CHAPTER

14

ANALYSIS AND DESIGN OF COMPOSITE STRUCTURE

14.1 INTRODUCTION

Composite structure is a structural member composed of two materials, ***steel and reinforced concrete structure***. Because it is composed of two materials the strength of composite structure is provided by strength of the steel and strength of reinforced concrete. In steel construction the composite structure is a composite beam and composite column. Composite beam consist of ***reinforced concrete slab with steel beam*** and connected with ***shear connector***. Composite column is steel column cased in reinforced concrete column or steel column encase reinforced concrete column.

This chapter describes the analysis and design procedure of composite structure such as ***composite beam***, ***composite column*** and ***composite beam-column***. The design of composite beam with formed steel deck and design shear connector also described.

14.2 BEHAVIOR OF COMPOSITE STRUCTURE

14.2.1 GENERAL

The classically design method of steel structure is assume that steel beam is carry the load independently. But with the advent of welding method we can provide the mechanical shear connector to ensure that the steel beam can act together with the reinforced concrete slab to carry the load.

14.2.2 ADVANTAGES & DISADVANTAGES

The use of composite structure has both advantages and disadvantages. The advantages and disadvantages of composite structure is involve the structural aspect and also the economical aspect.

The advantages of the composite structure are :

- Shallower steel beam so the ***weight of steel is reduced (20% - 30%)***.
- Increased on floor stiffness.
- Increased of span length.

The disadvantages of the composite structure are :

- Increased of the long term deflection.
- Use of temporary shoring.

14.2.3 COMPOSITE ACTION

The composite action is developed when the load is ***carried by two structural materials act as one unit***. In the case of composite beam the load is carry by reinforced concrete slab together with steel beam. To ensure the two structural materials can acts compositely we must ensure that there is ***no slip between the materials***. To prevent the slip between two materials the ***mechanical shear connector*** usually used. When the composite action is can be developed the strength of composite structure is provided by strength of reinforced concrete and strength of steel.

14.2.4 SHORED & UN-SHORED CONSTRUCTION

Until the concrete has cured there is no composite action can be developed so the weight of the slab must be resisted by other temporary structure. After the concrete has cured the composite action is possible.

There are two general method of construction of composite structure, as follows :

- *Shored Construction*, in shored construction the ***temporary shoring*** is used to support the wet concrete so no steel beam is carries the wet concrete load. After the concrete is cured the temporary shoring will ***removed*** and the load is carry by the ***composite of steel beam and reinforced concrete slab***.
- *Un-Shored Construction*, in un-shored construction the wet concrete is carried by the ***steel beam***. After the concrete is cured the load is carried by the ***composite of steel beam and reinforced concrete slab***. The steel beam must be ***designed during the construction*** and ***during the services***.

Although the use of temporary shoring will be reduced the steel beam section but it will cause additional cost for the temporary shoring. The effect steel beam reduction is not so economic compared with the temporary shoring cost.

14.3 PROPERTIES OF COMPOSITE STRUCTURE

14.3.1 GENERAL

Because the composite structure is composed of two materials we need to find the properties of combined materials that can be ***analyzed as one unit of structure***. The major properties we need to calculate are the ***effective width of the reinforced concrete slab*** and ***elastic stress distribution of composite structure***.

14.3.2 EFFECTIVE WIDTH

The concept of effective width of reinforced concrete slab is similar as in the ***ACI code*** but with some simplification by AISC – LRFD code. As already know that the ***effective width of reinforced concrete slab is used only in positive flexure moment*** and for negative moment is neglected because the slab is in tension. Actually the stress distribution at the slab is not uniform and ***converted becomes uniform stress over the effective width***.

The effective width of reinforced concrete slab is taken as the smallest of :

TABLE 14.1 EFFECTIVE WIDTH

INTERIOR GIRDER	EXTERIOR GIRDER
$b_E \leq \frac{L}{4}$	$b_E \leq \frac{L}{8} + b_{edge}$

$b_E \le b_0$	$b_E \le \frac{1}{2} b_0 + b_{edge}$

where :

b_E = effective width

L = beam span length

b_0 = center to center bema spacing

b_{edge} = distance of edge beam center to edge of slab

For non-uniform beam spacing the ***half of effective width (left or right side from the beam center)***can be taken as :

TABLE 14.2 EFFECTIVE WIDTH – NON-UNIFORM BEAM SPACING

INTERIOR GIRDER	EXTERIOR GIRDER
$b_{E1} \le \frac{L}{8}$	$b_E \le \frac{L}{8} + b_{edge}$
$b_{E1} \le \frac{1}{2} b_0$	$b_E \le \frac{1}{2} b_0 + b_{edge}$

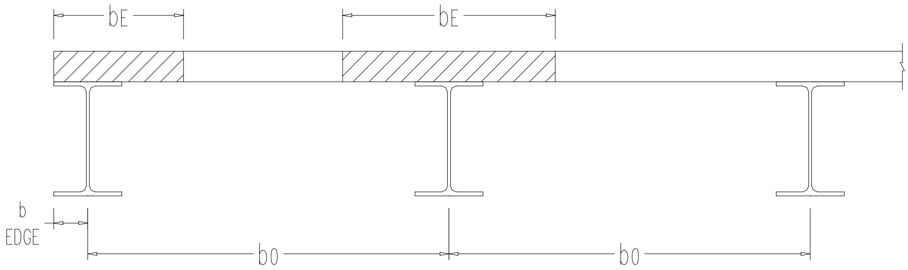

FIGURE 14.1 EFFECTIVE WIDTH

14.3.3 ELASTIC STRESS DISTRIBUTION

Before the ultimate strength design is explained it is very important to know the elastic stress distribution of the non-homogen materials that is the composite material. The elastic stress distribution is needed if the ***composite action is cannot be developed because of the limitation of width thickness ratio is exceeded***.

Based on the basic engineering mechanics the stress distribution formula is only can be used for the ***homogen material***, as follows :

$$f_b = \frac{Mc}{I} \qquad f_v = \frac{QS}{It} \qquad [14.1]$$

where :

f_b = elastic bending stress

f_v = elastic shear stress

For the composite material the equation above cannot used anymore, we must modified the composite section becomes ***transformed section***. The transformed section method transforms the ***concrete material into an amount of steel*** that has the same effect as the concrete.

The method of transformed section requires the ***strain in the steel is the same as the concrete strain already replaced***.

The strain of the steel and the replacement concrete is :

$$\varepsilon_c = \varepsilon_s \Rightarrow \frac{f_c}{E_c} = \frac{f_s}{E_s}$$
$$f_s = \frac{E_s}{E_c} f_c = n f_c \qquad \textbf{[14.2]}$$

where :

n = modular ratio

The equation above means the steel stress f_s is similar as n times of the concrete stress f_c.

If the equation is written in area of steel and concrete becomes :

$$\frac{P}{A_s} = n\left(\frac{P}{A_c}\right)$$
$$A_s = \frac{A_c}{n} \qquad \textbf{[14.3]}$$

So the required steel area that replaces the concrete is ***area of concrete divide by the modular ratio n***. in composite structure usually done by divide the ***effective width of reinforced concrete slab by the modular ratio n*** and the ***slab thickness is still the same***.

The figure below shows the ***transformed area of the composite structure*** using a transformed section method.

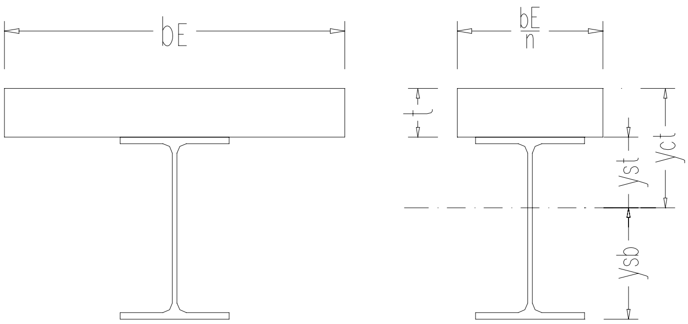

FIGURE 14.2 TRANSFORMED SECTION

The ***elastic stress distribution at the steel*** is calculated as follows :

$$f_{st} = \frac{My_{st}}{I_{tr}}$$
$$f_{sb} = \frac{My_{sb}}{I_{tr}} \qquad \textbf{[14.4]}$$

where :

f_{st} = steel stress at top fiber

f_{sb} = steel stress at bottom fiber

M = elastic flexure moment

y_{st} = distance of top fiber of steel from the neutral axis

y_{sb} = distance of bottom fiber of steel from the neutral axis

I_{tr} = moment of inertia of the transformed section about the neutral axis

The ***elastic stress distribution at concrete*** is :

$$f_c = \frac{My_{ct}}{nI_{tr}} \qquad \textbf{[14.5]}$$

where :

f_c = concrete stress

y_{ct} = distance of top fiber of concrete from the neutral axis

n = modular ratio

I_{tr} = moment of inertia of the transformed section about the neutral axis

The location of neutral axis is calculated based on the ***transformed section***, as follows :

- The area of transformed concrete is $\left(\frac{b_E}{n}\right)t$
- The area of steel section is still the same as original.

The moment of inertia is calculated also for the transformed section about the neutral axis of the transformed section.

The figure below shows the comparison of the elastic stress distribution of actual composite section and the transformed section.

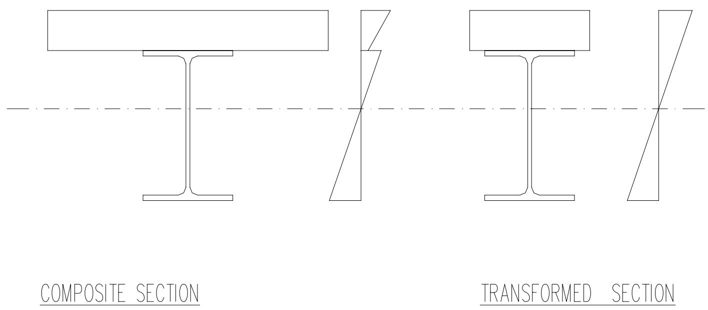

FIGURE 14.3 ELASTIC STRESS DISTRIBUTION

14.4 ANALYSIS OF COMPOSITE BEAM – ELASTIC STRESS

14.4.1 General

The flexural strength of composite beam is depended to the ***width thickness ratio of the beam web***. It is depend on the ***compact section*** or ***non-compact section*** category. The limitation of width thickness ratio of beam web is similar as in rolled beam limitation.

The flexural strength of the composite beam is determined based on the ***elastic stress distribution at the first yield of the steel if the beam web is non-compact***, as follows :

Table 14.3 Non-Compact Composite Beam

ksi	MPa
$\frac{h}{t_w} > \frac{640}{\sqrt{F_y}}$	$\frac{h}{t_w} > 3.76\sqrt{\frac{E}{F_y}}$

where :

h = height of web

t_w = thickness of web

E = modulus of elasticity

F_y = yield strength

14.4.2 Flexural Strength

The flexural strength of non-compact composite beam is determined based on ***elastic stress distribution at the first yield of the steel***. The reason is if the ***web is slender the steel beam cannot provide full plastic strength*** due to the ultimate load. As previously explained the elastic stress distribution is using the ***transformed section method***.

The elastic section modulus of the transformed section for the ***extreme compression fiber and extreme tension fiber*** is :

$$S_{ct} = \frac{I_{tr}}{y_{ct}}$$
$$S_{sb} = \frac{I_{tr}}{y_{sb}} \quad [14.6]$$

where :

S_{ct} = elastic section modulus of extreme concrete compression fiber

S_{sb} = elastic section modulus of extreme steel tension fiber

I_{tr} = moment of inertia of transformed section

y_{ct} = distance of top fiber of concrete from the neutral axis

y_{sb} = distance of bottom fiber of steel from the neutral axis

The nominal flexural strength of non-compact steel beam is :

$$M_n = F_y S_{sb}$$
$$\phi_B M_n = 0.90(M_n) \quad [14.7]$$

14.5 ANALYSIS OF COMPOSITE BEAM – PLASTIC STRESS

14.5.1 GENERAL

As previously explained that the flexural strength of composite beam depend to the width thickness ratio of the beam web.

The flexural strength of the composite beam is determined based on the ***plastic stress distribution if the beam web is compact***, as follows :

TABLE 14.4 COMPACT COMPOSITE BEAM

ksi	MPa
$\frac{h}{t_w} \leq \frac{640}{\sqrt{F_y}}$	$\frac{h}{t_w} \leq 3.76\sqrt{\frac{E}{F_y}}$

where :

h = height of web

t_w = thickness of web

E = modulus of elasticity

F_y = yield strength

To calculate the flexural strength based on the plastic stress distribution we must compute first the location of ***plastic neutral axis (PNA)***. The location of PNA may be in the ***reinforced concrete slab*** or in the ***steel***. The analysis is using the ***Whitney rectangular stress distribution (ACI code) of the concrete*** and ***yield strength of the steel***.

14.5.2 PLASTIC NEUTRAL AXIS IN RC SLAB

When the PNA lies in the slab the analysis is similar as in reinforced concrete with singly reinforced beam.

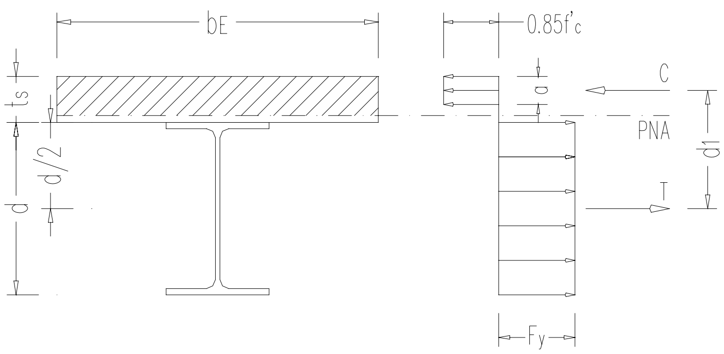

FIGURE 14.4 PNA IN RC SLAB

The resultant of compressive force of the concrete slab is :

$$C = 0.85f'_c\, ab_E \qquad [14.8]$$

The resultant of tensile force of the steel beam is :

$$T = A_s F_y \qquad \textbf{[14.9]}$$

where :

C = resultant of compressive force of concrete

f'_c = cylinder concrete compressive strength

a = depth of concrete compressive block

b_E = effective flange width

T = resultant of tensile force of steel beam

A_s = area of steel beam

F_y = yield strength of steel beam

And the static horizontal equilibrium of the resultant force is :

$$\begin{aligned} &\sum H = 0 \Rightarrow C = T \\ &0.85 f'_c\, a b_E = A_s F_y \\ &a = \frac{A_s F_y}{0.85 f'_c\, b_E} \end{aligned} \qquad \textbf{[14.10]}$$

The nominal flexural strength of the composite beam is :

$$\begin{aligned} M_n &= C d_1 = 0.85 f'_c\, a b_E \left(\frac{d}{2} + t_s - \frac{a}{2}\right) \\ M_n &= T d_1 = A_s F_y \left(\frac{d}{2} + t_s - \frac{a}{2}\right) \end{aligned} \qquad \textbf{[14.11]}$$

The design flexural strength is :

$$\phi_B M_n = 0.85 (M_n) \qquad \textbf{[14.12]}$$

This condition which is the PNA is on the RC slab means that the concrete slab ***is capable*** to developing in compression the full nominal strength of the steel beam in tension. It called as ***slab adequate*** condition.

The ***PNA is in the RC slab*** if follows the condition below, as follows :

$$0.85 f'_c\, t_s b_E \geq A_s F_y \qquad \textbf{[14.13]}$$

14.5.3 PLASTIC NEUTRAL AXIS IN STEEL BEAM

If the depth of compressive concrete block ***a*** is exceed the slab thickness then the location of PNA is in the steel beam.

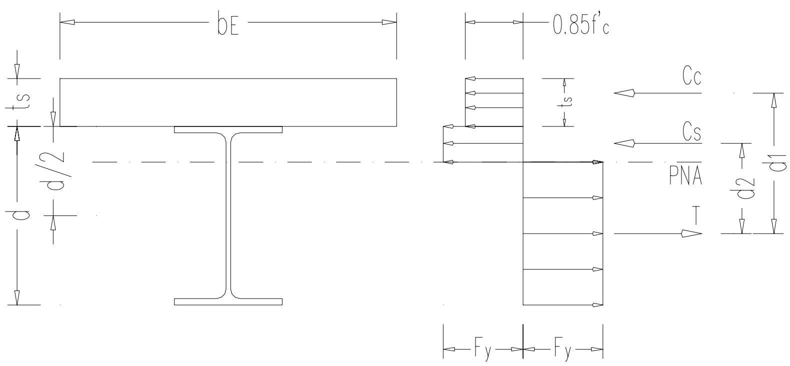

FIGURE 14.5 PNA IN STEEL BEAM

The resultant of compressive force of concrete is :

$$C_c = 0.85f'_c\, t_s b_E \qquad \textbf{[14.14]}$$

The static horizontal equilibrium of the resultant force is :

$$T = C_c + C_s$$
$$T = A_s F_y - C_s \qquad \textbf{[14.15]}$$

where :

T = resultant of tensile force of steel beam

C_c = resultant of compressive force of concrete

C_s = resultant of tensile force of steel beam

So the resultant of tensile force of steel beam is :

$$C_c + C_s = A_s F_y - C_s$$
$$C_s = \frac{A_s F_y - C_c}{2} \qquad \textbf{[14.16]}$$
$$C_s = \frac{A_s F_y - 0.85f'_c\, t_s b_E}{2}$$

The nominal flexural strength of the composite beam is :

$$M_n = C_c d_1 + C_s d_2 \qquad \textbf{[14.17]}$$

The design flexural strength is :

$$\phi_B M_n = 0.85(M_n) \qquad \textbf{[14.18]}$$

This condition which is the PNA is on the RC slab means that the concrete slab ***is not capable*** to developing in compression the full nominal strength of the steel beam in tension.

The ***PNA is in the steel beam*** if follows the condition below, as follows :

$$0.85f'_c\, t_s b_E < A_s F_y \qquad \textbf{[14.19]}$$

14.6 SHEAR STRENGTH

14.6.1 GENERAL

The shear strength of the composite beam is ***provided by the beam web*** without any contribution of the reinforced concrete slab. So the analysis of shear strength is similar as in the rolled beam section.

14.7 SHEAR CONNECTOR

14.7.1 GENERAL

Due to the flexure there will be ***horizontal shear force*** between the reinforced concrete slab and the steel beam. The horizontal force is equal to the ***compressive force in the concrete C***. To ensure the ***fully composite action this force must be resisted*** so there is ***no slip*** between the concrete and the steel beam. Usually a ***mechanical shear connector*** is used to ensure there is no sip between the concrete and the steel beam.

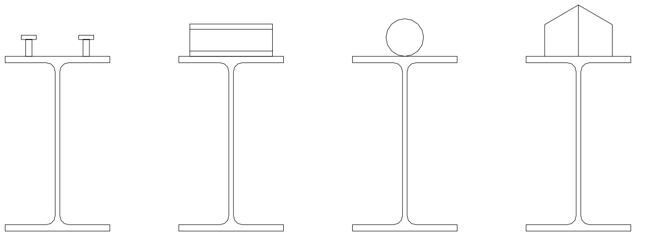

FIGURE 14.6 SHEAR CONNECTOR

The followings are the type of mechanical shear connector usually used in composite construction as shown in the figure above, as follows :

- *Stud Connector*, stud connector is like structural bolt but ***without thread***.
- *Channel Connector*, use a steel channel section.
- *Spiral Connector*, use a spiral rebars.
- *Angle Connector*, use steel angle section.

14.7.2 DESIGN LOAD

The shear connector is used to resist the ***compressive force of the concrete*** at the location of ***zero flexure moment and the maximum flexure moment***.

The design load of the shear connector is taken as the ***minimum*** of the following, as follows :

TABLE 14.5 DESIGN LOAD OF SHEAR CONNECTOR

POSITIVE MOMENT REGION	NEGATIVE MOMENT REGION	ACTION	CONDITION
$V_h = 0.85f'_c\, b_E t_s$	–	*FULLY COMPOSITE*	*REQUIRED*
$V_h = A_s F_y$	$V_h = A_{s1} F_y$	*FULLY COMPOSITE*	*REQUIRED*
$\sum Q_n$	$\sum Q_n$	*PARTIAL COMPOSITE*	*PROVIDED*

where :

V_h = horizontal shear force between the concrete and steel beam

Q_n = nominal strength of one shear connector

A_{s1} = area of compression reinforcement

The fully composite action assume there is no slip between the concrete and steel beam, partial composite action assume there is slip between the concrete and steel beam.

14.7.3 STUD SHEAR CONNECTOR

The nominal strength of one stud shear connector embedded in solid concrete slab is :

$$Q_n = 0.5A_{sc}\sqrt{f'_c\, E_c} \le A_{sc}F_u \quad \textbf{[14.20]}$$

where :

Q_n = nominal strength of one stud shear connector

A_{sc} = section area of stud connector

f'_c = cylinder compressive strength of concrete

E_c = modulus of elasticity of concrete

F_u = tensile strength of stud connector

There is no resistance factor used in calculation of shear connector strength.

14.7.4 CHANNEL SHEAR CONNECTOR

The nominal strength of channel shear connector embedded in solid concrete slab is :

$$Q_n = 0.3(t_f + 0.5t_w)L_c\sqrt{f'_c\, E_c} \quad \textbf{[14.21]}$$

where :

Q_n = nominal strength of channel shear connector

t_f = flange thickness of channel shear connector

t_w = web thickness of channel shear connector

f'_c = cylinder compressive strength of concrete

E_c = modulus of elasticity of concrete

There is no resistance factor used in calculation of shear connector strength.

14.7.5 NUMBER

The number of shear connector required between the ***zero moment to maximum moment*** is :

$$N_1 = \frac{V_h}{Q_n} \qquad \textbf{[14.22]}$$

where :

N_1 = number of shear connector

V_h = horizontal shear force

Q_n = nominal strength of ***one shear connector***

The number of shear connector must be distributed uniformly within the length they are required.

14.7.6 PLACEMENT

The shear connector is placed between ***adjacent zero moment and maximum moment and distributed uniformly***.

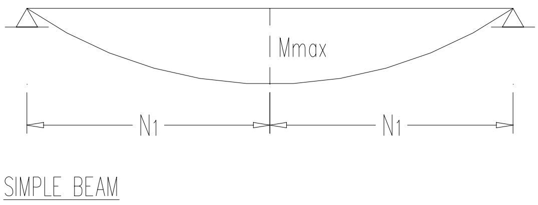

FIGURE 14.7 SHEAR CONNECTOR FOR SIMPLE BEAM

For simple beam structure the number of shear connector ***N_1 is distributed uniformly at the L/2 length***. So for full span we need ***$2N_1$*** shear connector.

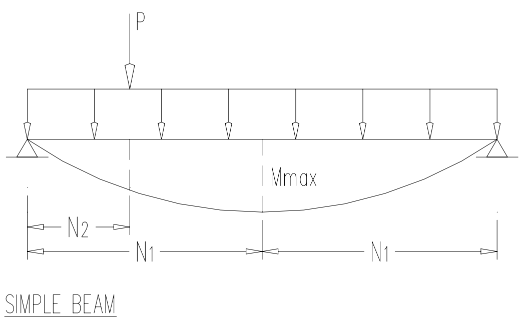

FIGURE 14.8 SHEAR CONNECTOR FOR SIMPLE BEAM WITH P LOAD

For simple beam structure with ***concentrated load*** the number of shear connector ***N_1 is distributed uniformly between the zero moment and maximum moment***. The ***additional shear connector N_2*** is required between ***zero moment and moment due to concentrated load***.

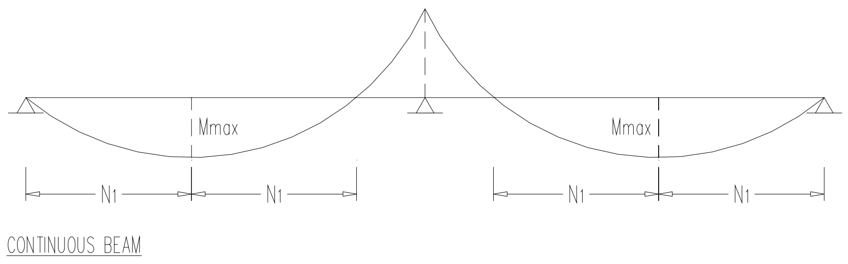

FIGURE 14.9 SHEAR CONNECTOR FOR CONTINUOUS BEAM

For continuous beam structure the number of shear connector ***N_1* is distributed uniformly between the zero moment and maximum moment and also between maximum moment and inflection point**.

At the negative moment region there is no composite action so theoretically it is not efficient to use shear connector in this region. The composite action is only provided by the ***longitudinal reinforcement and the steel beam***.

14.7.7 SIZE & LIMITATION

The followings are the limitation of stud shear connector, as follows :

- Maximum stud diameter is ***2.5 x flange thickness*** of the steel section.
- Minimum length is ***4 x stud diameter***.
- Minimum longitudinal spacing is ***6 x stud diameter***.
- Maximum longitudinal spacing is ***8 x slab thickness***.
- Minimum transverse spacing is ***4 x stud diameter***.
- Minimum concrete cover is ***1 inch***.

The following is the ***standard size of stud connector*** from the ***AWS Structural Code (1996)*** and ***minimum length limits from AISC***, as follows :

TABLE 14.6 STUD SHEAR CONNECTOR

ϕ (inch)	L (inch)
½	2
⁵/₈	2 ½
¾	3
⁷/₈	3 ½
1	4

14.8 COMPOSITE BEAM WITH FORM STEEL DECK

14.7.8 GENERAL

Usually the form steel deck is used in many of floor slab and left in place as integral of the structure. The form steel deck consists of ***ribs that can be perpendicular*** or ***parallel to the supporting beam***. The major function of the form steel deck is to provide ***lateral support before the concrete is cured***.

The following is the basic assumption of the analysis of composite beam with form steel deck, as follows :

- If the rib is ***perpendicular to supporting beam*** the concrete below the top of deck is ***neglected in the calculation of section properties*** and A_c.
- If the rib is ***parallel to supporting beam*** the concrete below the top of deck may be ***included in the calculation of section properties*** and A_c.
- The capacity of the shear connector is ***reduced***.
- ***Fully composite action usually cannot be developed*** because the limitation of the number of shear connector required. The ***partial composite action will govern*** for the composite bema with form steel deck.

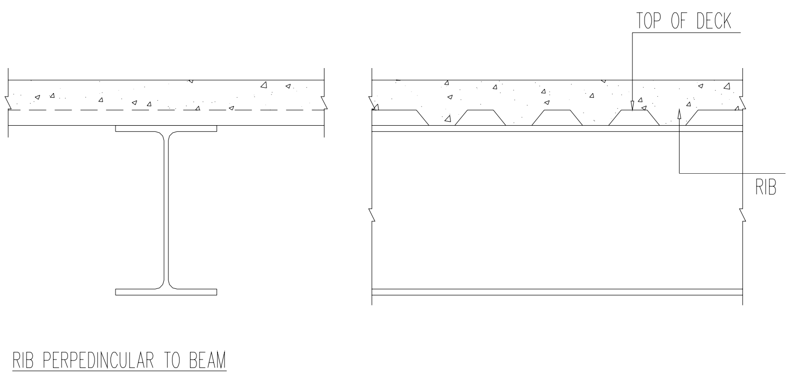

FIGURE 14.10 FORM STEEL DECK

14.7.9 REDUCED CAPACITY OF SHEAR CONNECTOR

Based on the test the ***strength of shear connector must be reduced*** when the rib is perpendicular to the supporting beam.

The reduction factor for shear connector for ***rib perpendicular with beam*** is :

$$\frac{0.85}{\sqrt{N_r}}\left(\frac{w_r}{h_r}\right)\left[\left(\frac{H_s}{h_r}\right)-1.0\right]\leq 1.0 \quad \textbf{[14.23]}$$

where :

N_r = number of stud per rib (maximum 3)

w_r = average width of rib

h_r = height of rib

H_s = length of stud

The length of stud must not exceed the following value ***(although the actual length is greater)***, as follows :

$$H_s = h_r + 75\text{mm} \quad \textbf{[14.24]}$$

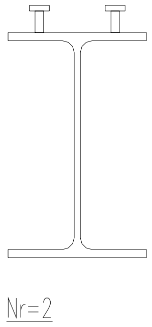

FIGURE 14.11 DETERMINATION OF N_R

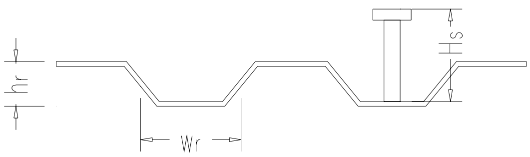

FIGURE 14.12 RIB DIMENSION

The reduction factor for shear connector for ***rib parallel with beam*** is :

$$0.60\left(\frac{w_r}{h_r}\right)\left[\left(\frac{H_s}{h_r}\right)-1.0\right]\leq 1.0 \qquad \textbf{[14.25]}$$

14.7.10 PARTIAL COMPOSITE ACTION

Partial composite action is a composite action when ***there are not enough shear connector to prevent slip*** between the concrete and the steel beam. The reason is the ***limitation of maximum number*** of shear connector cannot be achieved because ***limited by rib spacing***. In partial composite action the full strength of the concrete and steel beam cannot fully develop. If the required number of the shear connector cannot be provided to produce full composite action then we must ***provide the shear connector less than the actual number***. The ***total of shear connector strength*** ΣQ_n then used as resultant of compressive force when calculate the composite beam strength. In partial composite action the plastic neutral axis ***(PNA) will usually fall within the steel cross section***.

The moment of inertia of the partial composite section is :

$$I_{eff} = I_s + \sqrt{\frac{\sum Q_n}{C_f}}\left(I_{tr} - I_s\right) \qquad \textbf{[14.26]}$$

where :

I_{eff} = effective moment of inertia

I_s = moment of inertia of steel section

C_f = resultant of compressive force for ***fully composite action***

I_{tr} = moment of inertia for fully composite action

The resultant of compressive force must be taken as the ***minimum*** of :

$$A_sF_y \qquad 0.85f'_c\,b_Et_s \qquad \sum Q_n \qquad [14.27]$$

Partial composite action occurs when the $\sum Q_n$ ***is governs.***

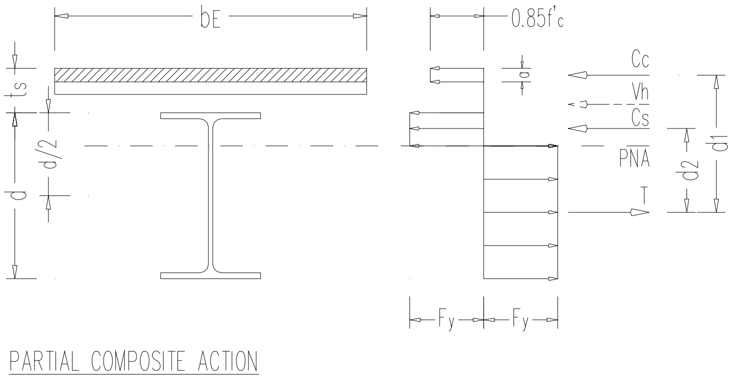

FIGURE 14.13 PARTIAL COMPOSITE ACTION

The figure above shows the internal force diagram for partial composite action.

The horizontal shear force between the concrete and steel beam is ***V_h*** which is equal to :

$$V_h = \sum Q_n \qquad [14.28]$$

Then the ***horizontal shear force V_h*** must equal to ***concrete compressive force C_c***, form this relationship we can find the depth of compressive block, as follows :

$$C_c = V_h$$
$$0.85f'_c\,b_Ea = V_h \qquad [14.29]$$
$$a = \frac{V_h}{0.85f'_c\,b_E}$$

The ***location of PNA*** can be find by maintain the following static horizontal equilibrium, as follows :

$$T - C_s - V_h = 0 \qquad [14.30]$$

The ***nominal flexure moment*** can be compute by take sum of moment at the tensile force resultant, as follows :

$$M_n = C_c(d_1) + C_s(d_2) \qquad [14.31]$$

To find the location of PNA is in the flange or below the flange the following equation can be used to check, as follows :

The resultant of compressive force at the flange is :

$$P_{yf} = b_ft_fF_y \qquad [14.32]$$

The net force transmitted at the interface between the concrete and steel beam is :

$$V_h' = T - P_{yf}$$
$$V_h' = (A_s F_y - P_{yf}) - P_{yf} \quad \textbf{[14.33]}$$

The PNA is in the flange if follows the condition below :

$$V_h' < V_h \quad \textbf{[14.34]}$$

To find the ***location of PNA in the flange*** the following relationship is used, as follows :

$$V_h = (A_s F_y - b_f t' F_y) - b_f t' F_y \quad \textbf{[14.35]}$$

14.7.11 Limitation

The following are the limitation of composite beam structure with form steel deck, as follows :

- Maximum rib height is ***3 inch***.
- Minimum average width of rib is ***2 inch***.
- Minimum slab thickness above top of deck is ***2 inch***.
- Maximum stud diameter is ***¾ inch***.
- Minimum height of stud above the top of deck is ***1 ½ inch***.
- Maximum longitudinal spacing is ***36 inch***.

14.9 COMPOSITE COLUMN

14.7.12 General

The analysis of composite column is similar as in ordinary steel column but there is some ***modification of parameters***. The parameters to be modified are ***F_y, E and r*** to match the experimental result with theoretical result.

14.7.13 Basic Axial Strength

The axial strength of composite column if the ***stability is ensured*** is :

$$P_n = A_s F_y + A_r F_{yr} + 0.85 f'_c A_c \quad \textbf{[14.36]}$$

where :

P_n = nominal axial strength
A_s = area of steel section
A_r = total area of longitudinal reinforcement
A_c = area of the concrete
F_y = yield strength of steel section
F_{yr} = yield strength of longitudinal reinforcement

If the equation above is divide with the area of steel section becomes :

$$\frac{P_n}{A_s} = F_{my} = F_y + F_{yr}\left(\frac{A_r}{A_s}\right) + 0.85 f'_c \left(\frac{A_c}{A_s}\right) \quad \textbf{[14.37]}$$

14.7.14 MODIFY F_{MY} – LRFD REQUIREMENT

The modify F_{my} according to LRFD code is :

$$F_{my} = F_y + c_1 F_{yr}\left(\frac{A_r}{A_s}\right) + c_2 f'_c\left(\frac{A_c}{A_s}\right) \qquad [14.38]$$

where :

F_{my} = modify F_y

F_y = yield strength of steel section

F_{yr} = yield strength of longitudinal reinforcement

A_s = area of steel section

A_r = total area of longitudinal reinforcement

A_c = area of the concrete

The constant of c_1 and c_2 is depend to the type of composite column, as follows :

TABLE 14.7 CONSTANT C_1 AND C_2

TYPE	C_1	C_2
PIPE & TUBE	1.0	0.85
ENCASED SHAPE	0.7	0.60

14.7.15 MODIFY E_M – LRFD REQUIREMENT

The modify E_m according to LRFD code is :

$$E_m = E_s + c_3 E_c\left(\frac{A_c}{A_s}\right) \qquad [14.39]$$

where :

E_m = modify E

E_s = modulus of elasticity of steel section

E_c = modulus of elasticity of concrete

A_s = area of steel section

A_r = total area of longitudinal reinforcement

A_c = area of the concrete

The constant of c_3 is depend to the type of composite column, as follows :

TABLE 14.8 CONSTANT C_3

TYPE	C_3
PIPE & TUBE	0.40
ENCASED SHAPE	0.20

14.7.16 MODIFY R_M – LRFD REQUIREMENT

The modify r_m according to LRFD code is :

$$r_m = r_s \geq 0.3b \qquad [14.40]$$

where :

r_m = modify r

r_s = radius of gyration of steel section

b = dimension of concrete in plane of buckling

Conservative approach of modify r_m is use the larger of the radius of gyration of steel section and the radius of gyration of concrete.

14.7.17 AXIAL STRENGTH

The axial strength of composite column is similar as in the axial strength of steel column but the calculation is using the ***modification parameters***.

14.7.18 LIMITATION

The following are the limitation of composite column, as follows :

- The structural steel at least ***4% of the total area*** or the behavior is as reinforced concrete column.
- For enchased section
  - ☑ Longitudinal reinforcements must be used. Load carrying bars must be continuous at framed levels.
  - ☑ Lateral reinforcement must be used. Spacing of ties must not exceed $^2/_3$ of least lateral column dimension.
  - ☑ Area of longitudinal and lateral reinforcement at least 0.18 mm_2 per m of bar spacing.
  - ☑ Minimum of cover is 38 mm.
- Concrete class
  - ☑ For normal concrete the concrete class is $21MPa \leq f'_c \leq 55MPa$
  - ☑ For light weight concrete the concrete class is $f'_c \geq 28MPa$
- Structural steel and reinforcement bars grade
  - ☑ The yield strength is $F_y \leq 380MPa$
- Minimum wall thickness of concrete fill pipe or tube
  - ☑ For rectangular section $t \geq b\sqrt{\dfrac{F_y}{3E_s}}$
  - ☑ For circular section $t \geq D\sqrt{\dfrac{F_y}{8E_s}}$

14.10 COMPOSITE BEAM – COLUMN

14.10.1 GENERAL

The analysis of composite beam – column is use ***approximate formula*** based on the test result by Galambos and Chapius. The nominal axial strength of composite column refers to the previous section and the ***nominal flexure strength is based on the plastic stress distribution of the composite section***.

14.10.2 FLEXURAL STRENGTH

The nominal flexural strength of composite beam – column based on the plastic stress distribution is approximately, as follows :

$$M_{nc} = F_y Z + \left[\frac{1}{3}(h_2 - 2c_r)A_r F_{yr}\right] + \left[\left(\frac{h_2}{2} - \frac{A_w F_y}{1.7f'_c\, h_1}\right)A_w F_y\right] \qquad [14.41]$$

$$c_r = \frac{(c_{rc} + c_{rt})}{2}$$

where :

M_{nc} = nominal flexural strength of composite section
Z = plastic section modulus of the steel section
F_y = yield strength of the steel section
A_w = web area of the steel section (***A_w=0*** for concrete fill steel shape)
A_r = total area of longitudinal reinforcement
F_{yr} = yield strength of longitudinal reinforcement
c_{rc} = distance from compression face to the reinforcing steel in that face
c_{rt} = distance from tension face to the reinforcing steel in that face
h_1 = with of composite section perpendicular to plane of bending
h_2 = with of composite section parallel to plane of bending

The design flexural strength of composite section is :

TABLE 14.9 DESIGN FLEXURAL STRENGTH

CONDITION	FLEXURAL STRENGTH
$\frac{P_u}{\phi_C P_n} \geq 0.3$	$\phi_B M_n = 0.85(M_{nc})$
$\frac{P_u}{\phi_C P_n} < 0.3$	*LINEAR INTERPOLATED*

For $\frac{P_u}{\phi_C P_n} < 0.3$ condition the design flexural strength is interpolated, as follows :

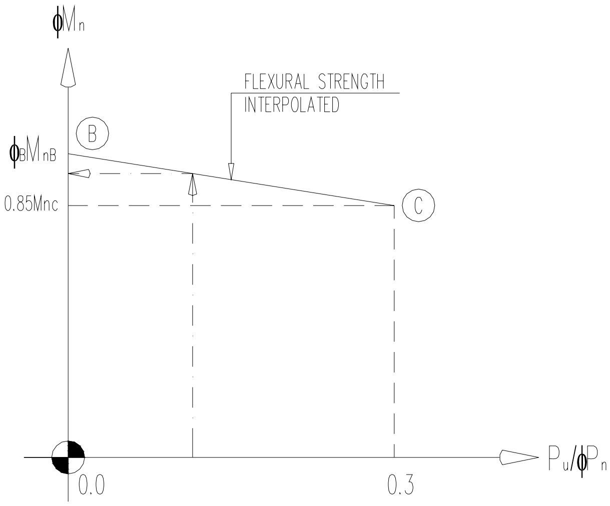

FIGURE 14.14 FLEXURAL STRENGTH OF COMPOSITE SECTION

$$\phi_B M_{nB} = 0.9 F_y Z \qquad \textbf{[14.42]}$$

where :

Z = plastic section modulus of the steel section

F_y = yield strength of the steel section