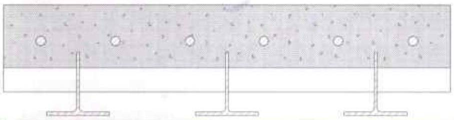
EXO



An Introduction to:
Exodermic Bridge Decks

Why Use An Exodermic Bridge Deck?

LIGHT WEIGHT

An Exodermic deck typically weighs 35% to 50% less than a reinforced concrete deck that would be specified for the same span. Reducing the deadload on a structure can often mean increasing the liveload rating. The efficient use of materials in an Exodermic deck means the deck can be much lighter without sacrificing strength, stiffness, ride quality, or expected life.

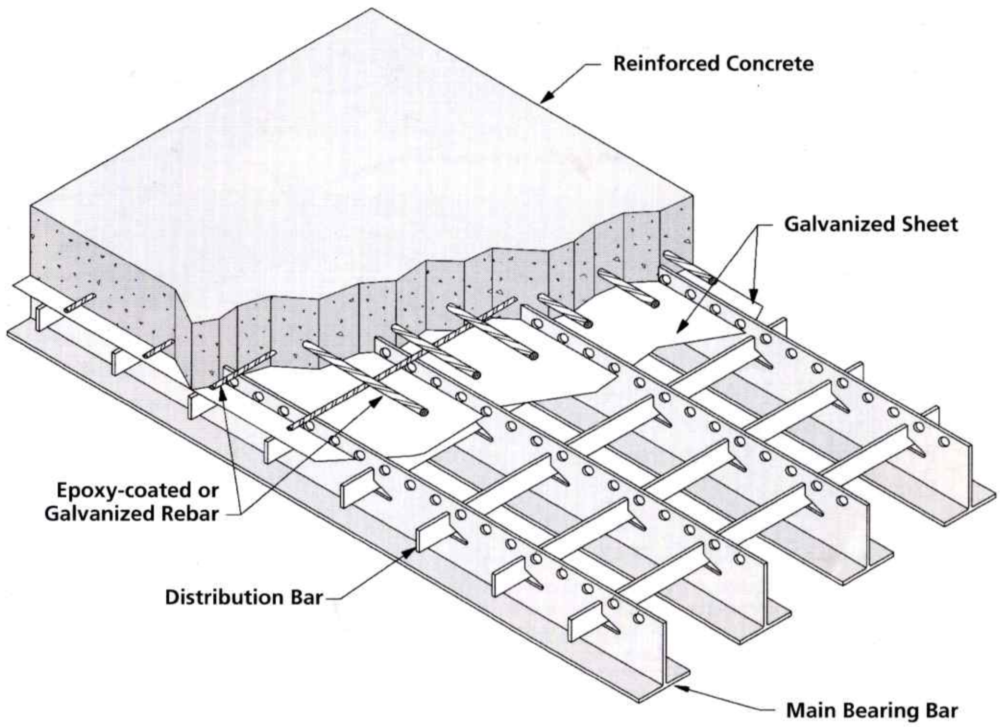
RAPID CONSTRUCTION

Precast Exodermic decks can be erected during a short, nighttime work window, allowing a bridge to be kept fully open to traffic during the busy daytime hours.

Cast-in-place Exodermic decks also permit considerable savings in construction time – the steel grid panels come to the site essentially ready for concrete. The steel grid component of an Exodermic deck acts as a pre-cut, pre-formed, stay-in-place form. Panels are quickly placed, and layout of the single mat of rebar is simple and straightforward, without the need for chairs or other aids in most cases. Cantilevered decks can be formed without temporary supports.

EASE OF MAINTENANCE

An Exodermic deck is easily maintained with standard materials and techniques, since the top portion of an Exodermic deck is essentially the same as the top half of a standard reinforced concrete deck. If desired, any overlay compatible with concrete can be used, including latex modified concrete, polymer concrete, microsilica concrete, or a membrane with asphaltic concrete overlay.



OVERVIEW

An Exodermic (or "composite, unfilled steel grid") deck is comprised of a reinforced concrete slab on top of, and composite with, an unfilled steel grid. This maximizes the use of the compressive strength of concrete and the tensile strength of steel. Horizontal shear transfer is developed through the partial embedment in the concrete of the top portion of the main bars which are punched with 3/4" holes.

Overall thickness of the system using standard components ranges from 6" to 9 1/2"; Total deck weights range from 39 to 74 pounds per square foot. Exodermic decks using standard components can span over 18'; larger main bearing bars and /or thicker concrete slabs can be chosen to span considerably further.

The concrete component of an Exodermic deck can be precast before the panels are placed on the bridge, or cast-in-place. Where the concrete is cast-in-place, the steel grid component acts as a form, the strength of which permits elimination of the bottom half of a standard reinforced concrete slab.

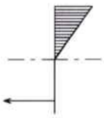
Exodermic decks are made composite with the steel superstructure by welding headed studs to stringers, floor beams, and main girders as appropriate, and embedding these headed studs in full depth concrete. This area is poured at the same time as the reinforced concrete deck when the deck is cast-in-place, or separately when the deck is precast. Exodermic decks require no field welding other than that required for the placement (with an automatic tool) of the headed shear studs.

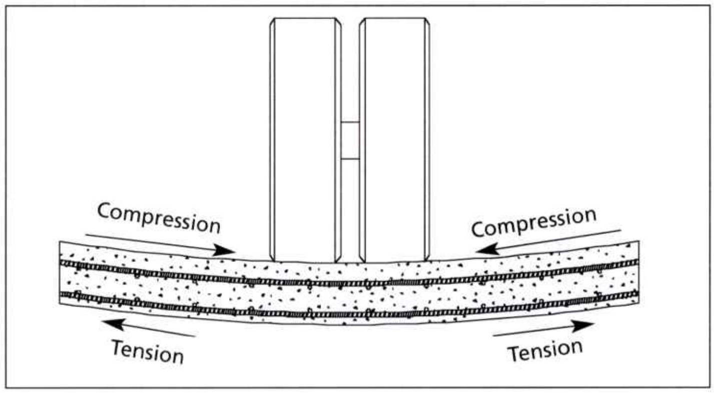
Exodermic Design — How It Works

In Positive Bending

Standard Reinforced Concrete Deck

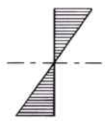
In a standard reinforced concrete deck, in positive bending, the concrete at the bottom of the deck is considered 'cracked' and provides no practical benefit. Thus, the effective depth and (stiffness) of the slab is reduced, and the entire bridge – superstructure and substructure – has to carry the dead load of this 'cracked' concrete.

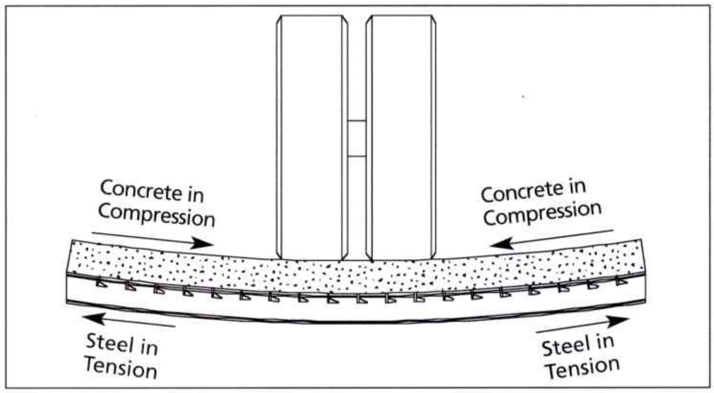




Exodermic Deck

In an Exodermic deck in positive bending, 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 or strength.

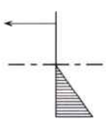


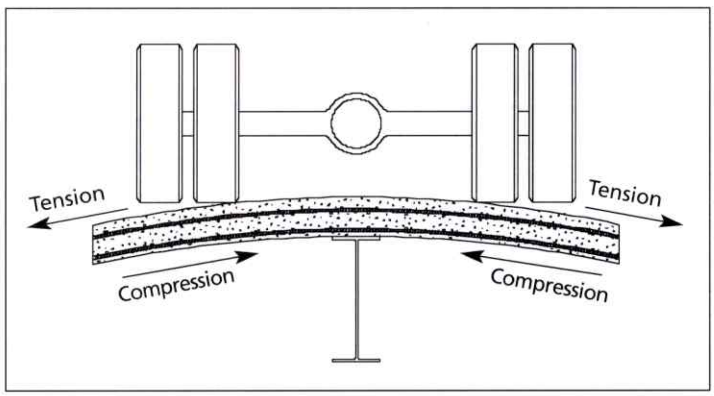


In Negative Bending

Standard Reinforced Concrete Deck

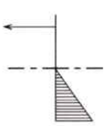
In negative bending, a standard reinforced concrete deck handles tensile forces with the top rebar; concrete handles the compressive force at the bottom of the deck.

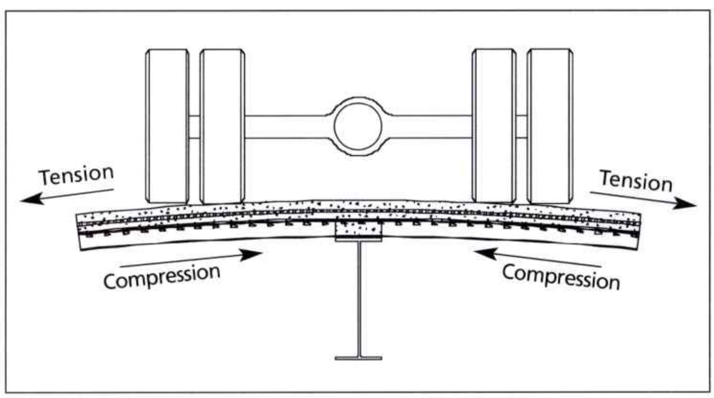




Exodermic Design

Similarly, in an Exodermic design, the rebar in the top portion of the deck handles the tensile forces, while the compressive force is borne by the grid main bearing bars and the full depth concrete placed over all stringers and floorbeams. Rebar can be selected to provide significant negative moment capacity for longer continuous spans and sizable overhangs.





Construction & Erection Notes

Precast Exodermic Decks

Pre-cast exodermic decks are an excellent choice where the roadway must be returned to active service as soon as possible. Precasting allows rapid deck replacement during a short, nighttime work window, with roadways fully open to traffic during the day.

During precasting, blockouts or slotted forms exclude concrete from deck panel areas that will be directly over the top flanges of stringers, girders, or floorbeams.

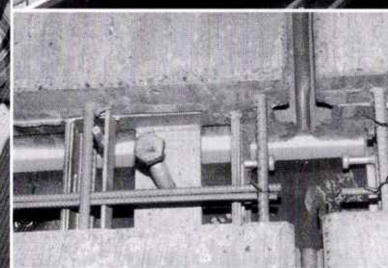
Haunches are generally formed before placing deck panels on the bridge. Self-adhesive foam strips, galvanized sheet steel or structural angles (connected with straps or welded to the supporting beam), and timber have all been used successfully.

Once positioned, panel elevation is set by built-in leveling bolts, headed shear connectors are welded to the superstructure through blockouts in the precast concrete, and this area is filled full depth with rapid setting concrete. The use of 3/8" maximum coarse aggregate is recommended. Alternatively, headed studs may be laid out and welded in position before the deck panels are landed.

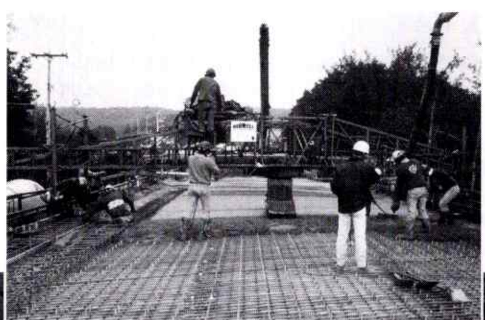
If desired, an overlay can be applied after all panels are placed. Latex modified concrete, polymer concrete, microsilica concrete, or a membrane and asphaltic concrete may be specified.

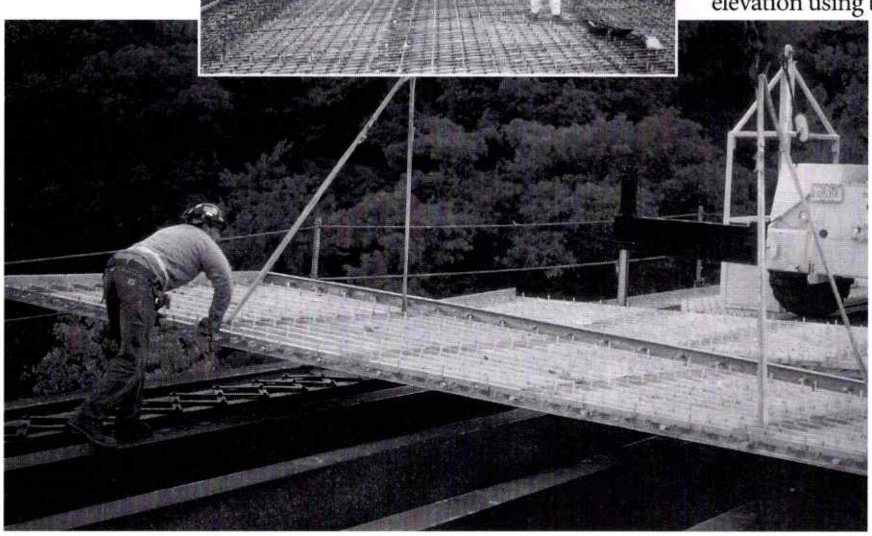
Typical transverse connections between panels are double female shear keys filled with rapid setting grout or concrete after the panels are in place. Field-placed haunch and shear key concrete should be properly consolidated with a 'pencil' type vibrator.

Where desirable (such as in areas over supports where negative movements are high), rebar can be spliced between panels by several methods.



Top Photo: Overnight Deck Replacement
Above Left: Shear Stud Placement
Above Right: Built-in Leveling Bolt and Transverse Shear Key
Below Left, Bottom: Grid Panel Positioning
Below Left, Upper: Concrete Placement - Cast-in-Place Deck





Cast-in-Place Exodermic Decks

Cast-in-place Exodermic decks are simple and straightforward to erect.

Haunches may be formed before placing deck panels on the bridge, using self-adhesive foam strips, galvanized sheet steel or structural angles (connected with straps or welded to the supporting beam), or timber.

Exodermic steel grid panels are placed and set to the required elevation using built-in leveling bolts.

Headed studs are welded or bolted through the grid to the superstructure, rebar is placed, and concrete is poured.

In effect, the steel grid panels act as super 'stay-in-place' forms, and little or no additional formwork is required in the field. Rebar layout is straight forward. Bottom rebar (typically #3 bars) sit directly on the main bars. Concrete fills the 'haunch' areas, capturing the headed shear studs at the same time the finished riding surface is poured. The use of 3/8" maximum coarse aggregate and a 'pencil' type vibrator are recommended.

The concrete can be finished with a textured surface for skid resistance, or any overlay compatible with standard reinforced.

Exodermic Design

Design History

Historically, the Exodermic deck evolved from traditional concrete-filled grids. The innovation 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 moved the neutral axis of the section close to the fabrication welds of the grid. A shear connecting mechanism was required between the grid and the slab to make the two composite. This was originally provided by the addition of "tertiary bars" to which were welded short, 1/2" diameter studs.

Revised Design

In the revised design described in this publication, the tertiary bars have been eliminated, and their function taken over by the extension of the main bars of the grid 1" into the slab. 3/4" diameter holes are punched in the top 1" of the main bars, to aid in the engagement of the bars with the concrete.

Static and fatigue testing of the revised design was conducted at Clarkson University, and is in accordance with ASTM specification D6275-98, "Standard Practice for Laboratory Testing of Bridge Decks." The fatigue test consisted of two million load cycles delivered to a two span continuous panel through two loading shoes simulating a full HS-20 truck axle (with impact). No significant difference in behavior of the panel was observed from start to finish of the test.

Design Flexibility

The designer has a number of choices to make in choosing an Exodermic deck configuration: main bar size and spacing, rebar size and spacing, and concrete thickness. A number of Exodermic decks have used a 4 1/2" concrete component in order to provide a standard 2 1/2" of cover over rebar, and 1" of bottom cover. Achieving desired deck thickness and weight may require reducing the concrete thickness. Exodermic decks have been constructed with concrete component thicknesses of 3" to 5". Service history dates to 1984, when an Exodermic deck was used on the longest bridge on the Garden State Parkway (NJ). Lightweight concrete can be specified where weight is particularly critical.

While any steel grid can be used in constructing an Exodermic deck, use of industry standard grid configurations is advised where possible to avoid costs associated with new tooling. The standard types are referred to by the size of structural T employed as the main bearing bar: WT4 × 5 or WT6 × 7. Please check with EBDI for availability of alternate main bar sizes. Section moduli and other properties of standard and non-standard Exodermic deck configurations are available from EBDI.

Choice of main bearing bar type is generally determined by desired deck thickness and span. Depending on span, the WT4 × 5 grid should provide the lightest option, minimizing the amount of full depth concrete over supports and the full depth transverse connection between panels.

The older style of Exodermic deck, using separate tertiary bars (with welded vertical studs), can still be specified, although the revised design presented in this publication should be significantly less expensive and more rapidly installed.

Design Criteria

- AASHTO 1996 16th Edition (with interims)
- Transformed Area Method (3.27.2.2)
- Service Load (working stress) Design

Materials

- A709 Grade 36 Steel $f_b = 0.55\ F_y = 20$ksi (10.32.1)
- A709 Grade 50 Steel $f_b = 27$ ksi (10.32.1)
- Steel Weight 490 lbs./cu.ft.
- Concrete weight 145 lbs/cu.ft. without rebar (10.38.1.3) (115 lbs/cu.ft. lightweight)
- $f'_c = 4000$ psi; n = 8 (10.38.1.3) (8.15.3.4)
- $f_c = 0.4f'_c$ (8.15.2.1.1)
- Concrete not considered in tension regions

Loads and Moments

- Impact 30% (3.8.2.1)
- Continuity factor: 0.8 for dead and live load (3.24.3.1)
- Dead load moment, precast: full composite section (n=24, if higher stresses result) (10.38.1.4)
- Dead load moment: cast-in-place: grid section only
- Live load: full composite section positive and negative moment
- Main Bearing Bars transverse to traffic:
  - $M_{DL} = WS^2/8$ (x 0.8 if continuous)
  - $M_{LL} = \{(S+2)/32\}\ P$ (× .8 if continuous) (3.24.3.1)
    For HS-20, P = 16 × 1.3 × 0.8, where 1.3 is the factor for impact and 0.8 for continuity
    For HS-25, P = 20 × 1.3 × 0.8, where 1.3 is the factor for impact and 0.8 for continuity
- Main Bearing Bars parallel to traffic:
  - $M_{DL} = WS^2/8$ (× 0.8 if continuous)
  - $M_{LL} = 900S$ (× 0.8 if continuous) (3.24.3.2)
- Distribution Factor S/5.5 (3.23.2.2)
- S = distance between edges of stringer flanges + 1/2 flange width (3.24.1.2.b)
- Deflection limited to *L*/800 (10.6.2)
- Also covered by AASHTO LRFD Specifications, 2nd Edition, 1998, Section 9.8.2.4.1 "Unfilled Grid Decks Composite" with Reinforced Concrete Slabs"

The information provided herein was prepared with reference to generally accepted engineering practices. It is the responsibility of the user of this information to independently verify such information and determine its applicability to any particular project or application. EBDI assumes no liability for use of any information contained herein. While Exodermic design is covered by US and Canadian patents (US: 4.531,857; 4,531,859; 4,780,021; 4,865,486; 5,509,243; 5,664,378. Canadian: 1,218,551; 1,286,137; 1,299,418), with additional US and international patents pending, its availability from multiple, independent, licensed suppliers allows it to be considered 'generic' in most jurisdictions.

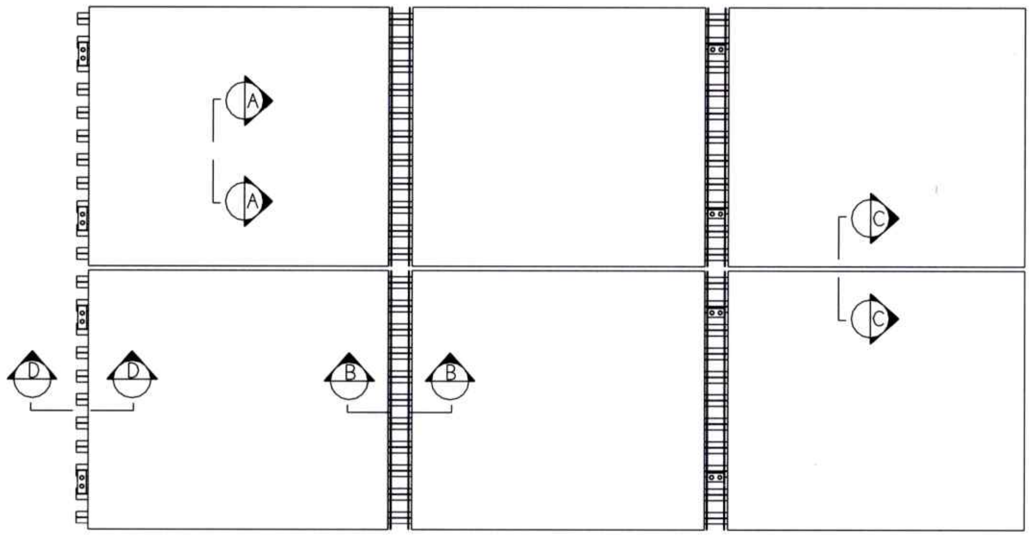
Deck Properties & Spans

Overall Depth (in.)	Concrete Thickness (in.)	Top Rebar & Spacing (in.)	Weight (lbs/sf): Normal Concrete	Weight (lbs/sf): Lightweight Concrete	Moment of Inertia (in⁴): I_{pos}	Moment of Inertia (in⁴): I_{neg}	Section Modulus (in^3), Positive Bending: Top of Concrete	Section Modulus (in^3), Positive Bending: Bottom of Main Bar	Section Modulus (in^3), Negative Bending: Top Rebar	Section Modulus (in^3), Negative Bending: Top of Distrib Bar	Section Modulus (in^3), Negative Bending: Bottom of Main Bar	Maximum Spans (ft.), Main Bars Transverse To Traffic, Cast in Place: HS-20	Maximum Spans (ft.), Main Bars Transverse To Traffic, Cast in Place: HS-25	Maximum Spans (ft.), Main Bars Transverse To Traffic, Precast: HS-20	Maximum Spans (ft.), Main Bars Transverse To Traffic, Precast: HS-25	Maximum Spans (ft.), Main Bars Parallel To Traffic, Cast in Place: HS-20	Maximum Spans (ft.), Main Bars Parallel To Traffic, Cast in Place: HS-25	Maximum Spans (ft.), Main Bars Parallel To Traffic, Precast: HS-20	Maximum Spans (ft.), Main Bars Parallel To Traffic, Precast: HS-25
Grid: WT4x5 @ 8" C-C (weight of grid w/ pans = 11.4 lbs/sf)																			
7.4	4.5	#6 @ 3	69.9	59.2	41.41	16.33	111.51	-9.35	-8.02	-53.89	6.29	12	11	12	11	10	8	10	8
7.4	4.5	#6 @ 4	68.8	58.0	41.40	14.23	111.08	-9.37	-6.13	-24.17	6.15	12	11	12	11	9	8	10	8
7.4	4.5	#5 @ 4	67.8	57.0	41.36	11.39	110.32	-9.40	-4.35	-11.96	5.85	12	9	10	8	8	6	7	6
7.4	4.5	#5 @ 8	66.7	55.8	41.35	7.58	109.92	-9.42	-2.41	-5.12	5.34	6	4	5	4	4	3	4	3
6.4	3.5	#6 @ 3	57.8	49.6	30.05	16.33	95.35	-7.75	-8.02	-53.89	6.29	10	9	10	9	10	8	10	8
6.4	3.5	#6 @ 4	56.7	48.4	29.82	14.23	93.04	-7.77	-6.13	-24.17	6.15	10	9	10	9	10	8	10	8
6.4	3.5	#5 @ 4	55.8	47.4	29.50	11.39	90.25	-7.79	-4.35	-11.96	5.85	10	9	10	8	8	6	7	6
6.4	3.5	#5 @ 8	54.7	46.2	29.23	7.58	87.73	-7.83	-2.41	-5.12	5.34	6	4	5	4	4	3	4	3
Grid: WT4x5 @ 10" C-C (weight of grid w/ pans = 10.0 lbs/sf)																			
7.4	4.5	#6 @ 5	66.8	56.0	35.50	11.38	102.07	-7.69	-4.90	-19.33	4.92	11	9	11	9	8	6	8	7
7.4	4.5	#5 @ 5	66.1	55.1	35.50	9.12	101.81	-7.70	-3.48	-9.57	4.68	9	7	8	6	6	5	6	5
7.4	4.5	#5 @ 10	65.2	54.2	35.50	6.07	101.89	-7.70	-1.93	-4.10	4.27	4	3	4	3	3	3	3	2
6.4	3.5	#6 @ 5	54.7	46.4	25.38	11.38	84.51	-6.35	-4.90	-19.33	4.92	9	8	9	8	8	6	8	7
6.4	3.5	#5 @ 5	54.0	45.5	25.21	9.12	82.62	-6.37	-3.48	-9.57	4.68	9	7	8	6	6	5	6	5
6.4	3.5	#5 @ 10	53.1	44.6	25.08	6.07	81.01	-6.39	-1.93	-4.10	4.27	4	3	4	3	3	3	3	3
Grid: WT4x5 @ 12" C-C (weight of grid w/ pans = 9.0 lbs/sf)																			
7.4	4.5	#6 @ 6	65.4	54.5	31.23	9.48	95.26	-6.54	-4.09	-16.11	4.10	9	7	10	8	6	5	7	5
7.4	4.5	#5 @ 4	65.5	54.6	31.25	9.41	94.98	-6.55	-4.19	-16.35	4.05	9	7	10	8	6	5	7	5
7.4	4.5	#5 @ 6	64.8	53.8	31.23	7.60	95.29	-6.54	-2.90	-7.98	3.90	7	5	7	5	5	4	5	4
6.4	3.5	#6 @ 6	53.4	45.0	22.21	9.48	78.24	-5.38	-4.09	-16.11	4.10	9	7	9	8	7	5	7	5
6.4	3.5	#5 @ 4	53.4	45.1	22.17	9.41	77.89	-5.38	-4.19	-16.35	4.05	9	7	9	8	6	5	7	5
6.4	3.5	#5 @ 6	52.7	44.3	22.12	7.60	76.91	-5.39	-2.90	-7.98	3.90	7	5	7	5	5	4	5	4
Grid: WT6x7 @ 8" C-C (weight of grid w/ pans = 15.3 lbs/sf)																			
9.4	4.5	#6@3	73.7	63.0	84.20	37.60	184.12	-14.68	-11.82	-26.27	10.87	18	16	18	16	15	13	17	14
9.4	4.5	#6@4	72.7	61.9	83.87	32.61	181.51	-14.72	-9.20	-18.19	10.52	18	16	18	16	15	13	15	12
9.4	4.5	#5@4	71.7	60.8	83.44	26.46	178.51	-14.76	-6.77	-11.91	9.91	17	15	16	13	10	9	10	9
9.4	4.5	#5@8	70.6	59.6	83.08	18.34	175.69	-14.81	-4.07	-6.51	8.84	8	8	8	8	6	6	6	5
8.4	3.5	#6@3	61.6	53.4	66.43	37.60	165.31	-12.83	-11.82	-26.27	10.87	16	14	16	14	16	13	16	14
8.4	3.5	#6@4	60.6	52.3	65.56	32.61	159.87	-12.83	-9.20	-18.19	10.52	16	14	16	14	16	13	15	12
8.4	3.5	#5@4	59.6	51.2	64.54	26.46	154.04	-12.81	-6.77	-11.91	9.91	16	14	16	13	10	9	10	9
8.4	3.5	#5@8	58.5	50.0	63.54	18.34	148.24	-12.80	-4.07	-6.51	8.84	8	8	8	8	6	6	6	5
Grid: WT6x7 @ 10" C-C (weight of grid w/ pans = 13.2 lbs/sf)																			
9.4	4.5	#6@5	70.0	59.1	71.64	26.09	166.10	-12.06	-7.36	-14.55	8.42	17	15	17	14	13	10	12	10
9.4	4.5	#5@5	69.2	58.3	71.44	21.17	164.20	-12.09	-5.41	-9.53	7.93	13	12	13	10	8	8	8	7
9.4	4.5	#5@10	68.3	57.3	71.29	14.67	162.53	-12.12	-3.26	-5.21	7.07	6	6	6	6	4	4	4	4
8.4	3.5	#6@5	57.9	49.6	55.65	26.09	144.91	-10.46	-7.36	-14.55	8.42	14	13	14	13	13	10	12	10
8.4	3.5	#5@5	57.1	48.7	55.03	21.17	140.69	-10.45	-5.41	-9.53	7.93	13	12	13	11	8	8	8	7
8.4	3.5	#5@10	56.2	47.8	54.44	14.67	136.60	-10.46	-3.26	-5.21	7.07	6	6	6	6	4	4	4	4
Grid: WT6x7 @ 12" C-C (weight of grid w/ pans = 11.8 lbs/sf)																			
9.4	4.5	#6@6	68.2	57.3	62.83	21.74	154.56	-10.23	-6.14	-12.12	7.01	14	13	15	12	11	9	10	8
9.4	4.5	#5@4	68.3	57.4	62.79	21.79	154.24	-10.24	-6.31	-12.34	6.97	14	13	15	12	11	9	10	8
9.4	4.5	#5@6	67.6	56.6	62.74	17.64	153.32	-10.25	-4.51	-7.94	6.61	11	9	11	9	7	6	7	6
8.4	3.5	#6@6	56.1	47.7	48.59	21.74	133.92	-8.85	-6.14	-12.12	7.01	13	12	13	12	11	9	10	8
8.4	3.5	#5@4	56.2	47.8	48.52	21.79	133.64	-8.84	-6.31	-12.34	6.97	13	12	13	12	11	9	10	8
8.4	3.5	#5@6	55.5	47.0	48.19	17.64	130.73	-8.85	-4.51	-7.94	6.61	11	9	11	9	7	6	7	6

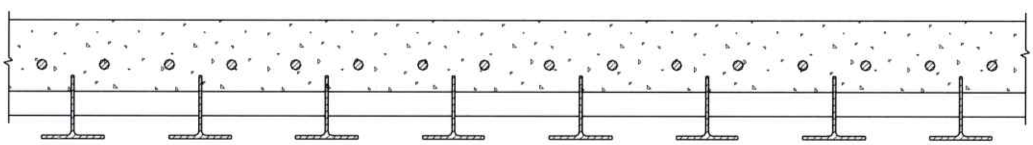
Notes:

- Spans are centerline support to centerline support, with 7" flange width assumed. 4000 psi concrete, n=8 (n=24 for sustained deadload).
- Weights shown are exclusive of "haunch" concrete (between top of beams and top of distribution bars), additional full depth concrete at connections between panels, and any additional deck overlay. Negative section modulus indicates tension.
- For other deck configurations, or for other information, please contact EBDI.

Typical Details

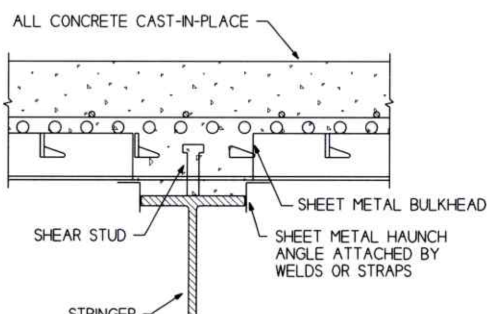


PLAN VIEW - PRECAST PANELS SHOWN (NOT TO SCALE)

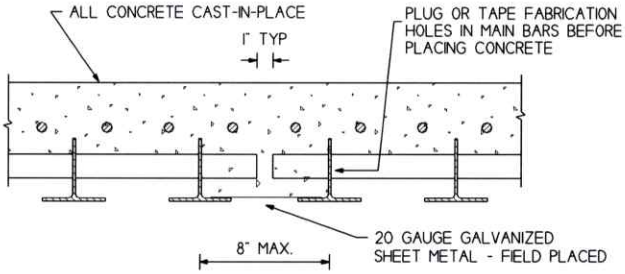


SECTION A-A

CAST-IN-PLACE DETAILS

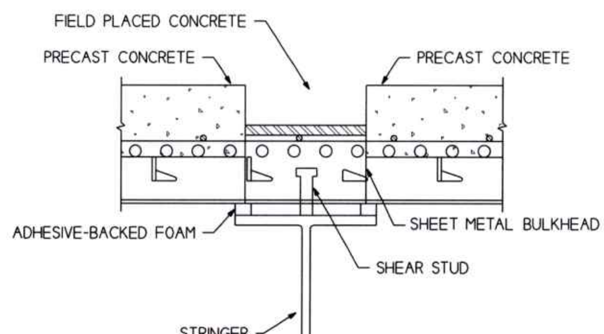


SECTION B-B
(OTHER HAUNCH FORMING OPTIONS POSSIBLE)

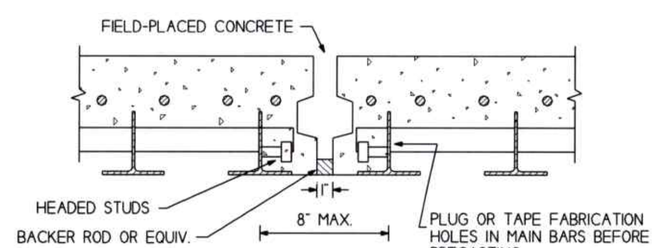


SECTION C-C

PRECAST DETAILS



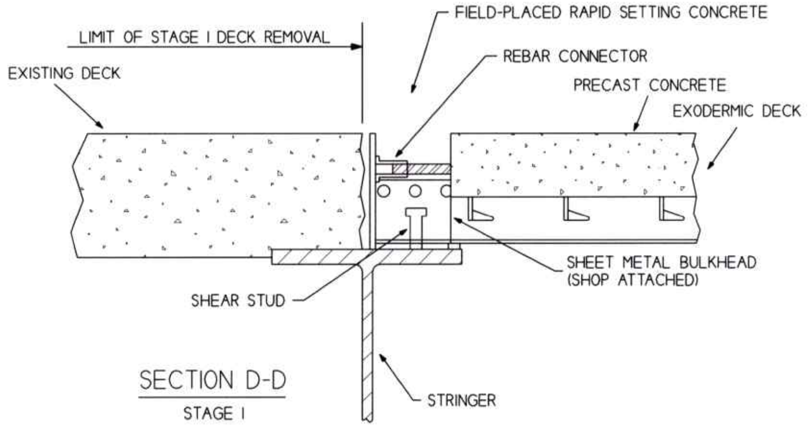
SECTION B-B
(OTHER HAUNCH FORMING OPTIONS POSSIBLE)



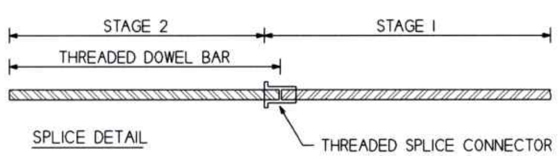
SECTION C-C

Typical Details

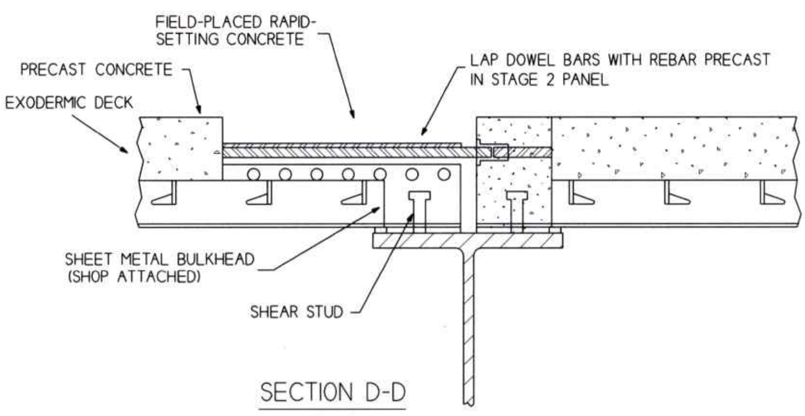
DECK SPLICE FOR STAGED CONSTRUCTION



SECTION D-D
STAGE I

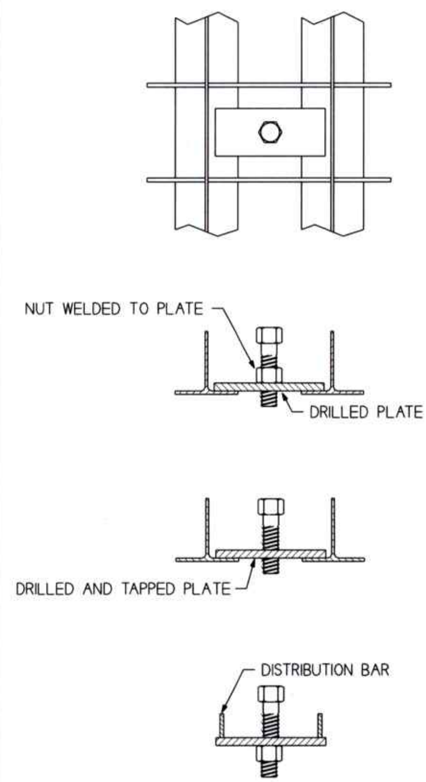


SPLICE DETAIL

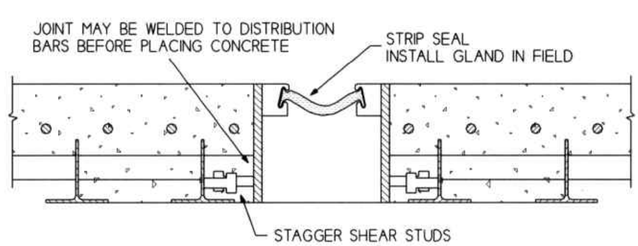


SECTION D-D
STAGE 2

ALTERNATE HEIGHT ADJUSTMENT DETAILS

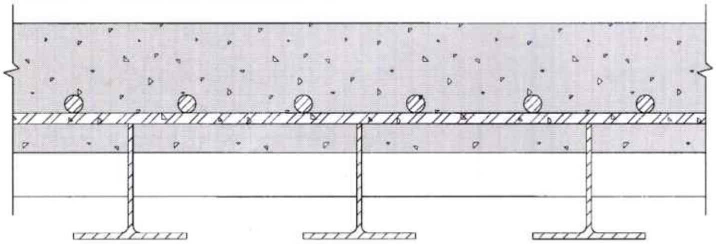


TYPICAL JOINT DETAIL



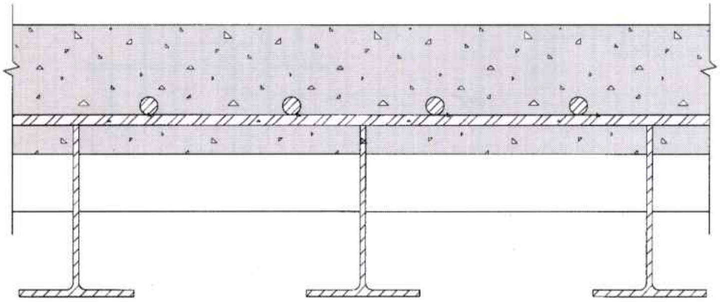
Alternate Grid Configurations

WT4 × 5 Main Bars



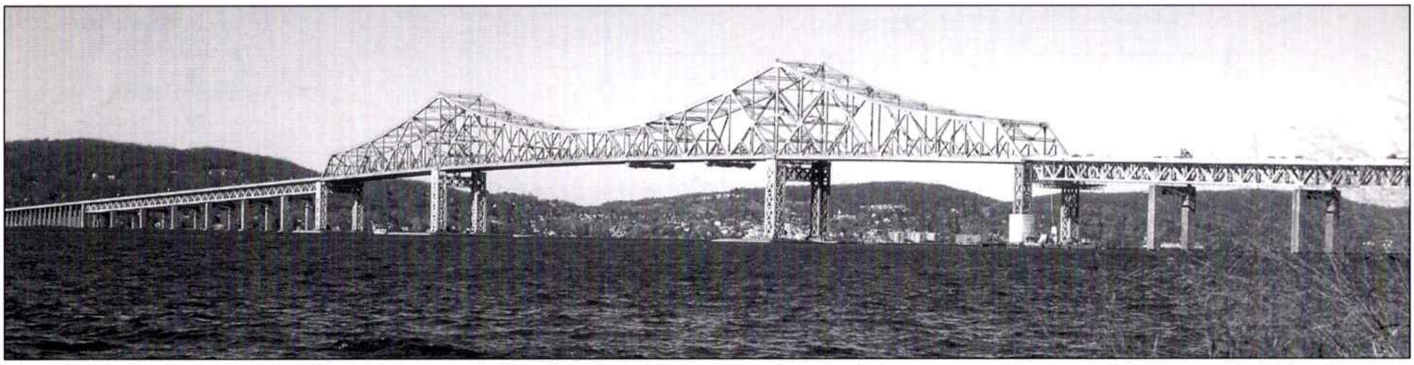
- Overall Deck Thickness: 6" to 7 1/2"
- Weight*: Lightweight concrete: From 39 lbs to 59 lbs
  Standard weight concrete: From 47 to 70 lbs
- Spans to: 12 ft. (HS-20); 11 ft. (HS-25), main bars transverse to traffic.
  10 ft. (HS-20); 8 ft. (HS-25), main bars parallel to traffic.
- Main bearing bar spacing: 8", 10", or 12"
- Distribution bar: 1 1/2" × 1/4" @ 6" c-c
- Rebar as required.

WT6 × 7 Main Bars



- Overall Deck Thickness: 8" to 9 1/2"
- Weight*: Lightweight concrete: From 42 lbs to 63 lbs
  Standard weight concrete: From 51 lbs to 74 lbs
- Spans to: 18 ft. (HS-20); 16 ft. (HS-25), main bars transverse to traffic.
  16 ft. (HS-20); 13 ft. (HS-25), main bars parallel to traffic.
- Main bearing bar spacing: 8", 10", or 12"
- Distribution bar: 2" × 1/4" @ 6" c-c
- Rebar as required.

**Note on weights: Weights shown include grid, typical rebar, and concrete. Add weight for full depth haunches over stringers and for shear keys or full depth connections between panels. Concrete weight without rebar is 145 lbs/cu.ft. (normal weight) (10.38.1.3) or 115 lbs/cu.ft. (light weight).*



The revised Exodermic design was used in the nighttime redecking of over 250,000 square feet of the east deck truss spans of the Tappan Zee Bridge over the Hudson River.

For Further Information

Exodermic Bridge Deck, Inc. is an information source for Exodermic design and construction, providing printed and computer-based design aids, suggested specifications, and informational materials to bridge engineers, owners, and contractors. EBDI is glad to provide sample designs for specific projects. Several computer programs aid the analysis of alternate loadings and deck configurations. Details are available on paper or diskette.

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