합성보의 시공중 처짐이 합성데크슬래브의 콘크리트 고임에 미치는 영향

Effect of Constructional Deflection of Composite Beam on Concrete Ponding in Metal Deck Slab

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Abstract

In the composite deck system, beams and deck plates deflect during construction. This lens-shaped deflection may cause problems in the serviceability of a building. Therefore, it should be compensated to be level. Several methods for leveling of floor slab are available, such as (1) increasing stiffness of structural members, (2) propping floor system, (3) cambering beams, (4) pouring additional concrete. In this study, additional weight and volume of concrete for level compensation are examined for various size of floors.

요 지

합성데크구조에서 보와 바닥판은 공사중 처짐이 발생한다. 이 렌즈형태의 처짐은 건물의 사용성 문제를 야기시킨다. 따라서, 수평이 되도록 보정되어야 한다. 수평보정을 위한 몇가지 방법이 있는데 (1) 부재의 강성을 증가하거나 (2) 지주로 바닥을 받치거나 (3) 보에 치올림을 두거나 (4) 추가 콘크리트를 타설한다. 본 연구에서는 추가콘크리트를 이용하여 바닥면을 수평보정하는 경우 여러 가지의 바닥크기에 대하여 추가콘크리트의 중량과 체적을 비교 검토하였다.

keywords : Concrete Ponding, Beam Deflection, Concrete Volume

핵심용어 : 콘크리트 고임, 보의 처짐, 콘크리트 체적

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1. Introduction

In steel buildings, composite beam and metal deck slab are widely used because of constructional efficiency and economic advantage. As composite beams become lighter than those in non-composite structure and LRFD method also leads to lighter floor members, they will deflect more during construction and consequently the amount of concrete in floor slab should be increased to meet the requirement of surface levelness.(4)

Referring to the study on the rainwater ponding phenomenon in roof system by Marino(1966), Ruddy(1986) investigated the ponding effect in floor slab due to concrete placement. Generally speaking, the deflection of floor system results from the deflection of girder, beam, and deck. This lens-shaped deflection requires the pour of additional concrete to level the slab surface. To create leveled surface usually one of the following method is adopted.

1. Shoring floor beams
2. Cambering floor beams
3. Increasing stiffness of floor beams
4. Placing additional concrete

In this study, based on Marino's study, simple equations to estimate the ratio of additional deflection induced by concrete placement to initial deflection after concrete placement in beam and girder are suggested. Also, an equation to estimate a volume under deflected surface in 3-span floor layout is suggested by modifying Ruddy's formula. Additional deflection and volume in floor slab due to concrete placement are estimated for various floor dimensions and slab thickness.

2. Additional deflection of beam due to concrete placement

In composite deck system, floors are composed of beam, girder and metal deck such as 2-span floor shown in Fig. 1. Due to initial deflection the floor deflects like a lens, causing additional concrete to level the surface. This problem is similar to water ponding in roof system. The difference of these problems is that the water ponding continues as water accumulates, while concrete volume increase due to initial deflection does not repeat because concrete is plastic and concrete placement is controllable.

A ponding analogy provides a convenient analytic method to predict additional deflection and concrete volume in floor system due to initial deflection of floor beams. In this study, Marino's formula is adopted to predict deflection. In deriving the formula, the following is assumed: (1) The deflection curve is a half sine wave, (2) Girder and beams are simply supported, (3) Load transferred from beam to girder is distributed load rather than concentrated load. The ratio of additional deflection due to additional concrete to initial deflection in beam is

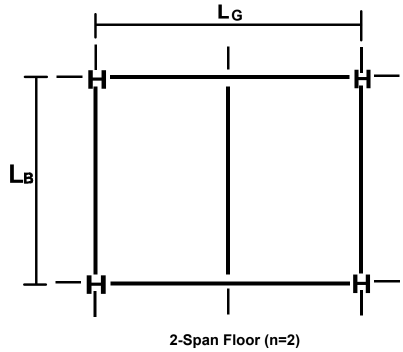

Fig. 1 Typical floor layout

$$\frac{\delta_{BI}}{\delta_{Bo}} = \frac{\alpha_B}{R}\left[1+\frac{\pi^2}{8}\alpha_G\left(\frac{\pi}{4}+\frac{1}{\rho}\right) + \frac{\pi^2}{8\rho} + 0.1835\,\alpha_B\alpha_G\right] \quad (1)$$

and that in girder is

$$\frac{\delta_{GI}}{\delta_{Go}} = \frac{\alpha_G}{R}\left[1-\frac{\pi}{4}\alpha_B+\frac{\pi}{4}\rho(1+\alpha_B)\right] \quad (2)$$

where,

$$R = 1-\frac{\pi}{4}\alpha_B\,\alpha_G, \qquad \rho = \frac{C_B}{C_G}$$

$$\alpha_G = \frac{C_G}{1-C_G}, \qquad \alpha_B = \frac{C_B}{1-C_B}$$

$$C_G = \frac{\gamma L_B L_G^4}{\pi^4 EI_G}, \quad C_B = \frac{\gamma\left(\frac{L_G}{n}\right)L_B^4}{\pi^4 EI_B}$$

According to a graphic representation of Eqs(1) and (2), theses ratios are linearly proportional to beam and girder flexibilities(Ruddy, 1986). In this study, to simplify computational procedure linear equations to estimate these ratios are suggested as follows:

$$\alpha = \frac{\delta_{BI}}{\delta_{Bo}} = 1.156\,C_B + 1.364\,C_G$$
$$\beta = \frac{\delta_{GI}}{\delta_{Go}} = 0.926\,C_B + 1.102\,C_G \quad (3)$$

3. Additional volume in slab surface due to concrete placement

Computation of volume under a deflected surface area is necessary to estimate additional concrete required to compensate the concave slab surface caused by concrete ponding. Ruddy(1986) suggested an equation to estimate the volume under the deflected slab area. The equation requires deflections at three points as shown in

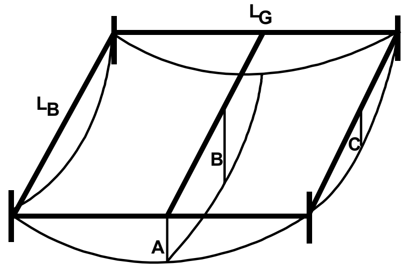

Fig. 2 Deflected slab surface

Fig. 2 and the volume under the deflected area is computed as

$$V_c = L_B L_G(0.231A + 0.405B + 0.231C) \quad (4)$$

where,

$$A = \delta_{Go} + \delta_{GI}$$
$$B = \delta_{Bo} + \delta_{BI} + \delta_{Go} + \delta_{GI}$$
$$C = \delta_{Bo} + \alpha_B\delta_{Bo}$$

Eq(4) is transformed by replacing coefficient A, B, C as follows:

$$V_c = L_B L_G\left[0.636(\delta_{Go}+\delta_{GI}) + 0.405(\delta_{Bo}+\delta_{BI}) + \frac{0.231}{1-C_B}\delta_{Bo}\right] \quad (5)$$

By substituting Eq(3) into Eq(5) a simplified volume equation is derived as follows:

$$V_c = L_B L_G\left[(0.636+0.59\,C_B+0.7C_G)\delta_{Go} + (0.405+0.486\,C_B+0.55\,C_G+\frac{0.231}{1-C_B})\delta_{Bo}\right] \quad (6)$$

The accuracy of Eq(6) is evaluated by comparing with Eq(4) in the subsequent section.

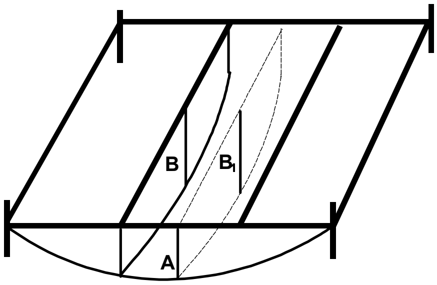

Fig. 3 Coefficient B for 3-span floor

Derivation of Eq(3) is based on 2-span case. As the number of span increases, B in Eq(3) departs from the center of a floor as shown in Fig. 3.

In this study, B in Eq(3) is modified according to the ratio of deflection at the center to at the one third of span. The ratio is 1.15 Then, the deflection at the center for the 3-span floor becomes

$$\begin{aligned} B_1 &= 1.15\times(\delta_{Bo}+\delta_{BI})+\delta_{Go}+\delta_{GI} \\ &= B+0.15\times(\delta_{Bo}+\delta_{BI}) \end{aligned}$$

Then, the volume for the 3-span floor becomes

$$\begin{aligned} V_c &= L_B L_G(0.231A+0.405B_1+0.231C) \\ &= V_c+0.06075\times L_B L_G(\delta_{Bo}+\delta_{BI}) \end{aligned} \quad (7)$$

In Ruddy's study, the concrete volume due to deck deflection was not included. To account for the volume under the deflected area of deck unit width of deck plate with simply supported boundary condition is considered. Then, the volume under the deflected area of deck can be calculated as follows:

$$\begin{aligned} V_D &= n\int_0^{L_B}\int_0^{\frac{L_G}{n}} D\sin\left(\frac{\pi x}{\frac{L_G}{n}}\right)dx\,dy \\ &= 0.637\,DL_G L_B \end{aligned} \quad (8)$$

where,

$$D=\delta_{Do}+\alpha_D\delta_{Do}$$

$$\alpha_D=\frac{C_D}{1-C_D},\quad C_D=\frac{\gamma(\frac{L_G}{n})^4}{\pi^4 EI_D}$$

The mid-span deflection of deck can be very different whether it is simple or continuous span. In this study, considering the continuity of deck provided by stud bolt, the mid-span deck deflection is assumed as the average of the mid-span deflection of 2-span and that of 3-span continuous beam and it is

$$\delta_{Do}=\frac{1}{2}\left(\frac{1}{185}+\frac{1}{145}\right)\frac{\gamma t(\frac{L_G}{n})^4}{EI_D} \quad (9)$$

Then, the volume increase rate(%) due to deck deflection is

$$\frac{V_D}{V_o}=38.17\frac{C_D}{1-C_D} \quad (10)$$

While American Society of Civil Engineer(ASCE, 1991) recommends the volume of additional concrete due to deck deflection for a simple span to be taken as

$$\frac{2}{3}\Delta\, lB \quad (11)$$

where, Δ is uniform load slab deflection, l is deck span, and B is the slab width.

4. Numerical Examples

To find out the effect of floor dimension, beam and girder span, topping concrete thickness on concrete ponding problem two types of floor layout is examined: 2-span (n=2) and 3-span(n=3) floors. The dimension of floor framing is listed in Table 1. For the selection of floor beam live load of 250, dead load of 360 kgf/m^2, topping concrete thickness of 8cm, and normal weight concrete are used. The floor beam and girder are listed in Table 2.

Table 1 List of floor dimension

Model No.	No. of Span(n)	L_G(m)	L_B(m)	L_D(m)
1		5	5	2.5
2		5	6	2.5
3	2	6	6	3.0
4		7	6	3.5
5		7	7	3.5
6		8	8	2.67
7		8	9	2.67
8	3	9	8	3.0
9		9	9	3.0
10		10	8	3.33

Table 2 Beam and girder list

Model No.	Beam	Girder
1	200×200×8×12	298×149×5.5×8
2	200×200×8×12	294×200×8×12
3	294×200×8×12	350×175×7×11
4	298×201×9×14	300×305×15×15
5	354×176×8×12	400×200×8×13
6	350×150×6.5×9	386×299×9×14
7	354×176×8×12	506×201×11×19
8	350×175×7×11	394×398×11×18
9	310×305×15×20	400×408×21×21
10	298×201×9×14	406×403×16×24

Note: All members are H-type section(unit:mm)

For the 5m×5m floor(Model No. 1) the initial deflections of beam and girder are

$$\delta_{BO} = \frac{5wL_B^4}{384EI_B} = 0.67cm$$
$$\delta_{Go} = \frac{PL_g^3}{48EI_g} = 0.41cm$$

and the flexibility constants C_G and C_B are

$$C_B = \frac{\gamma(\frac{L_G}{n})L_B^4}{\pi^4 EI_B} = 0.0434$$
$$C_G = \frac{\gamma L_B L_G^4}{\pi^4 EI_G} = 0.0316$$

Using Eqs(1) and (2), deflection ratios δ_{BI}/δ_{Bo}, δ_{GI}/δ_{Go} are 0.09 and 0.07, respectively. Then, additional deflections are $\delta_{BI} = 0.06\,cm$, $\delta_{GI} = 0.029cm$. Similarly, the rest of models are calculated and listed in Table 3. The proposed simplified equations showed error of 5% or less as shown in Table 3. The total deflection of Model No. 10(10m×8m) is 1.691cm and this is less than the deflection limit $l/300 = 3.33cm$. Generally, the additional deflection due to concrete ponding is not a level to surpass beam deflection limit.

Table 3 Additional deflection due to concrete ponding (unit: cm)

Model No.	δ_{Bo}	δ_{Go}	δ_{BI}		δ_{GI}	
			Eq(1)	Eq(3)	Eq(2)	Eq(3)
1	0.67	0.41	0.060	0.062	0.029	0.031
2	0.90	0.41	0.093	0.098	0.034	0.036
3	0.61	0.50	0.056	0.059	0.036	0.038
4	0.71	0.65	0.082	0.085	0.060	0.062
5	0.74	0.61	0.083	0.086	0.055	0.057
6	0.99	1.08	0.157	0.158	0.139	0.139
7	1.35	0.90	0.227	0.228	0.122	0.121
8	1.10	1.08	0.186	0.186	0.147	0.146
9	1.24	1.09	0.221	0.220	0.157	0.155
10	1.21	1.44	0.261	0.253	0.251	0.240

Also, additional volume is computed using Eqs (4), (6), and (7) and it is listed in Table 4. The error of the suggested equation is mostly less than 1%. For the 3-span floor Ruddy's equation underpredicts the additional volume about 5%. Additional deflection and volume due to deck deflection are

$$C_D = \frac{\gamma(\frac{L_G}{n})^4}{\pi^4 EI_D} = 0.0244$$

$$\delta_{Do} = 0.0597\,t\;\pi^4 C_D = 0.166\,cm$$

$$\delta_{DI} = \alpha_D \delta_{Do} = 0.00416\;cm$$

$$V_D = 38.17\frac{C_D}{1-C_D}\;\;V_o = 0.0280\;\;m^3$$

Table 4 Additional volume due to concrete ponding (unit: m^3)

Model No.	Ruddy Eq(4) (a)	This Study Eq(6) (b)	This Study Eq(7) (c)	Ratio (b)/(a)	Ratio (c)/(a)
1	0.18	0.184	-	1.022	-
2	0.27	0.273	-	1.011	-
3	0.27	0.274	-	1.011	-
4	0.40	0.398	-	0.995	-
5	0.46	0.463	-	1.007	-
6	0.95	0.947	0.954	0.997	1.007
7	1.17	1.171	1.24	1.000	1.059
8	1.13	1.132	1.19	1.002	1.053
9	1.37	1.374	1.43	1.003	1.041
10	1.58	1.572	1.65	1.001	1.050

Table 5 Additional deflection and volume due to deck deflection

Model No.	δ_{Do} (mm)	δ_{Dc} (mm)	$V_D(m^3)$ This Study (a)	$V_D(m^3)$ ASCE (b)	Ratio (a)/(b)
1	1.72	0.04	0.0280	0.0286	0.979
2	1.72	0.04	0.0336	0.0343	0.979
3	3.55	0.19	0.0859	0.0853	1.006
4	6.58	0.68	0.1944	0.1844	1.054
5	6.58	0.68	0.2268	0.2151	1.054
6	2.21	0.07	0.0934	0.0947	0.987
7	2.21	0.07	0.1050	0.1065	0.987
8	3.55	0.19	0.1717	0.1706	1.006
9	3.55	0.19	0.1931	0.1919	1.006
10	5.41	0.45	0.2991	0.2889	1.035

Note: Deck : D-75×200×58×65×1.2 (I_D=180 cm^4)

The rest of additional deflection and volume are listed in Table 5. The contribution of deck deflection to volume increase is less than 4%. The difference between this study and ASCE is less than 2% except when Ld is larger than 3.33m. To find out the effect of unit weight of concrete normal weight and light weight concrete are compared in Fig. 4. The volume increase ratio of light weight to normal weight concrete is about 0.79, which is close to the concrete unit weight ratio, i.e., 1.8/2.3=0.783.

In Fig. 5, the effect of slab thickness increase on the additional volume increase is investigated by increasing topping concrete thickness from 80 to 90 and 100mm. Larger floor area models showed less volume increase ratio than smaller one.

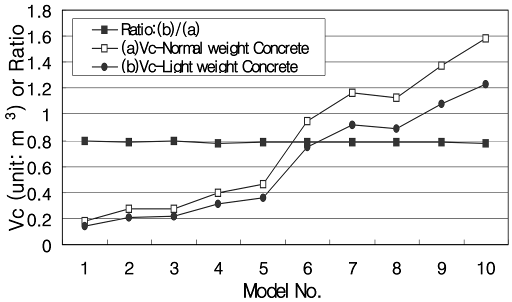

Fig. 4 Effect of unit weight of concrete

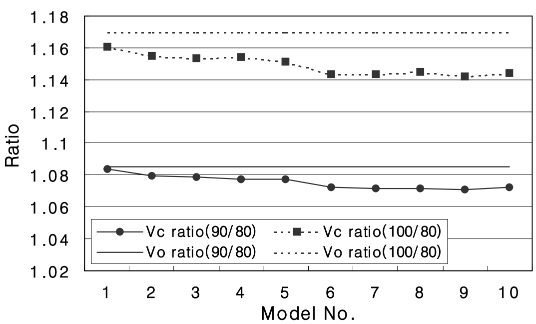

Fig. 5 Effect of concrete slab thickness

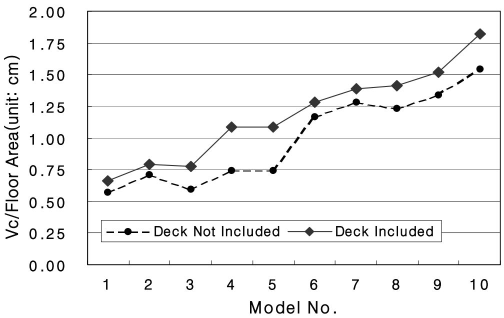

Fig. 6 Additional concrete slab thickness

Fig. 6 shows the additional volume per unit area, and this is equivalent to the additional concrete thickness required to compensate deflected slab surface. The average of this value is about 0.86cm, 1.67cm for 2-span, 3-span floor, respectively. This leads to the increase of gravity load transferred to column. Considering tributory area of a column, the additional weight per floor area transferred to a column is 16.4kgf/m^2 for 2-span, 38.2kgf/m^2 for 3-span floor.

5. Conclusion

In this study, additional deflection and volume due to concrete ponding in composite floor are estimated for various size of floors. The findings of this study are

1) Additional deflection due to concrete ponding does not surpass beam deflection limit, but additional weight due to concrete ponding is about 16~38kgf/m^2. This additional gravity load should be considered in the estimation of column load in a midor high-rise building.
2) Additional slab thickness required to compensate surface concavity is about 0.86, 1.67cm for 2-span, 3-span floor, respectively.
3) For the floor area of 25~80m^2 with beam and girder span of 5~10m, the additional concrete volume increase due to concrete ponding is about 10.8%. Ryan(1987) mentioned that common construction practice for concrete volume increase is 10 % and this needs confirmation. The contribution of deck deflection to additional volume increase is less than 4% when the deck span is less than 3.33m.
4) The ratio of additional volume increase to initial volume increase depends on floor area and the ratio difference of examples is about 2%.

The concrete ponding causes additional placement of concrete, but the consequent increase of slab thickness is instrumental in enhancing flexural capacity of slab and resistance to floor vibration. The application of the proposed analytical approach to practice requires confirmation with field data.

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Notation

A= Total mid-span girder deflection

B= Total mid-span beam deflection at the mid-bay

B_1= Total mid-span beam deflection at the mid-bay of a floor with 2 beams

C= Total mid-span deflection of beam on column line

C_B = Flexibility constant of beam

C_D = Flexibility constant of deck

C_G = Flexibility constant of girder

D= Total mid-span deflection of metal deck with unit width

t = Average concrete slab thickness(cm)

V_C= Additional concrete due to initial deflection of floor beams (m^3)

V_D= Additional concrete due to initial deflection of deck plate (m^3)

V_o= Initial concrete volume of a floor (m^3)

α= Deflection ratio of beam

β= Deflection ratio of girder

γ= Unit weight of concrete(tf/m^3)

δ_{B0}= Initial deflection of beam(cm)

δ_{BI}= Additional deflection of beam(cm)

δ_{Do}= Initial deflection of deck plate(cm)

δ_{DI}= Additional deflection of deck(cm)

δ_{Go}= Initial deflection of girder(cm)

δ_{GI}= Additional deflection of girder(cm)