engineers, which will be important for further technology transfer.
The FRP superstructure used for the New Oregon Bridge Project weighs approximately 115 psf yet has a higher ultimate capacity than a steel or concrete system would. Extensive testing was performed to determine appropriate design properties for the FRP laminates. Full scale beams were fabricated and tested for flexure and shear and another for two million fatigue cycles. All tests showed good correlation among a simplified grillage analysis, hand calculations, and a 3D finite element model. Since no specific AASHTO criteria have been developed for FRP, the following protocol was used to determine acceptability of the system.

1) Confidence in the properties of the FRP materials at the coupon level was established. The material was manufactured in strict accordance with ISO 9001 quality procedures and then tested and certified by an outside entity. The design team was assured that there would be consistency in quality throughout the manufacturing process.

2) A rigorous finite element model was used. The design was also checked by simple application of conventional elastic beam theory. The ability to load rate the bridge in the future without relying on sophisticated methods was important to the bridge owner.

3) The completed structural panels were subjected to load testing in the shop, prior to shipping and then again after the bridge was fully assembled on site. The actual response of the structures was checked against the theoretically predicted behavior. Tests displayed no non-linearities that might indicate an unacceptable condition. The results of the various tests and analyses methods were consistent within a few percent. A final load test of the completed bridge provided additional information that was used to produce load ratings of the structure.

4) The bridge railing was given special attention for obvious safety and liability reasons. Prototypes were tested in flexure, shear, and in an ultimate loading condition to validate the system devised for the bridge railing anchorage.
The superstructure panels were provided with a permanent, shop applied resin coating to protect it from degradation due to ultra-violet (UV) light and to prevent moisture ingress. No further painting is expected to be necessary over the life of the structure.

Another measure taken to extend the life of the structure was the application of a thin (1/4") protective polymer concrete wearing surface. This epoxy and aggregate overlay was installed after all panels were anchored and joined, providing an extra layer of protection against water and chloride penetration into the concrete deck and field joints. In the future, if this wearing surface wears, it can easily be refreshed in-kind.

As additional protection against deterioration, only non-corrosive stainless steel reinforcement was used in the deck. The concrete deck was placed on the FRP, in shop conditions and handled properly to avoid cracking. The entire concrete deck can be replaced in the field if necessary, though this is not expected to be necessary over the life of the bridge.

SUBSTRUCTURE

Prefabricated concrete components were assembled like “Lego” blocks rather than formed and cast in place as a unit. The first abutment took approximately 1 week before the prefabricated bridge seat was able to be installed; the south abutment was constructed to a similar level in less than 1 day.

Fabrication in a controlled shop conditions consistently provides a good quality product that shorter time required in the field. Both the abutments and wingwalls used locally pre-cast concrete blocks. All of these blocks were easily lifted by an excavator, and put in place and aligned by a small crew. After each layer of blocks was installed on the abutment and wingwall, the backfill was installed and compacted. Between selected layers, geogrid was installed into the backfill to provide additional stability to the wall.

The site was subjected to very high water within a year of completion and the modular system suffered no damage at all.

ASSEMBLY

The new structure has a span length of 8.9 m (29.2 ft), and a 8.5 m (28.0 ft) rail-to-rail width. These dimensions did not allow for the superstructure to be fabricated as single unit. This was especially true based on the fact that the superstructure was prefabricated in Australia and then shipped to the United States for installation. In order to allow for shipping and placement, the superstructure was fabricated as four full length panels, each being 2.18 m (7.15 ft) wide. The size of the panels meant that no special hauling permits would be required for overwidth or overweight vehicles for delivery to the project site.

As the substructure was being readied, the superstructure panels were being shipped to the project site. The panels were also light enough that they were able to be lifted off of the delivery
trucks (25,000#) and set in place using two excavators, eliminating the need for a crane at the job site and saving on the cost of installation. See figure 3.

Figure 3. The superstructure consists of four light weight panels

Each of the four panels for the superstructure were designed rectangular in section and constructed with the same dimensions. The bridge seat was sloped to provide the crown on the deck for drainage. Once the panels were aligned, anchor bolts were installed and grouted through the superstructure into pre-existing holes in the bridge seat.

The panels were joined along longitudinal joints with a closure pour of non-shrink cement grout or polymer concrete. This joint constituted a shear key needed to assure that panels worked together under load. See figure 4. Two of the three keys were filled with Portland cement based grout. The final joint was filled with an epoxy and aggregate mixture. The purpose of the different joint material is to determine the durability of this connection over time, and with various materials.

Figure 4. Shear key between deck panels
BRIDGE RAILING

Standard New York State Department of Transportation (NYSDOT) approved, crash-tested steel railing was used on the bridge. It meets the requirements of TL-3 loading defined in NCHRP Report 350. Anchorage units (aka rail post stubs) were designed using AASHTO load criteria for this railing such that bolted connections provide for a progressive failure of the system in the event of a collision. These units develop strength primarily from stainless steel embedded in the concrete deck and can survive a vehicular collision that destroys the railing, yet leaves the concrete deck intact. It is galvanized and epoxy coated and bolts onto the bridge. See figure 5.

Although it is expected to be 100% maintenance free over the life of the bridge, it is replaceable if need be. A full scale, destructive test verified its inherent strength and the fact that the deck will not be damaged.

Figure 5. Bridge Railing Anchorage

SCHEDULE

Demolition of the existing bridge started September 7, 2004. In order to achieve accelerated construction, an aggressive construction schedule was included in the contract, as well as per-day incentives. The duration of the road closure, which included the total time for the demolition of the existing bridge and the construction of the new bridge, was set at 40 calendar days in the contract. An incentive/disincentive clause was also included in the contract, which had a payment/credit of $1000 per calendar day for a maximum of 10 calendar days to encourage the contractor to complete the construction as rapidly as possible. Conducting this demonstration of accelerated construction on a low risk, low volume road allowed the County to gain experience with this type of contract so they could be confident when employing it in the future.
The abutments and wingwalls were ready for installation of the superstructure on September 21, two weeks to the day after the road was closed to traffic. The first truck carrying the two interior superstructure panels arrived at the job site at approximately 11:30 am. By approximately 1:00 pm these two panels were in place and aligned. The second truck carrying the final two panels arrived at approximately 3:00 pm. By approximately 5:30 pm, all four of the panels had been put into place and the fit checked. The next day, all panels were anchored to the abutments and the longitudinal joints installed.

LOAD TESTING AND RATING

On October 5, two trucks weighing approximately 34 tons each were driven over the bridge in specific locations to measure the actual deflections and strains of the bridge. These results compared favorably to the predicted values, proving that the mathematical models were truly representative of the actual structure. Inventory ratings for the bridge are Inventory HS96 (173 tons) and Operating HS148 (267 tons). The high capacity is testament to the fact that the design of FRP structures is deflection driven. It also indicates that there may be additional costs that can be taken out in the future to make them even more economical. The maximum live load deflection under HS25 design load has been determined to be $L / 1745$, which is about twice as stiff as the specification called for. Dead load stresses are less than 4% of the FRP’s ultimate value, which will eliminate any potential for creep.

SUMMARY

Though New Oregon Road in Erie County is a small project, it is likely to have a large impact on future construction. It demonstrated:
1) How little field time is truly needed to replace a small highway bridge.
2) Maintenance-free short span superstructures can be affordable.
3) Bridge owners could easily and quickly install a new superstructure on existing abutments to immediately improve a bridge without getting involved in a large project.
4) Prefabricated, lightweight structural panels can be employed to quickly replace decks on existing bridges that have high traffic volumes with little disruption to traffic.

CONCLUSIONS

Interrupting traffic to perform infrastructure repair is costly and is becoming unacceptable to the motoring public. The New Oregon Road project serves as a model case study for an alternative approach. A prefabricated, lightweight superstructure was installed in two days as part of total bridge replacement that took only 31 days. The County’s contractor used a small crew and light equipment to demolish the old bridge, install a modular substructure, and have a completely new bridge ready for traffic in 1/3 the time of a conventionally handled project. This sets a new standard for the schedules of short span bridge replacement projects. Furthermore, because of
the selection of corrosion resistant materials, a service life in excess of 100 years is expected, without the need for any midlife deck replacement.

ACKNOWLEDGMENTS

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REFERENCES

O’Connor, Jerome S. “GRP Bridge Decks & Superstructures in the USA,” Reinforced Plastics, page 26-31, June 2008