Form Deck - A Versatile Family of Products

Richard B. Heagler

Author

Richard B. Heagler is director of engineering for Nicholas J. Bouras, Inc., and United Steel Deck, Inc. of Summit, New Jersey. He received his bachelor of science and master of science and professional degrees in civil engineering from the University of Missouri at Rolla. He has been involved in the steel deck industry for over thirty-five years. In 1962 he began his career at Granco Steel Products, St. Louis, Missouri and joined Nicholas J. Bouras, Inc. in 1977.

Mr. Heagler has written articles on connecting steel deck and on designing with steel deck, and is the author of *Engineers Notebook for the Design of Composite Steel Beams and Girders with Steel Deck.* He is also the principal author of the Steel Deck Institute's *Composite Deck Design Handbook.*

Mr. Heagler is the chairman of the Steel Deck Institute's Technical Committee on Floor Deck, and is the chairman of the American Society of Civil Engineer Standards Committee on Composite Deck. He is also an ex-president of the Steel Deck Institute.

Mr. Heagler is a registered Professional Engineer in the state of Missouri, New Jersey, and New York.

Summary

Composite floor deck has received most of the research attention over the last thirty years. But, non composite for deck is the most versatile of the deck products. These products range in thickness of 0.135" to 0.015" and the applications are numerous. This paper discusses some of the experience factors, fire ratings, and design details that are used with form decks.

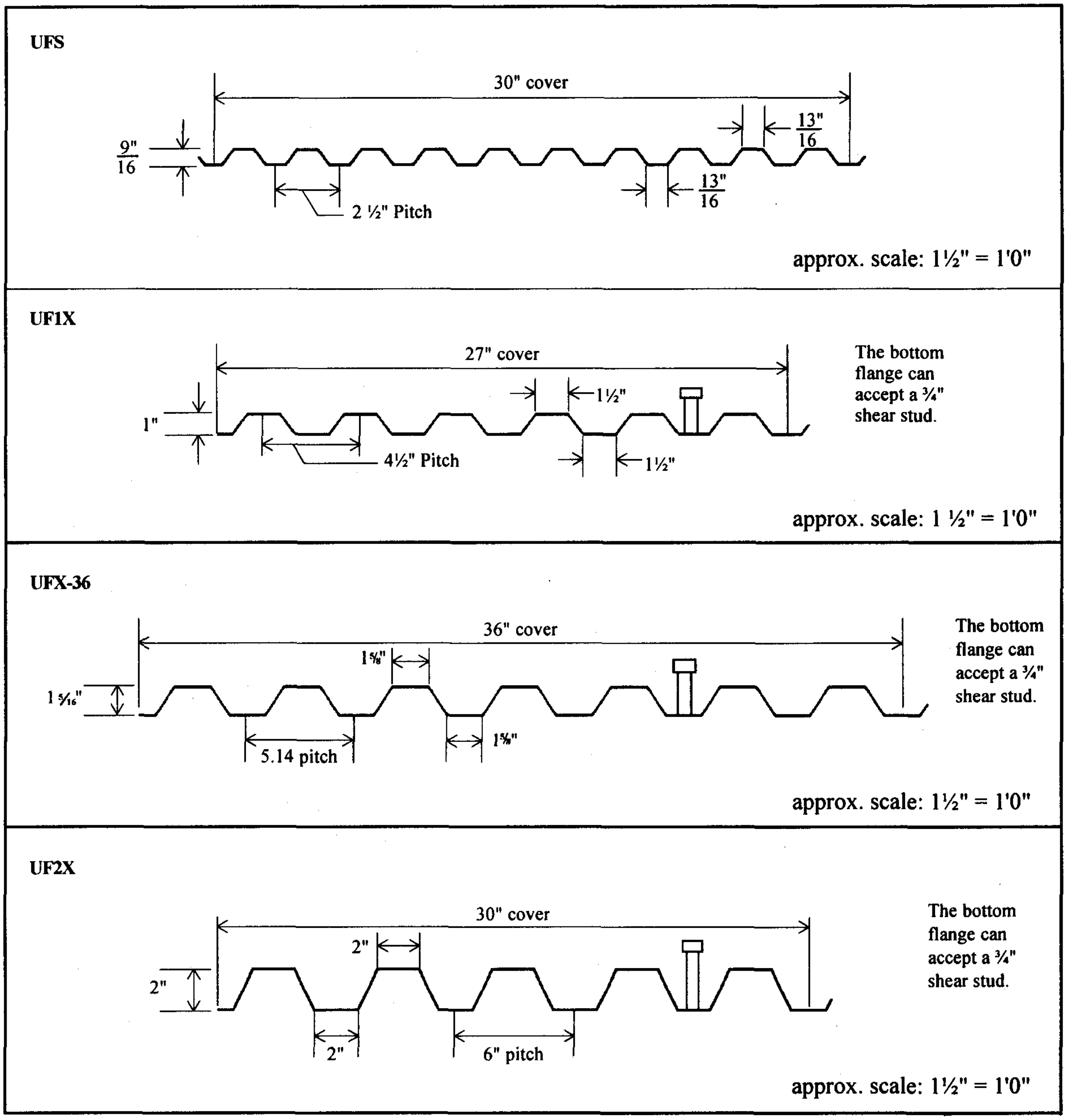
STEEL FORM DECK

INTRODUCTION

Composite deck is the product that has attracted the most attention and certainly the most research during the last thirty years. However, before there was composite deck there was non composite "form deck" which still enjoys a part of the market. "Form deck" might be considered a misnomer because the material is used in many ways besides being a stay in place form for concrete. The purpose of this paper is to discuss the usual "form" use as well as other functions and present some of the engineering and "experience" that influences the design.

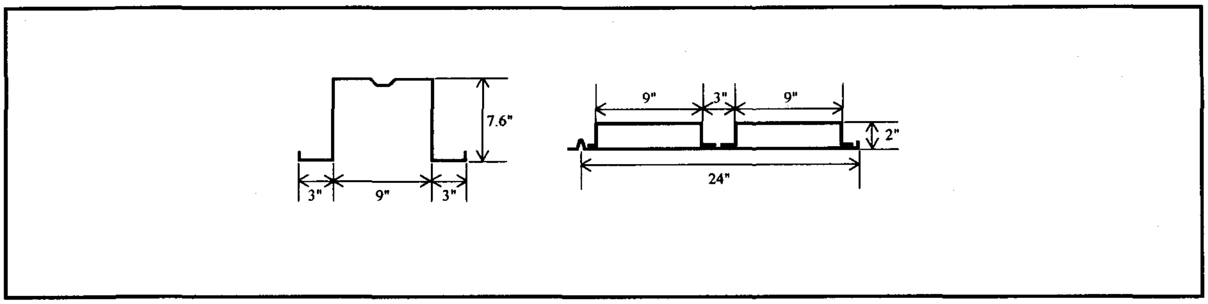
Because this deck type can be used in such a variety of ways it has not had the same design or profile constraints that have influenced the shapes of the two other conventional products - roof deck and composite deck. Indeed, almost any deck, including floor deck and roof deck, can be considered to be "form deck" simply depending on its use. Figure 1 shows form deck profiles regularly produced by United Steel Deck, Inc. and Figure 2 shows some of the custom profiles that have been produced to satisfy a particular job needed. The gages range from 10 (0.135 in., 3.4 mm) to 28 (0.0149 in., 0.38 mm) and the depths range from 9/16 in. (14 mm) to 7.6 in. (193 mm). This great variety of types illustrates that the product covers a wide range of uses. The steel grades also cover a wide range - specified yield points range from 33 to 80 ksi.

Figure 1



UFS
30" cover
13"/16
9"/16
13"/16
2 ½" Pitch
approx. scale: 1½" = 1'0"
UF1X
27" cover
1½"
1"
4½" Pitch
1½"
The bottom flange can accept a ¾" shear stud.
approx. scale: 1 ½" = 1'0"
UFX-36
36" cover
1⅝"
1 5/16"
5.14 pitch
1⅝"
The bottom flange can accept a ¾" shear stud.
approx. scale: 1½" = 1'0"
UF2X
30" cover
2"
2"
2"
6" pitch
The bottom flange can accept a ¾" shear stud.
approx. scale: 1½" = 1'0"

Figure 2

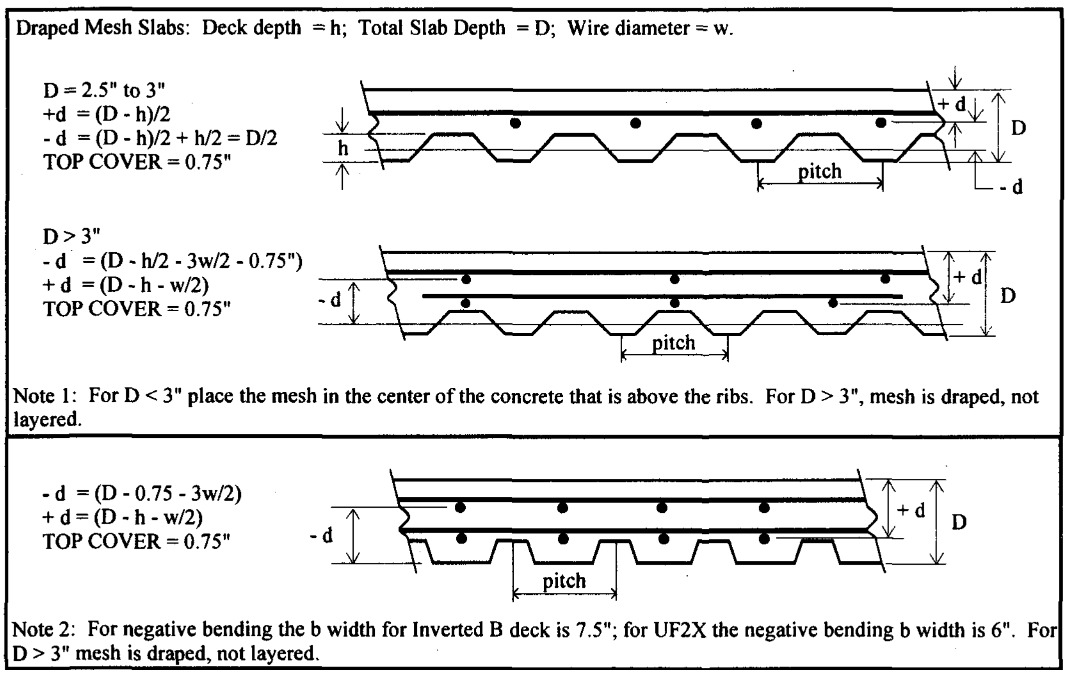


I. FORM FOR REINFORCED CONCRETE SLABS

When deck is used as a stay in place form for reinforced concrete slabs the first obvious question is how the ribs influence the slab design. The second, not so obvious question, is about the functions the deck performs after the slab is in use - we are talking about stay in place forms, not a removable form.

For building construction the rib influence on the slab design is illustrated in figure 3.

Figure 3

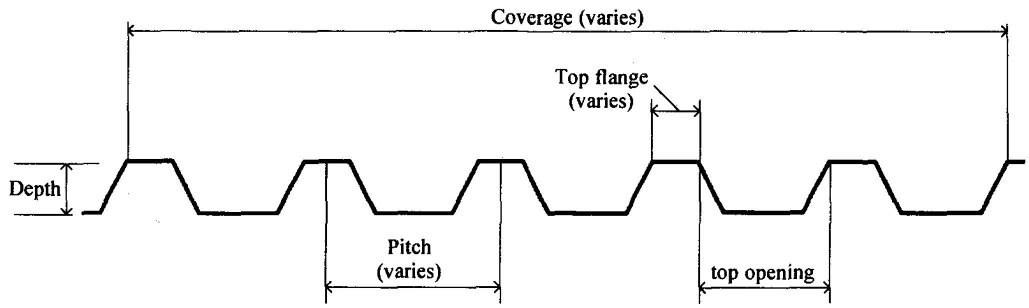


Note 1 Form decks with h < 1.5 and Pitch < 6.0 have a slab b width of 12" for both positive and negative bending.

Note 2. Form decks with h ≥ 1.5 or Pitch ≥ 6.0 have a slab b width of 12" for positive bending and a b width for negative bending = average rib width x 12/pitch.

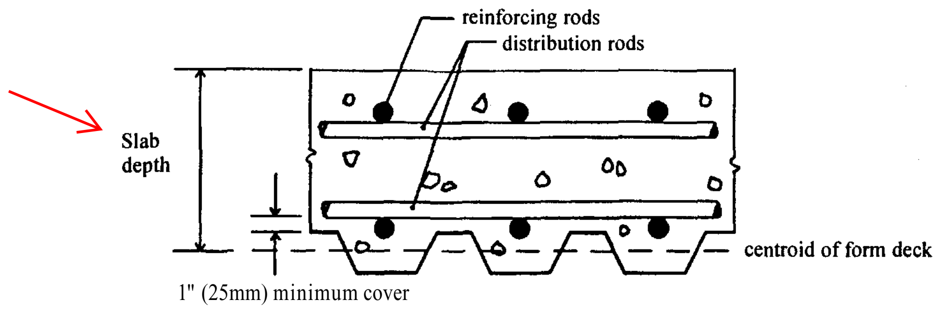
These design considerations evolved from experience rather than from an extensive research program and, in general, reflect the normal conservative approach used by engineers. For stay in place bridge forms the rib influence depends on the design considerations of the particular state highway department. Figure 4 shows a cross section of bridge form panel.

Figure 4



Almost every dimension is shown as a variable and in fact manufacturers can vary the pitch and the rib width. Some highway departments want the rib spacing (pitch) to match the rebar spacing; in this case the bottom of the slab is located at the centroid of the form deck as shown in Figure 4A.

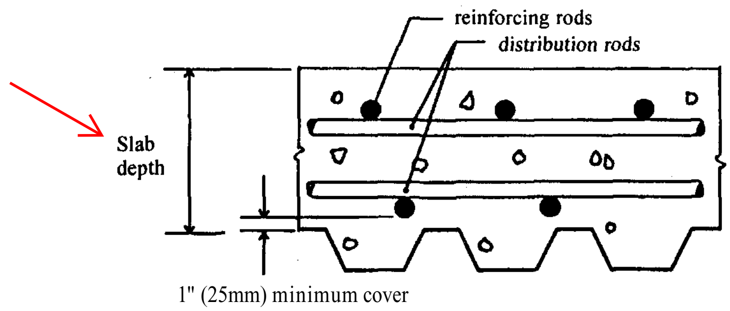
Figure 4A



Bottom of slab at centroid of form

The opinion of other highway departments is that the bottom of the slab is the top of the deck as shown in Figure 4B; in this case the concrete in the ribs is simply dead load so it can be advantageous to keep the rib width as narrow as possible.

Figure 4B

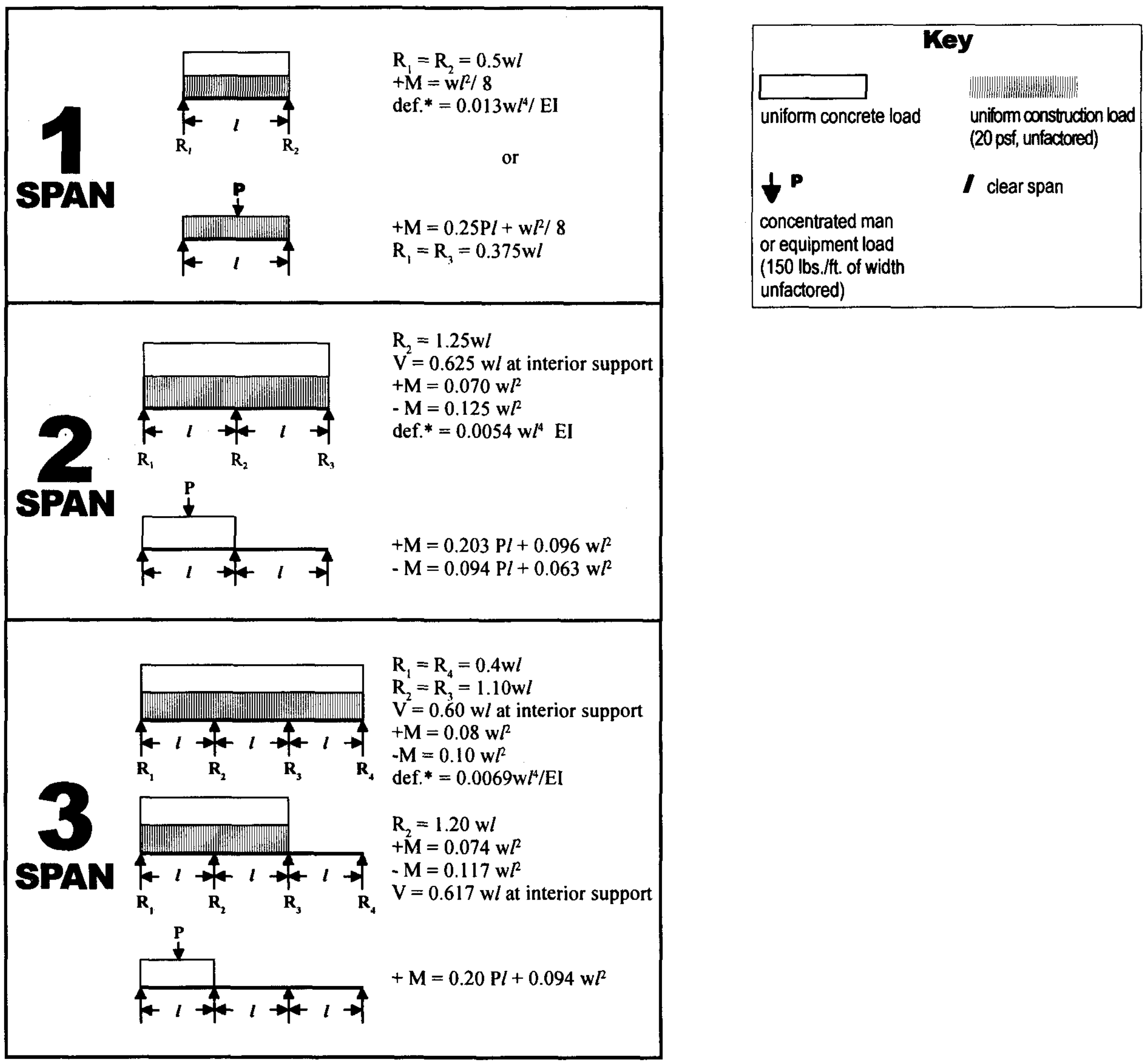


Bottom of slab at top of form

Deck manufacturers are more concerned with the performance of form deck under construction loading than the slab design. The deck must be capable of supporting the concrete weight and the loads of workmen during the concrete placing phase and the slab design is the responsibility of the design engineer or architect.

For building construction, the SDI construction loading shown in Figure 5 is used.

Figure 5



For single spans only, the concrete load shall include either an additional 50% of the concrete weight or 30 psf whichever is less.

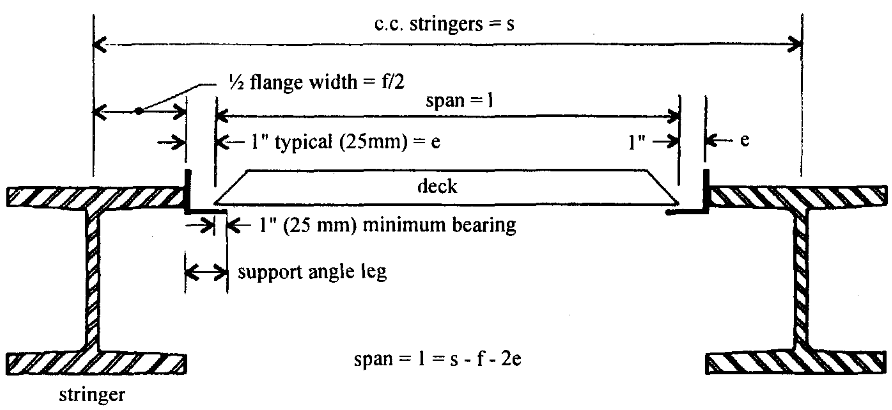
* Deflection is to be calculated using only concrete plus deck weights uniformly distributed overall spans.

This is the same loading used for composite floor deck. The loading formulas are used to calculate the maximum allowable unshored spans; most slab construction is done without the use of intermediate shores. If there are construction loading conditions different than those shown in Figure 5 then the engineer should either calculate the spans (or effects) based on the loading or contact the deck manufacturer to assist in the calculations.

Bridge form is a special application of form deck. If the use of the form deck is on a highway bridge the construction loading is generally controlled by the State Department of Transportation Specifications. If the bridge is not a highway bridge, but is for private use, then the designer is free to use the form deck loading recommended by the Steel Deck Institute for building construction. The following information is for public highway bridges designed by state D.O.T.'s.

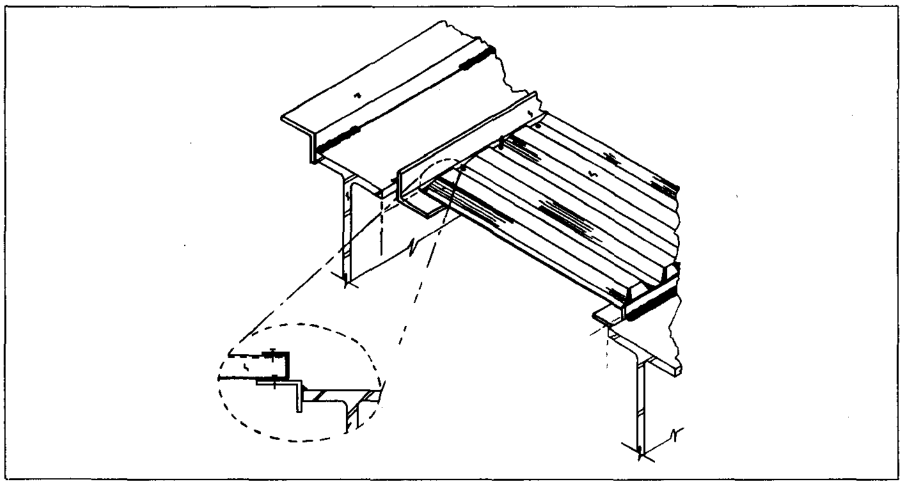
The construction loading is based on the weight (mass) of the concrete plus the deck and a uniform construction load. The deck is in a single span condition as illustrated in figure 6.

Figure 6



Highway Departments do not allow the bridge form to bear directly on the stringer flanges as is normal in building construction so the support angles shown in figure 6 are used. These support angles are usually furnished by the deck supplier. Unless there are unusual span or slab depth conditions that require the use of special deck profiles, the deck is furnished with ends that are crimped closed in a tapered manner. The detail in figure 6A shows a case where an end closure is used.

Figure 6A



For stress calculations the construction load is 50 psf (2.4 kPa). The allowable bending stress is 0.725 times the yield strength of the steel but not to exceed 36 ksi (250 MPa). For deflection calculations the concrete plus the deck is to be a minimum of 120 psf (5.7 kPa). The allowable deflection is the least of 1/180 of the span, or 0.5" (13 mm); however, if the span exceeds 120 inches (3 m) the deflection is limited to the least of 1/240 of the span or 0.75 inches (19 mm).

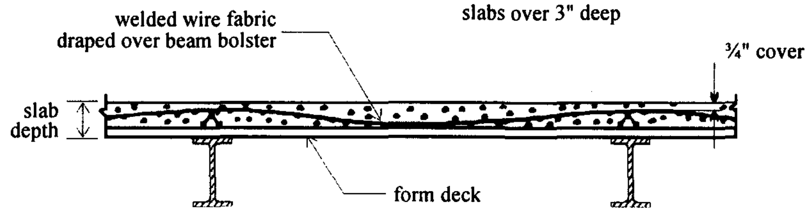
For building construction the slab design can be influenced by the choice of form deck. If the deck selected is not shored, and if the deck finish is selected so the deck can be considered permanent, then the deck will continue to carry the slab dead load for the life of the structure and the slab needs only to be reinforced to carry the service loads. For most exposures a permanent finish is galvanizing.

Another influence on designing the reinforcing is that the deck does provide some unknown amount of shrinkage reinforcement. Many successful slabs have been constructed with less than the ACI recommended amount of temperature steel.

A word of caution is needed about the use of randomly placed fibers (fibrous admixtures) in lieu of standard reinforcing bars or welded wire fabric. Fibrous admixtures should not be used to replace reinforcement. If fibers are inadvertently used for this purpose, then the form deck is to be considered the sole load carrying member for stress purposes. There may also be fire considerations that are compromised by the substitution.

Draped mesh construction is very frequently used with form deck - see Figure 7.

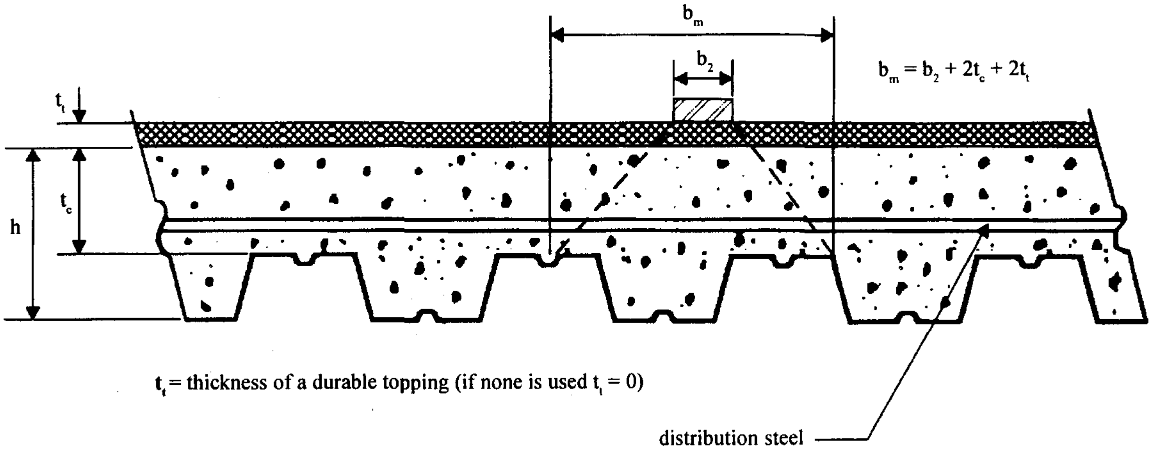
Figure 7



With this type of construction the deck usually bonds to the slab and for uniform service loads (such as in offices) the deflection calculation can be done in a similar manner as used for composite decks; that is, the composite I is calculated by averaging the cracked and uncracked transformed sections where the form deck provides the steel reinforcing. The contribution of the welded wire fabric is not included in the calculation. If concentrated loads are part of the design, then the design engineer may feel more comfortable using only the cracked transformed I; again the welded wire fabric is not included. Individual deck manufacturers can provide their I values on request. For bar reinforced slabs it is suggested that the stiffness be calculated using the standard transformed section analysis. The deck may be added into the calculation at the discretion of the designer.

For buildings, the distribution of concentrated loads can be done in the same way as done for composite slabs. The formulas are shown in Figure 8.

Figure 8



$b_m = b_2 + 2t_c + 2t_t$

single span bending: $b_e = b_m + 2(1 - x/l)x$; where x is the location of the load.

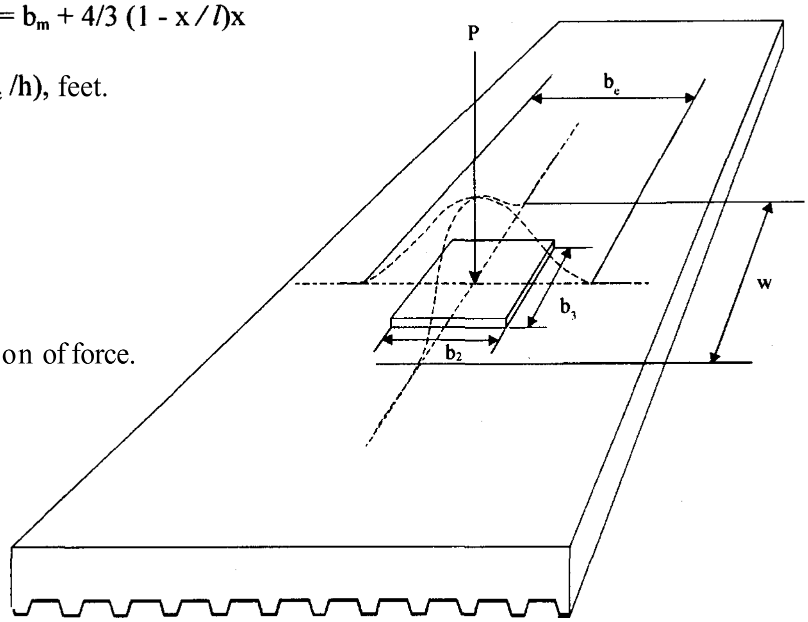
continuous span bending: $b_e = b_m + 4/3\,(1 - x/l)x$

shear: $b_e = b_m + (1 - x/l)x$

but in no case shall $b_e > 8.9(t_c/h)$, feet.

weak axis Moment = $\dfrac{Pb_e}{15w}$

$w = \dfrac{l}{2} + b_3$;but not to exceed l



Curved lines
represent distribution of force.

For bridges, state DOT distributions are applicable.

Vertical shear can be checked as it is for composite slabs. The shear resistance is the sum of the deck shear resistance and the concrete but the total of $\phi V_{deck} + \phi V_{concrete}$ is not allowed to exceed $\phi\, 4\,(f'_c)^{1/2} A_c$. Published deck properties include the shear resistance and also the A_c for various slab depths.

II. INSULATING FILLS ON FORM DECK

Lightweight insulating cementitious fill roof systems are supported by form deck. This construction may also include embedded rigid insulation boards within the poured fill material. In most cases the fill material has an "aggregate" of some insulating material such as vermiculite, expanded perlite, foamed glass, or simply be very highly air entrained where the air bubbles are the "aggregate". The fill material is generally not considered to add to the vertical load carrying capacity - the deck is selected to carry this load - but it does add to the stiffness and to the diaphragm strength. Individual fill manufacturers can provide load limits based on deflection and often can also provide diaphragm tables. The Steel Deck Institute (SDI) has diaphragm tables for the only generic form deck (2 ½" x ½"*)* both with an without embedded boards. Not all fill material types are covered in the SDI tables.

In many cases the fill material contains a great deal of water. Some of this water is absorbed by aggregate materials and the fill stays rather damp. During the life of the roof system it will be subject to many days of solar exposure and the heat can cause a vapor pressure to develop within the fill. The form deck must be vented to relieve the pressure so that the roof membrane is not distressed. When these fill systems were new in the market, the deck was vented by either installing clips or rolling indentations into the side laps to create a venting space along each deck edge. Tests were done at Granco Steel Products Company to determine the venting ability of deck with rolled in slits. These tests showed vents that provided between 1 and 1.5% of the projected area were sufficient to relieve the vapor pressure. However more important than the actual area size was the distribution of the vents. Small well distributed slits were better than widely spaced large openings.

Because of the great amount of water in the mix and because some of the insulative additives hold water for a long time, and because the deck must carry the load for the life of the roof, a galvanized finish is required.

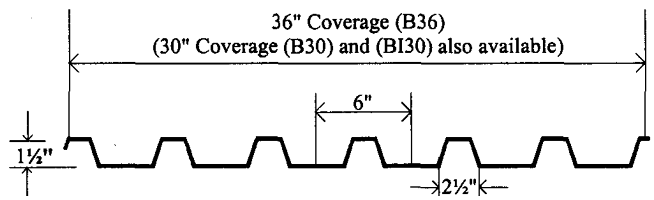
If insulation boards are embedded in the fill material it is recommended that the boards be held away at least three feet from the edges, where the diaphragm shear transfers into the frame.

III. EXPOSED ROOFING

Form deck as exposed roofing runs a wide range of uses from temporary coverings to permanent architectural applications. The details of construction vary with the application. For instance if the use is to provide temporary cover over a walkway, then perhaps complete sealing against leaks may not be too important and side laps may be done without any extra attention. If, on the other hand, the roof is to be a permanent cover then some thought should be given to continuously caulking the seam; perhaps with a caulking tape. Slope also helps to keep water out of joints and slopes 45° or greater do not generally require caulking. Attention should also be given to the form deck orientation. Figure 9 shows the common B (wide rib) roof deck used inverted as exposed roofing.

Figure 9

Type B



By inverting the deck the side lap is kept high and out of the bottom of the "gutter". While this detail is recommended for exposed roofs it is incorrect for built up roofs because the insulation board would have less bearing and a greater rib opening to span.

Thermal movement of roof panels should also be considered. For most insulated buildings continuous sheet lengths should not exceed 60' (18 m). Exposed screw fasteners should have neoprene sealing washers.

The standard uniform load tables are applicable for exposed roofing. The usual loads are caused by snow and wind. Some thought should be given to individual man loads but no standard has been written to address this. It is the recommendation of our company, United Steel Deck, Inc., that the deck be examined with a 200 pound load distributed over a 1' width at mid span. The deflection should not exceed $\ell/120$ and the stress should be limited to $F_y/$ 1.24 (for ASD). Since most man loading occurs during erection a contractor may plank the deck if these guide values can't be met.

Uplift loads caused by wind can cause a slightly different uniform load table for the form deck. Frequently, in ASD, the design stress is allowed a 1/3 stress increase. In most cases the uplift capacity is not controlled by the deck but by the fasteners used to attach the deck to the structure. The most common control mechanism for screws is pull over. Figure 10 gives pull over values for various screw head diameters.

Figure 10

Pull over strength generally controls the uplift values of screws. The table for pull over covers roof deck with a tensile strength **(F_u)** of 45 ksi which is the lowest of the acceptable range for roof deck, and 60 ksi for form deck. The roof deck gage range is 16 to 22 gage; the form deck gages are 24, 26, 28.

Screw pull out from structural steel framing or from joists is not a failure mode. Pull out failure is a definite possibility when light gage framing is used. The table shows pull out values for steel with 33, 40 and 50 ksi yields with corresponding tensile strength of 45, 55 and 65 ksi.

Pull Over Values, Lbs.

d_w	Gage						
	16	18	20	22	24	26	28
0.400	1610	1280	970	800	860	640	540
0.415	1680	1330	1000	830	890	670	560
0.430	1740	1380	1040	860	920	690	580
0.480	1940	1540	1160	960	1030	770	640
0.500	2020	1600	1210	1000	1080	810	670

The table pull over strengths Lbs., are based on $F_u = 45$ ksi for 16 thru 22 gage, and 60 ksi for 24 thru 28 gage.

SCREW DATA				
Screw Size	d dia.	d_w nom. head dia	Avg. tested tensile strength, kips	
10	0.190	0.415 or 0.400	2.56	
12	0.210	0.430 or 0.400	3.62	
¼	0.250	0.480 or 0.520	4.81	

Pull Out Strength, Lbs. = $P_{not} = 850\, t_2\, d\, F_u$

Screw #	F_u	Gage, t_2*						
		10	12	14	16	18	20	22
10	45	980	760	540	435	345	260	215
	55	1190	930	665	530	420	320	260
	65	1410	1100	785	630	500	375	310
12	45	1080	840	600	480	380	290	235
	55	1320	1030	735	590	465	350	290
	65	1560	1210	865	695	550	415	340
¼	45	1290	1000	715	570	455	340	280
	55	1570	1220	875	700	555	420	345
	65	1860	1440	1030	825	655	495	405

* Use the SDI decimal thickness, t_2, for the gage.
The safety factor for pull over and pullout (ASD) is 3, but for wind loading the 1/3 load increase may be proper. The f factor (LRFD) is 0.5.

IV SIDING

Form deck as siding is generally used in the more utilitarian structures.

The uniform load tables apply when analyzing wind loads; in ASD a 1/3 increase for wind loading may be appropriate. If the wall is expected to also perform as a diaphragm then attention must be given to the fastenings.

Caulking of side laps, flashing, insulation, and corner details use the same techniques as with other metal siding products.

V SHELVING

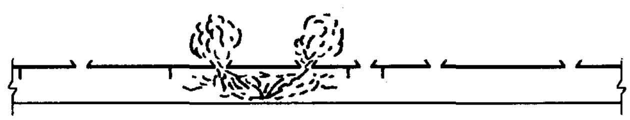
Industrial storage systems frequently use form decks as load carrying planes installed in angle frames. The usual form deck length tolerance is normally ½" (13 mm) but for shelving it may be reduced to ¼" (6 mm). This means that the rolling machine and the automatic shear must be slowed down and the increased production costs are reflected in the price of the product.

VI DRAFT CURTAINS (Curtain Boards)

Steel Form deck, because it is "non combustible" is frequently used in large open area buildings as a smoke control curtain. These curtains are made by hanging the deck vertically from primary structural members. The lightest available deck is obviously the best choice.

The function of the curtains is to limit the spread of the heat and smoke below the ceiling and thereby aid in venting. Figure 11 shows the cross section of a building and the location of the vertically suspended curtains.

Figure 11



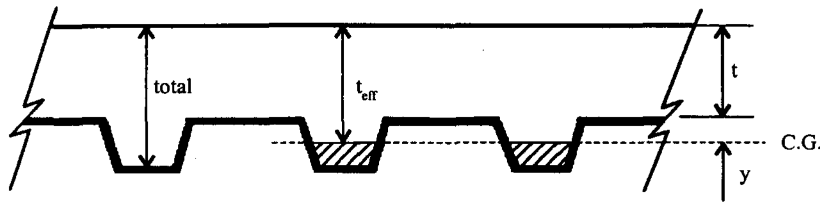
The curtain spacing should not be greater than eight times the ceiling height and should be not less than 20% of the ceiling height where the ceiling height is measured at the vent. In most cases the curtain should be greater than 10 feet (3 m) above the floor. Smaller spacings of curtains may be needed around areas that are particularly subject to smoke damage - in general the curtain spacing should not be closer than twice the ceiling height. Tighter spacings and deeper lengths can be needed around special hazards.

VII CALCULATING FIRE RESISTANCE FOR SLABS WITH FORM DECK

There are several tested and U.L. listed assemblies for composite floor deck, both with and without spray on fire protection or suspended ceilings. U.L. allows the use of non-composite form decks of the same cross section in these assemblies; the slabs must be appropriately reinforced. These ratings are covered in the D__ construction group of U.L. Many form deck ratings with spray on protection, drywall, or suspended ceilings are listed by U.L.; these are in the G__ construction group and the most common form deck in the ratings is the standard 2.5" x 0.5" (nominal) generic profile. No calculations are needed for these well defined constructions.

Any regularly ribbed deck can be used as a stay in place form. Fire resistance for ribbed formed slabs can be calculated by using the information published in *Guidelines for Determining Fire Resistance Ratings of Building Elements,* published by the Building Officials and Code Administrators International, (BOCA), Copyright 1994. No doubt this was written for deep ribs and fairly thin toppings as used in some precast concrete panels rather than steel deck formed slabs where ribs are generally shallow and concrete cover thicknesses can be relatively large. Therefore, the rule that the maximum effective thickness (t_e) cannot exceed two times the cover does not always limit the effective thickness to a reasonable amount because twice the concrete cover can frequently be greater than the total depth of the system. We recommend an additional limit for steel deck formed slabs which is the effective thickness cannot be greater than the concrete cover plus the distance to the centroid of the steel deck as measured from the top of the form deck. Figure 12 shows the added limit.

Figure 12



The rules for determining the equivalent thickness of formed slabs are:

A *Where the spacing of ribs or undulations is equal to or greater than four times the minimum thickness, the equivalent thickness is the minimum thickness.*

B. *Where the spacing of ribs or undulations is equal to or less than two times the minimum thickness, the equivalent thickness is calculated by dividing the net cross-sectional area by the panel width. The maximum thickness used to calculated the net cross-sectional area shall not exceed two times the minimum thickness.*

C. *Where the spacing of ribs or undulations exceeds two times the minimum thickness but is less than four times the minimum thickness, the equivalent thickness is calculated from the following formula:*

$$t + [(4t/s) - 1]\,(t_e - t)$$

where:

s = spacing of ribs or undulations
t = minimum thickness
t_e = equivalent thickness calculated in accordance with item B

The attached tables provide the effective thickness based on these rules for the form deck products made by United Steel Deck, Inc. These tabulated effective thicknesses can be used in conjunction with figure 13 to determine the hourly fire resistance of any particular form deck floor slab.

Figure 13

Concrete Aggregate Type	**Minimum eqivalent thickness (inches)* for fireresistance rating (hours)**				
	1 hr.	**1½ hrs.**	**2 hrs.**	**3 hrs.**	**4 hrs.**
Siliceous	3.5	4.3	5.0	6.2	7.0
Carbonate	3.2	4.0	4.6	5.7	6.6
Sand-lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

* 1 inch = 25.4 mm

Naturally the slab must be reinforced with bars or welded wire mesh in accordance with ACI design procedures in order to carry the intended superimposed load. The tabulated effective thicknesses are conservative when compared to successfully tested (and U.L. listed) systems.

B Deck

1.5000" x 6.0000" with width = 36.000"			
Cover, in.	**Total Slab Depth, in.**	**Effective Thickness, in.**	**Control**
2.0000	3.50	2.2	B
2.2500	3.75	2.5	B
2.5000	4.00	2.7	B
2.7500	4.25	3.0	B
3.0000	4.50	3.2	B
3.2500	4.75	3.5	C
3.5000	5.00	3.8	C
3.7500	5.25	4.1	C
4.0000	5.50	4.4	C
4.2500	5.75	4.7	C
4.5000	6.00	5.0	C
4.7500	6.25	5.3	C
5.0000	6.50	5.6	C
5.2500	6.75	5.9	C
5.5000	7.00	6.2	C
5.7500	7.25	6.4	C
6.0000	7.50	6.7	C
6.2500	7.75	6.9	C
6.5000	8.00	7.2	C
6.7500	8.25	7.4	C
7.0000	8.50	7.7	C

B Inverted

1.5000" x 6.0000" with width = 36.000"			
Cover, in.	**Total Slab Depth, in.**	**Effective Thickness, in.**	**Control**
2.0000	3.50	2.5	B
2.2500	3.75	2.8	B
2.5000	4.00	3.0	B
2.7500	4.25	3.3	B
3.0000	4.50	3.5	B
3.2500	4.75	3.9	C
3.5000	5.00	4.2	C
3.7500	5.25	4.5	C
4.0000	5.50	4.9	C
4.2500	5.75	5.1	C
4.5000	6.00	5.4	C
4.7500	6.25	5.6	C
5.0000	6.50	5.9	C
5.2500	6.75	6.1	C
5.5000	7.00	6.4	C
5.7500	7.25	6.6	C
6.0000	7.50	6.9	C
6.2500	7.75	7.1	C
6.5000	8.00	7.4	C
6.7500	8.25	7.6	C
7.0000	8.50	7.9	C

TABLES

UFX36

1.3125" x 51400" with width = 36.000"			
Cover, in.	**Total Slab Depth, in.**	**Effective Thickness, in.**	**Control**
1.6875	3.00	2.0	B
1.9375	3.25	2.3	B
2.1875	3.50	2.5	B
2.4375	3.75	2.8	B
2.6875	4.00	3.1	C
2.9375	4.25	3.4	C
3.1875	4.50	3.7	C
3.4375	4.75	4.0	C
3.6875	5.00	4.3	C
3.9375	5.25	4.6	C
4.1875	5.50	4.8	C
4.4375	5.75	5.1	C
4.6875	6.00	5.3	C
4.9375	6.25	5.6	C
5.1875	6.50	5.8	C
5.4375	6.75	6.1	C
5.6875	7.00	6.3	C
5.9375	7.25	6.6	C
6.1875	7.50	6.8	C
6.4375	7.75	7.1	C
6.6875	8.00	7.3	C

UF2X

2.0000" x 6.0000" with width = 30.000"			
Cover, in.	**Total Slab Depth, in.**	**Effective Thickness, in.**	**Control**
2.0000	4.00	2.5	B
2.2500	4.25	2.8	B
2.5000	4.50	3.0	B
2.7500	4.75	3.3	B
3.0000	5.00	3.5	B
3.2500	5.25	3.8	C
3.5000	5.50	4.2	C
3.7500	5.75	4.5	C
4.0000	6.00	4.8	C
4.2500	6.25	5.2	C
4.5000	6.50	5.5	C
4.7500	6.75	5.8	C
5.0000	7.00	6.0	C
5.2500	7.25	6.3	C
5.5000	7.50	6.5	C
5.7500	7.75	6.8	C
6.0000	8.00	7.0	C
6.2500	8.25	7.3	C
6.5000	8.50	7.5	C
6.7500	8.75	7.8	C
7.0000	9.00	8.0	C

TABLES

UFS

0.5625" x 2.5000" with width = 30.000"			
Cover, in.	**Total Slab Depth, in.**	**Effective Thickness, in.**	**Control**
1.9375	2.50	2.2	C
2.1875	2.75	2.5	C
2.4375	3.00	2.7	C
2.6875	3.25	3.0	C
2.9375	3.50	3.2	C
3.1875	3.75	3.5	C
3.4375	4.00	3.7	C
3.6875	4.25	4.0	C
3.9375	4.50	4.2	C
4.1875	4.75	4.5	C
4.4375	5.00	4.7	C
4.6875	5.25	5.0	C
4.9375	5.50	5.2	C
5.1875	5.75	5.5	C
5.4375	6.00	5.7	C
5.6875	6.25	6.0	C
5.9375	6.50	6.2	C

UF1X

1.0000" x 4.5000" with width = 27.000"			
Cover, in.	**Total Slab Depth, in.**	**Effective Thickness, in.**	**Control**
2.0000	3.00	2.3	B
2.2500	3.25	2.5	B
2.5000	3.50	2.8	C
2.7500	3.75	3.1	C
3.0000	4.00	3.4	C
3.2500	4.25	3.7	C
3.5000	4.50	4.0	C
3.7500	4.75	4.3	C
4.0000	5.00	4.5	C
4.2500	5.25	4.8	C
4.5000	5.50	5.0	C
4.7500	5.75	5.3	C
5.0000	6.00	5.5	C
5.2500	6.25	5.8	C
5.5000	6.50	6.0	C
5.7500	6.75	6.3	C
6.0000	7.00	6.5	C
6.2500	7.25	6.8	C
6.5000	7.50	7.0	C
6.7500	7.75	7.3	C
7.0000	8.00	7.5	C

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