# Deflections for Composite Steel Deck Floors

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# DEFLECTIONS FOR COMPOSITE STEEL DECK FLOORS

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**ABSTRACT:** Composite steel deck floors have become a prevalent means of building floor slab construction. The increased use of higher strength concretes and shallower sections have led to more emphasis on serviceability considerations in design. A method of predicting short-term composite cold-formed steel deck deflections is proposed. Measured deflections are compared with calculated deflections using a proposed empirical procedure. The proposed method shows significant improvement over the method suggested in the Specifications for Design and Construction of Composite Slabs. Measured deflections are also compared with calculated values obtained using the method currently recommended by ACI 318-89 for normally reinforced concrete. The proposed equations are recommended to replace the procedure currently used in the Specifications for the Design and Construction of Composite Slabs.

## INTRODUCTION

The instantaneous deflection behavior of noncellular steel deck panels with normal weight concrete were investigated. Examined were deflection data from 142 previously conducted shear-bond strength tests (Lamport 1984). A governing instantaneous deflection equation was developed, which predicts the deflections of one-way composite cold-formed steel-deck reinforced concrete slab systems subjected to service design loads (Lamport and Porter 1990).

The data base consisted of nine span lengths ranging from six feet (1.83 m) to seventeen feet (5.18 m) and three nominal cold-formed steel-deck depths: 1-1/2" (38.1 mm), 2" (50.8 mm) and 3" (76.2 mm) from six deck manufacturers. Steel deck thicknesses ranged from 16 (1.6 mm) to 22 (0.85 mm) gage. Composite section depths were 3" (76.2 mm) to 9" (228.6 mm) with widths from 24" (0.61 m) to 36" (0.91 m). Shear transferring devices consisted of either embossments or welded wires. The concrete used for all specimens was Type 1 Portland cement with a specified

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minimum strength of 2500 (175.8 $kg/cm^2$) to 3000 psi (210.9 $kg/cm^2$) at 28 days. The data base distribution by deck depth, span length and gage are given in Table 1. Specimens were subjected to two-point loading with varying shear spans, (L') as shown in Fig. 1.

**CURRENT CODE RECOMMENDATIONS**

Specifications for the Design and Construction of Composite Slabs (ASCE Standard 1984) recommends a simple average for the composite effective moment of inertia, $I_d$ for deflection calculations at service design loads.

$$I_d = 1/2(I_u + I_{cr}) \quad (1)$$

$I_d$ was based on deflection data from specimens used to determine the shear-bond characteristics of composite steel deck sections (Porter and Ekberg 1976).

Figure 2 shows a typical load-deflection curve of a long span specimen. The figure indicates that the current criteria overestimates the initial stiffness of the section, leading to unconservative estimates of the actual deflection for loads at or below service design load and becomes excessively unconservative as the load approaches ultimate. When comparing the experimental deflection closest to service design load with calculated deflections using Eq. 1 the current code criteria underestimates the measured deflections by an average of 26% for all specimens. When considering each span separately the shorter span, i.e. 66" (1676.4 mm) span group deflections were under estimated by approximately 13% whereas for the 198" (5029.2 mm) span specimens the deflections were underestimated by an average of 46%.

**ACI RECOMMENDED $I_e$ FOR NORMALLY REINFORCED CONCRETE SLABS**

The deflection procedure recommended by the American Concrete Institute (ACI) in Building Code Requirements for Reinforced Concrete (ACI 318-89, 1989) was developed by Branson (Branson 1965). The method is based on an elastic analysis of stresses and strains on a cracked reinforced concrete section using modular ratio theory. To account for the tension stiffening effect of the uncracked concrete in the tension zone, and variation in I along the beam span, Branson suggested an empirical equation for $I_e$ as

$$I_e = (M_{cr}/M_a)^3 I_g + \{1 - (M_{cr}/M_a)^3\} I_{cr} \leq I_g \quad (2)$$

The range of $I_e$ is from $I_g$ when $M_a$ is below $M_{cr}$ to $I_{cr}$ as $M_a$ approaches overload. Equation 2 was developed from a statistical study of test specimens which had $M_{max}/M_{cr}$ values from 2.2 to 4.0 and $I_g/I_{cr}$ ratios from 1.35 to 3.5. For these limits, Eq. 1 provides a reasonable estimate of the average stiffness of a beam. The accuracy of Eq.1 is approximately ±25% (ACI 435 1972) for service loads.

**RECOMMENDED $I_e$ FOR COMPOSITE STEEL-DECK SLABS**

The proposed criteria is based on work by Lamport and Porter (Lamport 1984). The method is similar in format with the method currently recommended by ACI 318-89 for normally reinforced concrete (ACI 318-89 1989). The method recommends an effective moment of inertia approach in which the moment of inertia varies between $kI_u$ when the applied moment is below the cracking moment, $M_{cr}$ an approaches the moment of inertia of the steel deck taken about the composite neutral axis, $I_D$, as the load approaches ultimate. The final recommended form of $I_e$ is as follows.

$M_a < M_{cr}$;

$$I_e = kI_u \quad (3)$$

$M_a \geq M_{cr}$:

$$I_e = kI_u(M_{cr}/M_a)^m + \{1-(M_{cr}/M_a)^m\}I_D \leq kI_u \quad (4)$$

where the power function m is ;

$$d_d \leq 2''; \qquad m = 0.55 \quad (5)$$

$$d_d = 3''; \qquad m = 1.3 \quad (6)$$

The stiffness reduction coefficient, k was included to reduce the initial stiffness below $I_u$. Of the specimens which had load levels (added dead load due to shore removal, superimposed dead load of loading apparatus, and applied live load) below the cracking moment, $M_{cr}$ over 90% had initial stiffnesses below $I_u$. Though the loads were not theoretically sufficient to cause the moment in the specimen to reach $M_{cr}$. An analysis of the data indicated that the stiffness reduction was related to the thickness of the concrete above the steel deck, $t_c$. The ratio of $I_{exp}/I_u$ decreased from an approximate mean of 0.90 to 0.65 as $t_c$ increased from 3.4" (86.4 mm) to 5.1" (129.5 mm).

Results of a linear regression analysis, indicated the stiffness reduction coefficient, k should be obtained using Eq. 7, 8 and 9 for 1-1/2" (38.4 mm), 2" (50.8 mm) and 3" (76.2 mm) nominal steel deck depths, respectively.

Values of k for $3.4'' \leq t_c \leq 5.1''$:

$d_d = 1\text{-}1/2''$;

$$k = 1.0 \quad (7)$$

$d_d = 2''$;

$$k = 2.0 - 0.293t_c \leq 1.0 \quad (8)$$

$d_d = 3"$;

$$k = 1.536 - 0.185t_c \leq 1.0 \tag{9}$$

Equations 7 - 9 were determined for the ranges of $t_c$ given. The upper limit of $t_c = 5.1"$ (129.5 mm) should include most slab depths used in normal construction. For values of $t_c > 5.1"$ (129.5 mm) the authors recommend the value of k be determined using $t_c = 5.1"$. For slab depths with $t_c < 3.4"$ (86.4 mm), the authors suggest that a value of $k = 1.0$ be used.

Figure 3 compares the current method, Eq. 1, the ACI 318-89 approach, for normally reinforced concrete, Eq. 2 and the proposed method Eqs. 3 - 9. The figure shows the cummulative percentage of calculated deflections which are within a given error range of the measured deflections for a typical midspan specimen. The figure indicates that proposed Eqs. 3 - 9, yield substantial improvement over Eq. 1. This improvement is even more pronounced in the longer spans where Eq. 1 is not capable of accounting for the extensive cracking that occurs. Equations 3 - 9 are also more conservative in the prediction of the experimental deflections for loads at and below service design load when compared to Eq. 1. Table 2 compares calculated deflections using Eq.1 and Eqs. 3 - 9 with measured values for selected tests values. The deflection values given correlate with the experimental deflections closest to service design load, where service design live load for a given specimen was determined by Eq. 10, (ASCE Standard 1984).

$$LL = [2V_e/L - 1.4(\gamma W_1 + W_3)]/1.7 \tag{10}$$

The factor $\gamma$ accounts for the amount of the self weight of the slab in composite action, i.e. the amount of the load applied to the composite system after shore removal. For the shoring at ends only $\gamma = 0.0$, shored at ends and center $\gamma = 0.625$ and for the entired deck length shored $\gamma = 1.0$.

## CONCLUSIONS

- The proposed effective moment of inertia approach for calculating instantaneous deflections of composite floor slabs given by Eqs. 3 - 9 were found to give reliable predictions of deflections for the spans, steel-deck depths and steel-deck types used in the investigation.

- The deflection predictions of the proposed method were usually more conservative than those given by Eq. 1, for loads at or below service design load.

- The proposed method Eqs. 3 - 9, unlike the current method Eq. 1, is more able to account for the extensive cracking that occurs in the longer spans, by the inclusion of the $(M_{cr}/M_a)$ term.

- The format of the proposed method is familiar to the designer in that it closely resembles the approach used by ACI 318-89 for normally reinforced concrete.

- The authors recommend that Eqs. 3 - 9 be used for deflection design computations involving slabs reinforced with cold-formed steel decking.

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## APPENDIX I.-REFERENCES


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**APPENDIX II.-NOTATION**

The following symbols are used in this paper:

$d_d$ Overall depth of steel deck profile, in.
$I_{cr}$ Moment of inertia of composite section based on cracked section, $in^4$/ft of width
$I_d$ Moment of inertia of composite section considered effective for deflection computations, $in^4$/ft of width
$I_D$ Moment of inertia of steel deck about its centroidal axis, $in^4$/ft width
$I_e$ Effective moment of inertia considering the effect of cracking, $in^4$/ft width
$I_{exp}$ Experimental moment of inertia of section, $in^4$/ft of width
$I_g$ Moment of inertia of gross section about centriodal axis, neglecting reinforcement, $in^4$/ft of width
$I_u$ Moment of inertia of composite section based on cracked section, $in^4$/ft of width
k Stiffness correction factor
L Length of span, in
LL Allowable superimposed live load for service conditions, psf
$M_a$ Maximum moment in member at stage deflection is computed, in lbs/ft of width
$M_{cr}$ Cracking moment, in lbs/ft of width
$t_c$ Depth of concrete above top corrugation of steel deck, in
$V_e$ Maximum experimental shear at failure obtained from laboratory tests (not including weight of slab), lbs/ft of width
$W_1$ Weight of slab ($DL_d$ + $DL_c$), psf
$W_3$ Dead load applied to slab, exclusive of $W_1$, psf
$\gamma$ Coefficient for proportion of dead load added upon removal of shore

**TABLE 1** Depth, Span and Gage of Cold-Formed Steel Decks

| Quantity | Depth (in) | Span (in) | Gage | Quantity | Depth (in) | Span (in) | Gage |
|---|---|---|---|---|---|---|---|
| 4 | 1-1/2 | 92 | 20 | 10 | 3 | 90 | 16 |
| 4 | 1-1/2 | 140 | 16 | 6 | 3 | 90 | 18 |
| 2 | 1-1/2 | 140 | 18 | 5 | 3 | 90 | 20 |
| 36 | 1-1/2 | 140 | 20 | 2 | 3 | 90 | 22 |
| 4 | 1-1/2 | 140 | 22 | 6 | 3 | 138 | 16 |
| 7 | 2 | 66 | 18 | 7 | 3 | 138 | 18 |
| 6 | 2 | 66 | 20 | 3 | 3 | 138 | 20 |
| 5 | 2 | 114 | 18 | 2 | 3 | 138 | 22 |
| 3 | 2 | 114 | 20 | 3 | 3 | 186 | 18 |
| 6 | 2 | 162 | 18 | 5 | 3 | 186 | 20 |
| 2 | 2 | 162 | 20 | 8 | 3 | 198 | 16 |
| | | | | 3 | 3 | 198 | 18 |
| | | | | 3 | 3 | 198 | 22 |

(25.4 mm = 1 in)

**TABLE 2** Comparison of Calculated Deflections with Measured Values for Deflections Closest to Service Design Load

| Deck Depth | Span | Test No. | Measured | Calculated | | Meas./Calc. | |
|---|---|---|---|---|---|---|---|
| | | | | Eq. 1 | Eqs. 3-9 | Eqs. 1 | Eqs. 3-9 |
| (in) | (in) | | (in) | (in) | (in) | | |
| 1-1/2 | 140 | 055 | 0.21 | 0.22 | 0.22 | 0.95 | 0.97 |
| 2 | 114 | 422 | 0.07 | 0.08 | 0.08 | 0.83 | 0.88 |
| 2 | 114 | 445 | 0.17 | 0.16 | 0.18 | 1.01 | 1.12 |
| 2 | 162 | 449 | 0.84 | 0.62 | 0.74 | 1.35 | 1.13 |
| 2 | 162 | 462 | 0.55 | 0.45 | 0.50 | 1.21 | 1.10 |
| 3 | 138 | 364 | 0.12 | 0.11 | 0.11 | 0.94 | 0.97 |
| 3 | 138 | 432 | 0.08 | 0.09 | 0.09 | 1.10 | 1.21 |
| 3 | 198 | 376 | 0.67 | 0.41 | 0.58 | 1.64 | 1.16 |
| 3 | 198 | 385 | 0.68 | 0.41 | 0.60 | 1.65 | 1.13 |
| 3 | 198 | 411 | 0.58 | 0.30 | 0.42 | 1.97 | 1.40 |

(25.4 mm = 1 in)

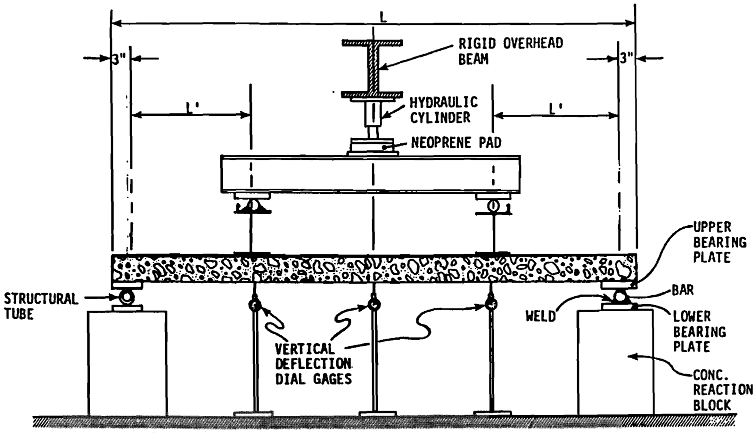


**FIGURE 1. Typical Specimen Subjected to Two-point Loading**

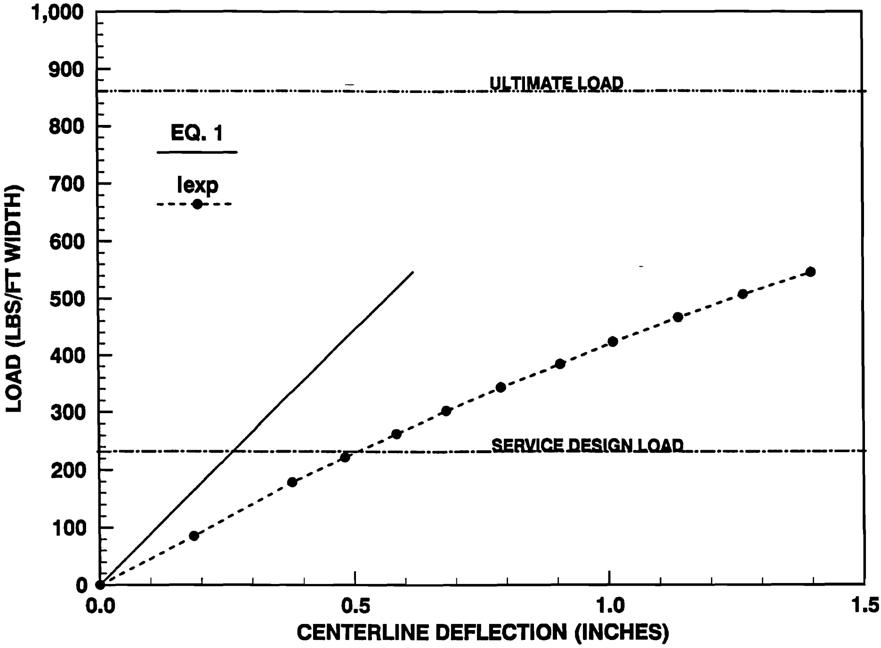


**FIGURE 2. Comparison of Measured and Calculated Deflections Using Eq. 1 for 198" Span Specimen No. 411**

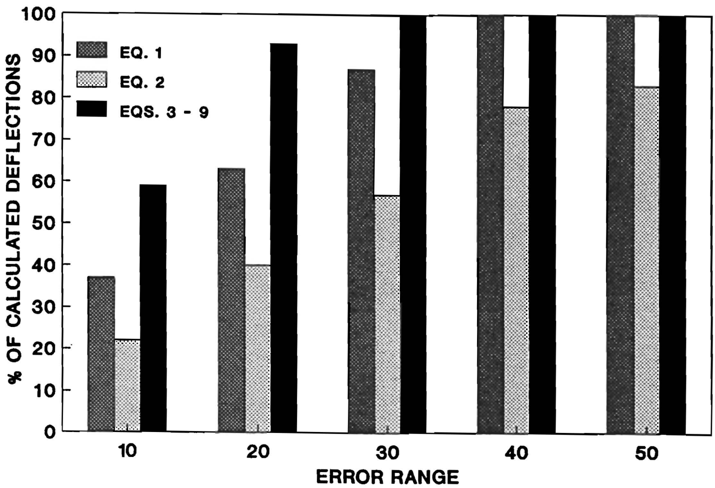


**FIGURE 3. Comparison of Calculated and Measured Deflections for 114" Span Specimen with 2" Nominal Steel Deck**