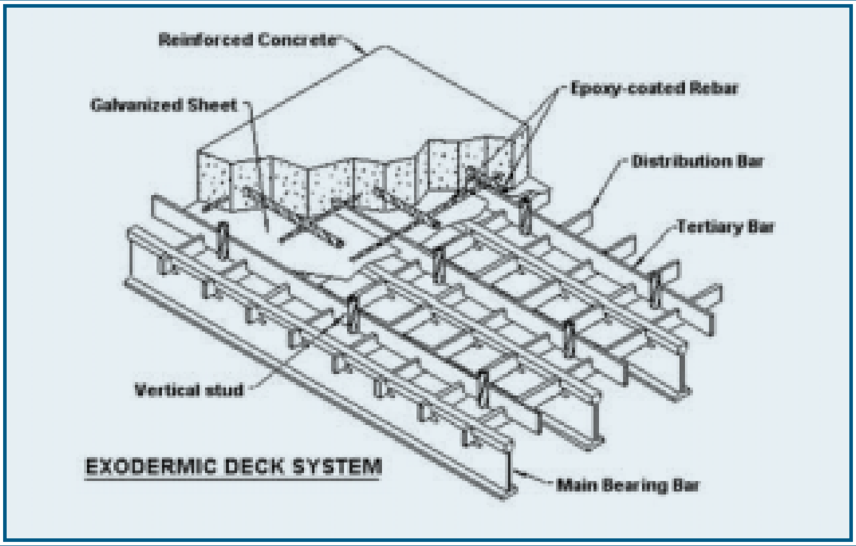
EXODERMIC DEXKS AND STEEL BRIDGES

Recent revisions to the Exodermic design promise to further reduce costs and simplify erection



Pictured at top is part of the Boston Central Artery/Tunnel Project. Shown above is a cut-away drawing of a typical Exodermic deck system.

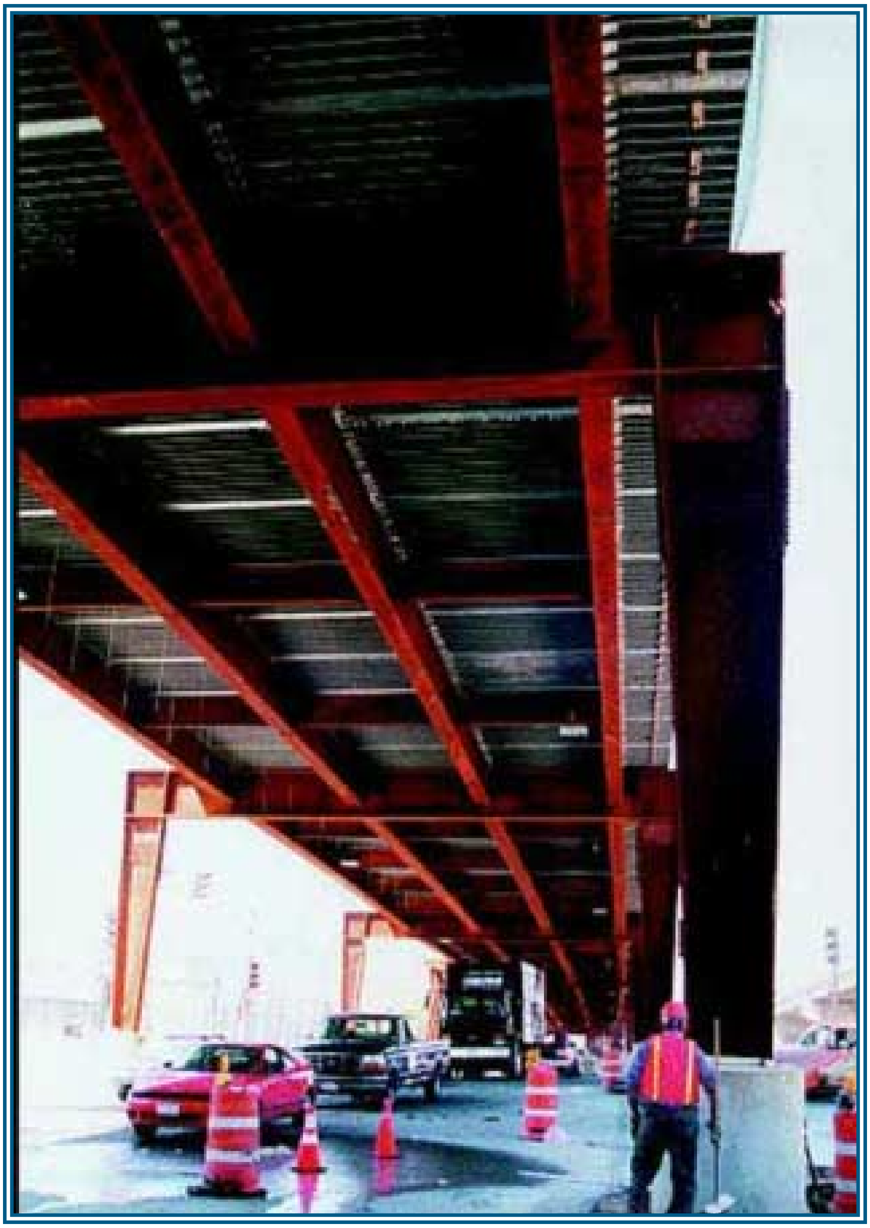
By Robert A. Bettigole

AN EXODERMIC OR "UNFILLED, COMPOSITE STEEL GRID" BRIDGE DECK (AASHTO LRFD 9.8.2.4) is comprised of an unfilled steel grid typically 7.5 cm to 13 cm (3" to 5.2") deep, with a 9 cm to 13 cm reinforced concrete slab on top of it. A portion of the grid extends up into the reinforced concrete slab, making the two composite. The concrete portion of an exodermic deck can either be cast-in-place (the grid panels act as rapidly erected formwork), or precast, where the fastest construction is needed. Because the materials (steel and concrete) in an exodermic deck are used more efficiently than in a reinforced concrete slab, an exodermic design can be substantially lighter without sacrificing stiffness and strength.

In a standard reinforced concrete deck, in positive bending, the concrete at the bottom of the deck is considered 'cracked' and provides no practical benefit. Thus, the effective depth of the slab is reduced, and the entire bridge—superstructure and substructure—has to carry the dead load of this s 'cracked' concrete. In an exodermic deck, essentially all of the concrete is in compression and contributes fully to the section. The main bearing bars of the grid handle the tensile forces at the bottom of deck. Because the materials (steel and concrete) in an exodermic deck are used more efficiently than in a reinforced concrete slab, an exodermic design can be substantially lighter without sacrificing stiffness and strength. In negative bending, the reinforcement in the concrete handles the tensile forces, as it does for a conventional concrete deck. Rebar in the concrete component of an exodermic deck can be specified to handle the negative moment, where the deck is continuous over supporting beams, or where a cantilever is required.

Exodermic decks can be specified to accommodate the particular requirements of a specific bridge. To date, overall deck thickness on different projects has ranged from 6.75" to 10". The concrete component of an exodermic deck can be precast or cast-in-place. In the latter case, the steel grid can be thought of as a composite stay-in-place form, where the strength of the steel grid panels permits longer spans, if necessary, and elimination of half the concrete.

If precast deck panels are called for, during precasting, blockouts are used so that there is no concrete over the grid in the areas that will be over floor beams and stringers. During erection, headed shear studs are welded through these openings in the deck onto the stringers or floor beams below. These portions of the deck are filled full depth with rapid-setting concrete which captures the shear connectors (now attached to the superstructure) and the grid and rebar of the deck modules, locking them together and making them composite. No field welding of the grid to supporting beams or grid panels to each other is required.



Shown is the underside of one of the bridges in the new Boston Central Artery/Tunnel Project.

Rehabilitation

Because the bridge deck bears the direct effect of the deteriorating influences of traffic, road salts, and weather, many bridge rehabilitation projects include bridge deck replacement. In some ways, this provides a design opportunity.

Where a bridge needs strengthening in order to achieve a specific load rating (typically HS-20 or HS-25), the designer has several options:

- Replace or strengthen the deficient steel elements — stringers, girders, floor beams, and truss members.
- If the existing deck was non-composite with its supporting beams, make the new deck composite through the use of welded headed shear studs to add significant capacity to the beams.
- Reduce the dead load that the structure must carry by reducing the weight of the deck. Any reduction in dead load permits a corresponding increase in live load capacity.

Reducing dead load increases liveload capacity directly. It also may reduce the amount of structural steel replacement or strengthening that is required. And reduced deck dead load can have a beneficial impact on the seismic performance of the structure, reducing the cost and complexity of seismic retrofits. An exodermic deck can reduce deck weight by 40% or more compared to a standard reinforced concrete slab without sacrificing stiffness or strength.

The other aspect of steel bridge rehabilitation addressed by exodermic decks is speed of deck replacement.

Closing bridge structures is increasingly untenable, and alternatives must be found. Even staged construction can be problematic. People value their time more, and are unwilling to spend it tied up in traffic.

NEW CONSTRUCTION

In new construction, reduction of deck dead load with a lightweight deck system permits a lighter steel superstructure and consequently, a lighter substructure as well. Speed of construction can also be an important consideration when evaluating deck choices, particularly where the new structure is replacing a bridge that has been withdrawn from service.

MILTON-MADISON BRIDGE

The US 421 bridge links the towns of Milton, KY, and Madison, IN, across the Ohio River. The 3200' bridge is a major link in the area, with the next closest crossing 25 miles up river. A $7.9 million rehabilitation contract was let in April 1996, with contractor Jim Skaggs, and their subcontractor, Intech Contracting submitting the low bid. A precast exodermic deck had been chosen by the Kentucky Department of Highways (KDOH) and their consultant, Hazelet & Erdal/Dames & Moore, in order to speed erection, and to reduce the dead load that the structure must carry. Although aided by the reduction in dead load, substantial structural repairs were required to truss members as well as floor beams.

The bridge is comprised of 19 spans of deck truss, thru truss, and deck girder construction. The four main spans are 600', 600', 727', and 254' in length. Because of the unacceptably long detour that closing the bridge would entail, KDOH determined the work would be done in stages, maintaining at least one lane of traffic on the two lane structure at all times. The narrowness of the bridge (less than 23' between trusses) and the desire to get the work done as quickly as possible required a precast, panelized deck system. Several other factors made the choice of an Exodermic deck compelling. Firstly, the light weight of the exodermic deck - 59 PSF with normal weight concrete versus approximately 100 PSF for a conventional standard weight concrete deck - reduced stress levels on the aging structure, and permitted an increase in the live load rating. Secondly, exodermic deck's cantilever capacity permitted staged construction and maintenance of traffic even though there are no center stringers on most spans. And thirdly, an exodermic deck offered an excellent riding surface. Unlike other lightweight deck systems, the top portion of an exodermic deck is essentially the top half of a standard concrete bridge deck and can be overlaid and maintained just as any standard concrete deck. On this project, after over 73,000 s.f. of bridge deck was replaced, the deck was milled ¼" and overlaid with 1½" of latex-modified concrete, in accordance with standard Kentucky Department of Highways practices for new bridge decks.

Deck replacement work began in August 1996 and was completed by early summer 1997, after delays due to severe flooding of the Ohio River. The contractor was able to ramp up productivity quickly. In less than one week, they were able to remove and replace over 360 linear feet (one lane) of deck and have it back in service, all the time maintaining traffic in the adjacent lane.

Maintenance and protection of traffic was a key concern of the Kentucky Department of Highways and the consultants. Throughout the project, traffic shared a reversible single lane around the work zone, with only occasional brief stoppages. During holidays, the bridge was completely open to traffic, as it was over the winter months. A temporary steel guardrail was used around the work zone to protect traffic and workers. With only an 11' lane width to work in, with traffic moving in the adjacent lane at virtually all times, the contractor came up with an innovative deck erection plan.

Moveable bridges such as the Main Street Bascule Bridge in Green Bay, are a growing market for Exodermic bridge deck systems.

Another view of the Exodermic bridge deck system during installation on the Main Street Bascule Bridge in Green Bay,

Deck replacement for a typical stage began with a long, split shift day. In the morning, the first crew began to remove the existing deck, using saws and large forklift trucks. By mid-afternoon, 360' of deck, one lane wide, had been removed, and a second crew followed the first, cleaning the tops of the stringers and forming the haunch areas. Finally, the two forklift trucks worked quickly to place approximately 53 exodermic deck panels, approximately 11' by 7', which include an integral precast curb and railing anchorages. By the end of the day, the old deck had been removed, and new panels set into approximate position, closing the opening in the deck. Safety of the project was much improved with this approach. The fork lift trucks were driven right onto the previously set panels, minimizing interruption of traffic, and avoiding the need for a crane on the bridge. The narrow roadway and thru truss design of most spans would have made use of a crane difficult at best. Over the next few days, panels were set into proper position and elevation (using built -in leveling bolts), rebar was coupled mechanically at the centerline of the bridge, shear studs were welded with a stud gun, and the panels secured in place with a concrete closure pour. Finally, the new barrier was bolted in place. Hazelet & Erdal Dames & Moore chose to mount the railing to the top of the curb to increase lane widths to 10'-5 ½". The Kentucky Department of Highways figured that this approach saved six months to a year over a conventional cast-in-place concrete deck.

On the Milton Madison Bridge, the exodermic deck was constructed of a 3¾" reinforced concrete slab composite with a 3" deep grid, for a total deck panel thickness of 6¾". Final deck thickness after milling and overlay placement was 8".

Boston Central Artery/Tunnel Project

On an average day, 95,000 vehicles travel the three southbound lanes of I-93 (the "Central Artery") in Boston. In the summer of 1997, this traffic began traveling on a 1700' viaduct constructed with a cast-in-place exodermic deck. The lightweight deck spans 11' between girders, and carries a precast concrete Jersey barrier on a 4' 4½" cantilever.

One portion of the Central Artery/Tunnel Project involves a third tunnel across the harbor, connecting the Massachusetts Turnpike (I-90) with Boston's Logan Airport. The new interchange between I-90, I-93 (the "Central Artery"), and the new tunnel will take an estimated 5 to 6 years to complete. For at least that time, I-93 traffic will be diverted to several "interim" viaducts.

The first of these is the 1700' Interim Viaduct over Albany Street, or "IVAS", now carrying the three southbound lanes of I-93 (beginning at the intersection with the Massachusetts Turnpike) for the duration of the project. Some estimates see the viaduct in service for as long as 8 to 10 years.

Albany Street is parallel and immediately adjacent to the existing I-93. In the fall of 1996, J.F. White/Slattery/Interbeton J.V., and their sub-contractor, Saugus Construction, began construction of IVAS. With the exception of the concrete component of the exodermic deck, the structure is of all steel construction – steel pilings, columns, pier caps, and girders. The lightweight of the structure's cast-in-place exodermic deck, and the efficiency of the deck in acting as a composite top flange on the girders, permitted the use of 36" rolled beams for the girders.

The efficient exodermic design permitted wide girder spacing (11') and a 4'-4½" cantilever. The steel grid portion of over 72,000 s.f. of exodermic deck was fabricated by L.B. Foster in western Pennsylvania, and was delivered in panels as large as 41'-10½" x 7' 10". The 5" deep steel grid is composite with a 4½" cast-in-place concrete slab, yielding a deck weight of 74 psf, over 30% less than a conventional concrete deck. Rebar in the slab was chosen to handle the large negative moments found at the cantilever and over the girders.

The deck's lightweight translated into steel savings in both the super and substructures, according to the project's designers, Berger Lochner, Stone & Webster joint venture. Each span (up to 104') is comprised of steel columns and pier caps into which frame four 36" rolled beams on 11' center. The entire structure (aside from pilings, etc.) was designed with re-use of local structures in mind. The exodermic deck will eventually be removed when the structure is dismantled, probably using a hydromilling technique known as "hydro-slotting". This technique permits the removal of the concrete over the girders that capture the deck rebar and grid as well as the welded headed shear studs attached to the beams.

Main Street Bascule Bridge

Because dead load has always been a primary consideration in the design of movable bridges, there has been a long history of the use of open steel grid for bridge decks on bascule bridges. Recently, however, owners have preferred to use a closed deck system where feasible, avoiding the riding surface that some drivers find disconcerting, and protecting the bridge and its machinery from the corrosive effects of road salt, debris, and precipitation.

Three new bascule bridges have been designed with exodermic decks to provide a closed deck while keeping deck dead load low. All three designs take advantage of the efficiency of the exodermic design, allowing the elimination of stringers. That is, the deck spans in the direction of travel, floor beam to floor beam. Two bridges are located in Florida, and are large, twin, double leaf trunnion bascules. The first such project to be erected is the Main Street Bridge in Green Bay.

The old Strauss Trunnion Bascule Bridge over the Fox River at Main Street in Green Bay had been slated for replacement for some time. When the piers began to exhibit some instability in 1995, the bridge was closed and demolished. At the time, the Chicago and Minneapolis offices of Parsons Brinkerhoff Quade & Douglas had already been selected to design a replacement bridge. After studies, the city chose a Scherzer rolling lift design over a more conventional trunnion-type bascule, in keeping with the predominance of the Scherzer type in the city.

Early on in the design process, a decision was made to provide a concrete riding surface, and the different deck options were considered. The final design called for an exodermic deck.Overall dimensions of the bridge are:

- Centerline pinion to centerline center break: 26m• Overall girder length: 34m• Centerline girder to centerline girder: 17.6m
- Roadway width: 16.6m• Sidewalk width (both sides): 2.9m
- Total width: 19.5m Framing consists of floor beams at 4.1m spacing, with longitudinal and bottom lateral bracing. In the absence of stringers, the exodermic deck spans floor beam to floor beam. The exodermic deck is composite with the floor beams through the use of standard welded-headed shear studs.

Revised Exodermic Design

The revised exodermic design is simpler and less expensive to fabricate, and with the elimination of the tertiary bars, deck erection will be simplified. Static and fatigue testing at Clarkson University has confirmed the merits of this evolution of the exodermic concept. A major redecking project on the Tappan Zee Bridge will be the first use of the revised exodermic design.

Historically, the exodermic deck evolved from traditional concrete-filled grids. The idea was to move the concrete from within the grid to the top of the grid in order to make more efficient use of the two components. Putting the concrete on top also allowed the use of reinforcing steel in the slab to significantly increase the negative moment capacity of the design, and to move the fabrication welds of the grid closer to the neutral axis of the section. A shear connecting mechanism was required between the grid and the slab, and this was provided by the addition of "tertiary bars" to which were welded short, ½" diameter studs. The tertiary bars are welded to the grid during fabrication of the exodermic grid panels, and extend up 1" into the structural slab.

In the revised design, the tertiary bars are eliminated, and their function is taken over by the extension of the main bars of the grid 1" into the slab; ¾" diameter holes are punched in the top 1" of the main bars, to aid in the engagement of the bars with the concrete.

TAPPAN ZEE BRIDGE PROJECT

Beginning in early summer, 1998, work is scheduled to begin on a 250,000 square foot redecking project on the New York State Thruway Authority's Tappan Zee Bridge. Precast exodermic panels using the revised exodermic design described above were employed, and all the work had to be done during nighttime lane closures. The contractor began work at 8 PM, and had to have all seven lanes completely open to traffic each morning by 6 AM. Similar nighttime deck replacement work using precast exodermic panels has been completed twice before on this bridge, in emergency repairs completed in 1994, and on one span on the west side of the bridge during a large rehabilitation project completed in 1997.

Robert A. Bettigole is President of Exodermic Bridge Deck, Inc. This article was condensed from a paper delivered at the World Steel Bridge Symposium. Copies of the full proceedings are available from the NSBA.