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Shear Bond Strength of Composite Slab: Comparison of Different Codes and Experimental Data

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***Abstract:*— In modern construction industry fast and economical construction is an essential requirement. Composite slab, in which profile deck acts as a permanent formwork during construction and as a tensile reinforcement after setting of concrete, satisfies both of these requirements. Still due to lack of particular standard for designing of composite slab, its usage is limited in India. Behavior of composite slab mainly depends on shear bond between profile deck and concrete, but from past research it was found that shear bond is the most critical type of failure in composite slab. So to understand it, various provisions for calculating shear bond strength from the different codes (ANSI/SDI C-2011, EN 1994-1-1 (2004), Hongkong(2011)) have been studied and their results are compared with experimental data taken from the past literature.**

***Key word:*-- Composite slab, longitudinal shear bond, ANSI/SDI, Eurocode.**

I. INTRODUCTION

Composite deck slab is special type of structure in which profiled steel sheet is used as both formwork and main reinforcement. It is mostly used in construction of office in which large open space is required. As profiled steel deck is very easy to fix in compare to traditional wooden formwork and also no need of removal of it, it saves lots of labor cost and time. a. Nearly 55% saving in time in compare to precast concrete frame construction and 14% in compare to steel frame with precast concrete slab panel was observed and 2.34% lower cost were observed for simple steel frame with precast concrete slab panel construction. (Dabhade et al., 2007) For same design moment composite deck slab requires less thickness compare to RCC slab so reduction in self weight and in result of which there is reduction in column and footing size means lots of saving in construction costs. Due to that many advantages it is becoming very popular in western countries. Steel deck profile can be divided broadly in three categories as following.

[1] L- shaped profile

It has advantage of good interlocking between concrete and profile sheet. So it provides higher ductility than other types but it is structurally week so it cannot be used as unsupported formwork for wet concrete. It has advantage of good interlocking between concrete and profile sheet. So it provides higher ductility than other types but it is structurally week so it cannot be used as unsupported formwork for wet concrete.

[2] Trapezoidal ribs (open trough profile)

It is structurally good so it can be used as permanent shuttering but its bond characteristic is not as good so it behaves as brittle compositely. As its bond characteristic can be increased by providing embossment on surface of ribs it is widely used now days.

[3] dove tail rib (re-entrant profile)

It is in between of L-shaped and trapezoidal ribs which provide good bond and also structurally capable to support wet concrete. Steel deck profile was being used in construction from 1920s. But initially it was used as load carrying floor system, in which Concrete topping was provided only for fire protection and smooth working platforms. It was not used as composite. First patent for steel deck system was registered in 1926 by Loucks and Gillet. (US1574586) and first paper on composite slab was presented by Friberg on 1954. In his paper he has designed composite slab by using working stress method and he has also made comparison of cost for RCC structure and composite slab having same strength. After that various company have started manufacturing their own steel profile deck but designing and testing procedure of all company was different because no standardize procedure was available at that time. To overcome this problem AISI (American Iron and steel Institute) sponsored large research program in IOWA institute. In result of which standardize procedure of testing and designing procedure was generalized. (Porter and Ekberg 1975). Which became bases of initial formulation of code for composite slab. (ASCE standard 1984).

From various experiments three modes of failure was observed in composite slab. [1] Vertical shear failure (short span) [2] Longitudinal shear failure [3] Flexural failure. Among all types of failure longitudinal shear failure mode was observed to be predominant. (Johnson, Oehler, Luttrell, Porter, Schuster) Longitudinal shear strength generally depends on various parameters like thickness of profile, embossment shape, size, spacing, depth, concrete density, surface coating, depth of slab, strength of steel deck profile etc. To understand behavior of shear bond strength various provisions from ANSI/SDI C-2011, Hongkong (2011), CSSBI S3-2008, ASCE (1992) and EN 1994-1-1 (2004) are studied. In this paper only three codes are presented because provision for CSSBI is similar to SDI code and ASCE code was replaced by SDI code. In further study one experimental example is taken from past literature (Hedao et al. 2013) and calculated shear bond strength from codes and experimental results are compared at end of the paper and conclusion is presented.

II. DESIGN STEPS

Design of composite slab can be divided into two stages. In first step steel deck is designed as a permanent formwork for construction load and in second step it is designed as a tension reinforcement for composite action.

(a) Design of profiled steel deck as a permanent formwork

Two types of formwork are generally provided. One with some intermediate support and one without any support. Later one is more appropriate because economy and fast construction can be possible in this case only.

In this stage two types of checks are generally carried out strength check and serviceability check. For these checks construction load which includes load of workers and other construction load, weight of wet concrete and self-weight of steel deck are considered. During calculating weight of wet concrete, one should also check for ponding effect. Ponding is phenomenon in which due to large deflection of sheet access concrete get accumulate at middle of sheets. This accumulation again increases deflection and in result more concrete accumulates. This cycle creates highly nonlinear problem so generally avoided. In general various properties of decks are provided by manufacturer of steel deck which can be used for serviceability and strength check but if it is not given than various code like EN 1993-1-3:2006 or IS 801-1975 can be used to calculate design moment of cold formed steel by effective width method.

(b) Design for composite action

In this stage it is checked for three type of strength. Vertical shear strength, longitudinal shear strength and flexural strength. Various formula and various clauses for determining this strength and serviceability is given in codes. Some of the formula is represented briefly in Table 1. As it was mentioned earlier that longitudinal shear strength is predominant failure mode in composite slab, main discussion will be carried out on this perspective only.

III. LONGITUDINAL SHEAR STRENGTH

Longitudinal shear bond failure is most common type of failure observed by many authors. As it depends on various parameter, it is not possible to calculate longitudinal shear strength analytically. To determine it various test were developed by so many researchers. (Daniels, Abdullah, Burnet). Among all that most acceptable test is shear bond test which is also known as full scale test or m-k test in Eurocode. As this method is not based on any mechanical model, its results can be used only for few parameters. If one change parameters like thickness of profile deck, strength of steel and concrete, provision of end anchorage and negative reinforcement than for calculating shear bond strength one has to perform additional tests. To overcome this limitations new method based on mechanical model was developed which is known as partial connection method it is given only in Eurocode 4. Beside this prequalified section is also suggested in ANSI/SDI code. This method can be used for developing new profile sheet.

(A) EN 1994-1-1 (2004)

In Eurocode two methods are given for calculating shear bond strength

[1] m-k method (Cl. 9.7.3(4))

$$\frac{V_u}{bd} = \frac{mA_p}{bL_s} + k \qquad \text{............(1)}$$

Where,

V_u = maximum ultimate shear force

A_p = Area of cross section of profile

b = width of slab

L'= Length of shear span also indicated by L_s

m,k = coefficients which are obtained by test.

L_s shold be taken 0.25L for uniformly loaded span. (Cl. 9.7.3 (5))

Length of span (L) should be reduced to 0.8L for internal span and 0.9L for external span in continuous designed slab. (Cl. 9.7.3 (6)).

Informative test procedure is given in ANNEX B of eurocode.

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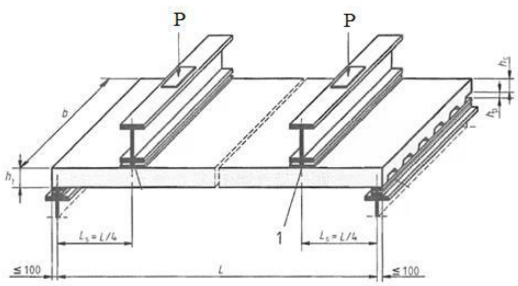

Fig 1 Full scale test arrangement

Minimum six tests are required for same profile deck having similar thickness. Three tests are conducted at short shear span and three tests are for longer span which is represented as region B and region A as shown in Fig 2. From three test in one group one test should be performed statically and two cyclic to remove effect of chemical bonding. (Cl. B.3.4)

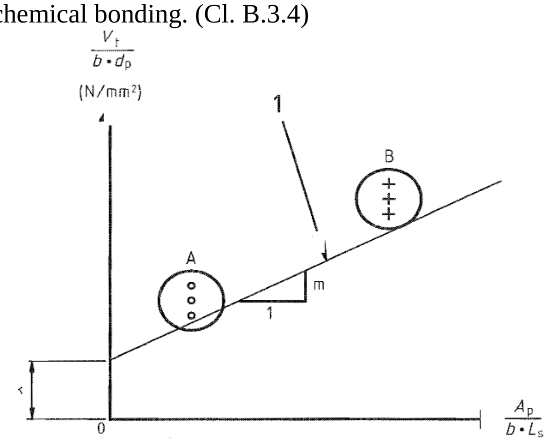

Fig 2 Regression analysis (EN 1994-1-1, 2004)

Same test results can be used for (a) profile which have higher thickness than which is tested. (b) Concrete which have strength higher than $0.8f_{cm}$ (c) steel grade higher than $0.8f_{ym}$. (Cl. B.3.1 (4)). This provisions reduce number of tests but give conservative results.

[2] PSC method. (Cl. 9.7.3 (8)).

To use partial connection method behaviour of composite slab must be ductile as defined by Cl. 9.7.3(3). Composite slab can be treated as ductile if failure load exceeds load causing 0.1mm slip by more than 10%. As partial connection method is developed by mechanical model it can be used to determine shear bond strength of slab with end anchorage and additional reinforcement (Cl. 9.7.3(10) and Cl.9.7.4.).

In partial connection generally deck does not yield so reduced bending resistance of deck contributes in total moment capacity of composite slab section. This main fundamental is used to derive PSC method. But to use this method proper ductility must be exist.

From Cl. 9.7.3 (8) resistance moment can be calculated by following.

$M_{p.Rd} = N_c \times z + M_{pr}$ (2)

Where $M_{pr} = 1.25M_{pa}\,[1-\frac{N_c}{N_{cf}}] \leq M_{pa}$ (3)

$z = h_t - 0.5x - e_p \times (e_p-e)\frac{N_c}{N_{cf}}$ (4)

$N_c = \tau_{u,Rd} b L_x < N_{cf}$ (5)

M_{pa} = ultimate moment capacity of profile deck

h_t = total depth of slab

e_p = plastic NA distance from bottom flange

e = elastic NA distance from bottom flange

$\tau_{u,Rd}$ can be calculated by full scale test. Minimum four test one has to perform. One for short span which is for checking ductility requirements and remaining three on maximum shear span.

From equation 2 graph between M_{Rd} and length can be plotted as shown in Fig3.

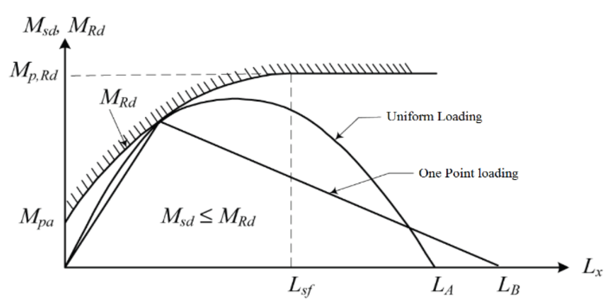

Fig 3 Calculation of M_{rd} by PSC method

This graph indicates failure envelope if bending moment diagram for given load touch or intersect resistant graph than failure will occur.

(B) ANSI/SDI - C- 2011

Two methods are given.

[1] Shear bond method

Schuster and seleim (1982) has given new shear bond equation which requires less test for calculating shear bond strength for deck having different thickness. It is suggested to perform minimum two tests one for shortest and one for longest shear span per uniform thickness. Equation is as shown below.

$$\frac{V_u}{bd} = k_1\frac{t}{L'} + k_2\frac{1}{L'} + k_3 t + k_4 \quad (6)$$

This equation can be used only when there are more than three different deck thicknesses. Where k1, k2, k3 and k4 coefficient can be calculated from test result by regression analysis using any software packages. Procedure of test is given in ANSI/SDI-T-CD- 2011.

If thickness is not considered as variable following

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equation is given.

$$\frac{V_u}{bd} = k_5 \frac{1}{L'} + k_6 \quad \text{...........(7)}$$

Where k5 and k6 can be calculated same as m-k coefficients. For calculating this coefficients minimum four 32tests are suggested in the code.

[2] Prequalified section method.

$$M_t = KM_f - k_4 S' \qquad (8)$$

Where $K = k_3 / (k_1 + k_2)$, S'= shear span

k_1 and k_2 = deck cross section factors

k_3 = slab width factor, k_4 = shear span factor

M'_f=Theoretical moment of resistance

This method is based on available experimental data which is suggested by luttrell (1986) initially. As this method is based on experimental data, usage of this method is limited for specific types of deck only.

(C) HONGKONG (Cl. 10.4.5.3 (2))

$$\frac{V_u}{bd} = \frac{mpd}{L'} + k\sqrt{f_c} \qquad (9)$$

Where Vu = maximum ultimate shear force
Ap = Area of cross section of profile
b = width of slab
L'= Length of shear span also indicated by Ls
Fc= characteristic strength of concrete which should not be more than 1.1fcm. Where fcm indicates mean cube strength of tested specimen. This equation is first suggested by Porter et al. (1975). This same equation was also recommended in ASCE (1992), and BS 5950 (1994).

But extensive research indicated that influence of compressive strength of concrete on shear bond strength is very less and using fc in shear bond equation gives scattered result during calculation of m and k coefficients so in euro code fc terms is eliminated.

Table 1 comparison of different codal provisions

Parameters	SDI-C-2011	EUROCODE 4	HONGKONG
Flexural Capacity	$M_{P.Rd} = N_{cf}(d_p\text{-}0.5x)$	$M_{P.Rd} = N_{cf}(d_p\text{-}0.5x)$ $M_{p.Rd} = N_{cf} \times z + M_{pr}$	$M_{P.Rd} = N_{cf} z$ $Z < 0.95 d_p$
Compressive Force	$N_{cf} = 0.85 f_{cd} bx$ $N_{cf} = \frac{A_p \times f_{yp}}{\gamma_{ap}}$	$N_{cf} = 0.85 f_{cd} bx$ $N_{cf} = \frac{A_p \times f_{yp}}{\gamma_{ap}}$	$N_{cf} = \frac{A_p \times f_{yp}}{\gamma_{ap}}$ $N_{cf} = 0.45 f_{ck} bx$ $X < 0.45 d_p$
Shear Bond Strength	$\frac{V_u}{bd} = k_1 \frac{t}{L'} + k_2 \frac{1}{L'} + k_3 t + k_4$ $\frac{V_u}{bd} = k_5 \frac{1}{L'} + k_6$	$\frac{V_u}{bd} = \frac{mA_p}{bL_s} + k$	$\frac{V_u}{bd} = \frac{mpd}{L'} + k\sqrt{f_c}$
Other methods for calculating shear strength bond	Prequalified Section Method	PSC method	-

IV. COMPARISON OF EXPERIMENTAL AND CALCULATED DATA

In this study experimental data from hedao et al. (2012) is used. Various coefficients needed for calculating shear bond strength are calculated by regression analysis. Value of these coefficients are shown in table.2

Table 2 calculated value of different coefficients

Eurocode	ANSI/SDI	Hongkong	PSC method
M= 102.57 K= 0.0378	K_5 = 103.698 K_6 = 0.0378	M = 102.573 K = 0.00666	τ_{Rd} = 0.0916

These coefficients are used to calculate shear bond strength for different shear spans and which is compared with available experimental data as shown in table 3.

Table 3 Comparison of experimental and calculated data

		Euro code		SDI Code		Hongkong code		PSC method	
Ls	Test load(kN)	factored load	ratio	factored load	ratio	Factored load	ratio	Factored load	ratio
300	52.33	47.10	0.90	47.10	0.90	46.63	0.89	41.15	0.79
375	48.76	38.61	0.79	38.6	0.79	38.14	0.78	34.70	0.71
450	41.1	32.95	0.80	32.95	0.80	32.48	0.79	30.39	0.74
525	35.85	28.90	0.81	28.90	0.81	28.43	0.79	27.32	0.76
600	30.38	25.87	0.85	25.87	0.85	25.40	0.84	25.01	0.82
675	26.12	23.51	0.90	23.51	0.90	23.04	0.88	23.22	0.89

V. CONCLUSIONS

[1] It is observed that PSC method is giving more conservative result than any other methods.

[2] All codes suggest to calculate shear coefficients only by considering two extreme span cases. Because of that for intermediate span very conservative result is coming which can be seen in ratio column of table 3.

[3] Shear bond method of both Eurocode (m-k) and SDI code gives nearly similar result but hongkong code gives slightly conservative result.

[4] Specimen having shorter shear span have large load carrying capacity and they also represents higher shear bond strength.

[5] No guidelines are given for reducing number of tests if coatings of sheet are different and density of concrete is different in the eurocode.

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