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الجامعة التكنولوجية

قسم هندسة البناء و الانشاءات

فرع المياه و سدود

Experimental and analytical study of concrete-encased Steel beam:

Elastic Stress Method

مشروع مقدم إلى قسم هندسة البناء و الانشاءات
في الجامعة التكنولوجية كجزء من متطلبات نيل شهادة البكالوريوس في علوم هندسة المياه
و السدود

من قبل

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بأشراف

الدكتور : عمار عباس

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بسم الله الرحمن الرحيم

(اقرأ باسم ربك الذي خلق* خلق الانسان من علق*
اقرأ وربك الاكرم*الذي علم بالقلم* علم الانسان مالم
يعلم*)

صدق الله العظيم

سورة العلق
الايات (١-٥)

الاهداء

إلى من لايطيب الليل إلا بشكره.. ولايطيب النهار إلى بطاعته ..
ولا تطيب اللحظات إلا بذكره .. ولا تطيب الآخرة إلا بعفوه..
"الله جل جلاله"

إلى من بلغ الرسالة وأدى الأمانة.. ونصح الأمة..نبي الرحمة..
"سيدنا محمد (ص)"

إلى من كلله الله بالهيبة والوقار.. إلى من علمني العطاء بدون انتظار..
إلى من أحمل أسمه بكل افتخار.. أرجو من الله أن يمد في عمرك لترى ثماراً قد حان
قطفها بعد طول انتظار
"والدي العزيز"

إلى ملاكي في الحياة.. إلى معنى الحب و معنى الحنان والتفاني..
إلى من كان دعائها سر نجاحي.. وحنانها بلسم جراحي..
"امي الحبيبة"

الى من حملوا اقدس رسالة في الحياة..الى الذين مهدوا لنا طريق المعرفة..
الى من علمونا التفاؤل والمضي الى الامام..
"اساتذتي الكرام"

الى اخواني واخواتي الذين لم تلدهم امي..الى من تحلوا بالاخاء..
وتميزوا بالوفاء..الى ينابيع الصدق الصافي..
الى من عرفت كيف اجدهم..وعلموني ان لا اضيعهم..
" زملائي وزميلاتي "

شكر وتقدير

في مثل هذه اللحظات يتوقف اليراع ليفكر قبل أن يخط الحروف ليجمعها في كلمات ... تتبعثر الأحرف.. وعبثاً أن يحاول تجميعها في سطور..

سطوراً كثيرة تمر في الخيال ولا يبقى لنا في نهاية المطاف إلا ان نتقدم بجزيل الشكر والعرفان إلى كل من أشعل شمعة في دروب عملنا، الى من وقف على المنابر واعطى من حصيلة فكرة لينير دربنا... إلى الأساتذة الكرام...

ونتوجه بالشكر الجزيل إلى من تفضل بالاشراف على هذا البحث فجزاه الله عنا كل خير فله منا كل التقدير والاحترام..

د. عمار عباس

Experimental and Analytical Study of Concrete-Encased Steel Beams:

Elastic Stress Method

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CHAPTER 1: INTRODUCTION

The design of structures for buildings and bridges is mainly concerned with the support and provision of load-bearing horizontal surfaces. Except in long-span bridges, these floors or decks are usually made of reinforced concrete, for no other material has a better combination of low cost, high strength, and resistance to corrosion, abrasion and fire.

The economical span for a reinforced concrete slab is little more than that at which its thickness becomes just sufficient to resist the point loads to which it may be subjected or, in buildings, to provide the sound insulation required. For spans more than few meters it is cheaper to support the slabs on beams or walls than to thicken it. When the beams are also of concrete, the monolithic nature of the construction makes it possible for a substantial breadth of slab to act as the flange of the beam that supports it. If beams are chosen to be of different material, like steel, it is called composite structure [Johnson, 1994].

The degree of fire protection that must be provided is another factor that influences the choice between concrete, composite and steel structures, and here concrete has an advantage. Little or no fire protection is required for open multi-storey car parks, a moderate amount for office blocks, and most of all for warehouses and public buildings. Many methods have been developed for providing steelwork with fire protection. Design against fire and the prediction of resistance to fire is known as fire engineering. Full or partial encasement of columns is an economical method for steel columns, since the casing makes the columns much stronger. Full encasement of steel beams is rare now because it is more expensive way for steel protection than the use chemical or nonstructural light weight material. But the author sees that the encasement of steel beams to form hidden beams, that the depth of the beam within the thickness of slab is very good way to avoid projected beams. In Iraq, it is cheap method for hidden and even for projected beams.

Composite construction employs structural members that are composed of two materials: structural steel (rolled or built-up) and reinforced concrete. Examples of composite members shown in Fig. 1 include (a) concrete-encased steel columns, (b) concrete-filled steel columns, (c) concrete-encased steel beams. and (d) steel beams interactive with and supporting concrete slabs. In contrast with classical structural steel design, which considers only the strength of the steel, composite design assumes that the steel and concrete work together in resisting loads. The inclusion of the contribution of the concrete results in more economical designs, as the required quantity of steel can be reduced.

Composite beams can take several forms. One of these forms is consisting of beams encased in concrete (Fig.1). This is a practical alternative when the primary fireproofing structural steel is to encase it in concrete and as well the contribution of concrete could be accounted to share in the strength of the beam [Rokach. 1991].

Our study here is coming to look for applicability of this form in the construction methods used in Iraq. This comes from the feasibility of this form to exclude shear connectors and it may be just insertion of the steel beam in the slabs of different thicknesses to form hidden or projected beams.

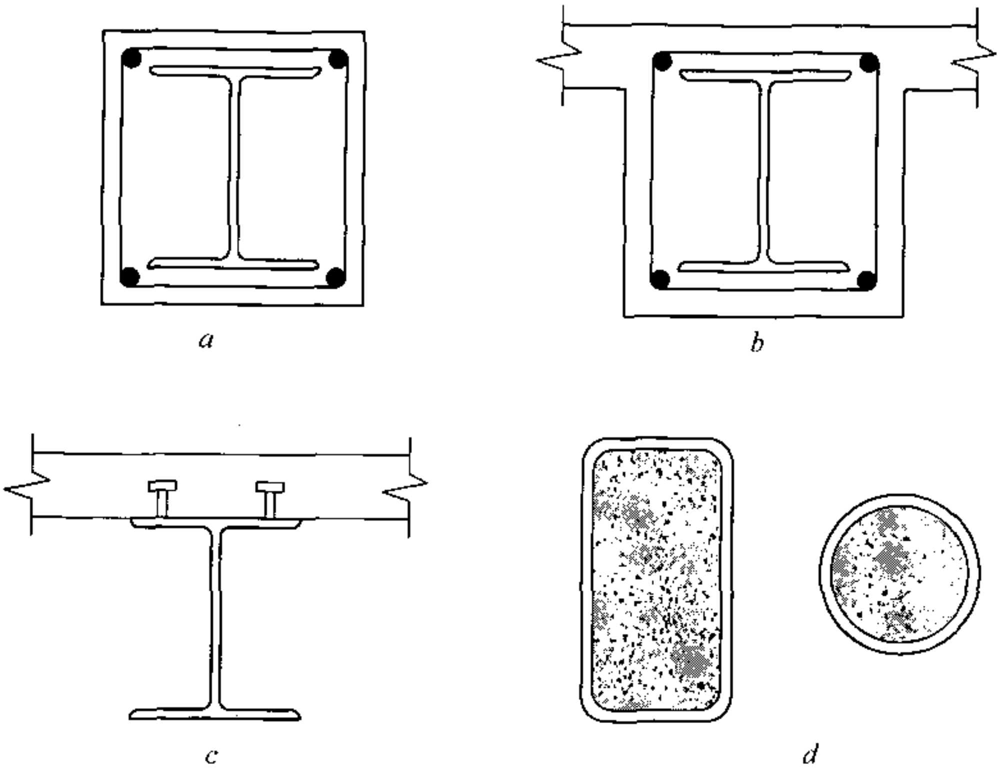

a
b
c
d

Fig. 1 Composite sections

The *advantages* of composite beams are:

- increased strength for a given cross sectional dimension.

- good fire resistance in the case of concrete encased beams.
- corrosion protection in encased beams.
- significant economic advantages over either pure structural steel or reinforced concrete alternatives.
- identical cross sections with different load and moment resistances can be produced by varying steel thickness, the concrete strength and reinforcement. This allows the outer dimensions of a beam to be held constant, thus simplifying the construction and architectural detailing.
- concrete encased steel beams are also stronger in resisting impact loads.

CHAPTER 2: EXPERIMENTAL PROGRAM AND ANALYSIS

2.1. Test Specimens

Two specimens were designed to represent a prototype beam used in medium-rise buildings. The test specimens had a square cross section of 150× 150 mm. Fig. 2 shows the configuration of the cross section. The test specimens consisted of the structural steel shape, longitudinal reinforcement, transverse reinforcement, and concrete; Figs. 3 and 4 show the beam before concrete pouring.

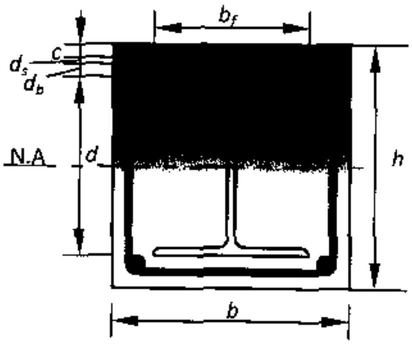


Fig. 2 Composite beam cross-section

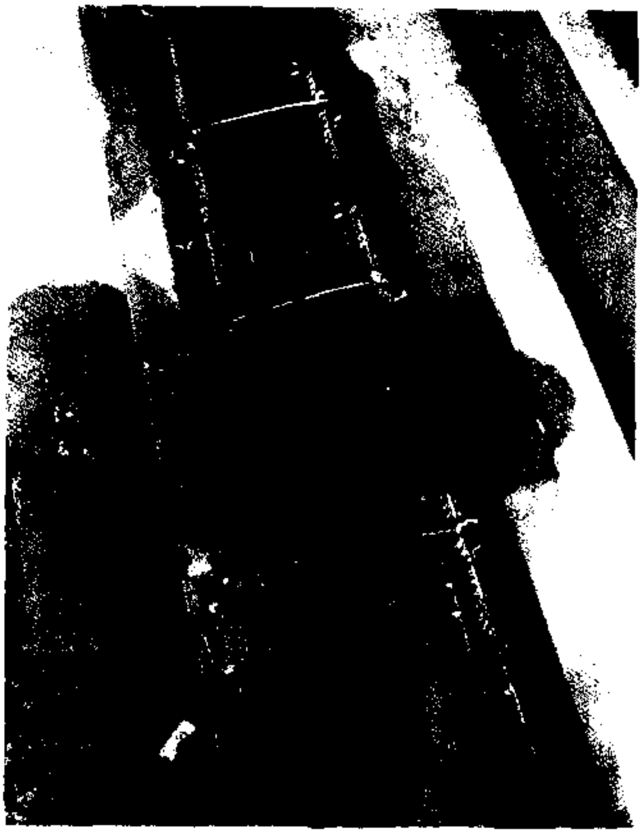


Fig. 3 Placing the steel core in the form

where

b_f :flange width

c:clear cover

d_s:diameter of stirrup

d_b: diameter of rebar

d:steel section debth

b: total width

h:total height

t_f:flange thickness

t_w:web thickness

Fig. 4 Preparing to concrete pouring

The I-shaped structural steel used in the specimens is a hot-rolled section, an H100×50×3 ×5.7 section. The ratio of the structural steel area to the gross area was 3.6%. The centroids of both the structural steel shape and the geometric center of the beam cross section are coincident.

As shown in Fig. 2, a longitudinal bar was placed at each corner of the beam. All the longitudinal bars were with minimum yield strength of 592 MPa, 12 mm in diameter and deformed. In addition, cross ties of 6 mm in diameter were used to engage the longitudinal bars and to enhance the deformation ductility of the beam. The stirrups spacing was 160 mm center to center. The measured material strengths are given in Table 1.

The concrete cube strength was 31.3 MPa measured at time of testing. The mix design for concrete is done depending on ACI code. Figs. 5 and 6 show the compression test of concrete cubes.

2.2. Test Setup and Test Procedure

Fig. 7 is showing the test machine and Fig. 8 illustrates the test setup for simulating the loading state of a beam. Roller and hinge supports were used at ends of the specimen. With this test setup, the bending moment is peak at mid-span of the specimen.

The lateral load was applied by a hydraulic jack to the midpoint of the beam, using a load step of 5 kN.

Fig. 5 Concrete cube before test

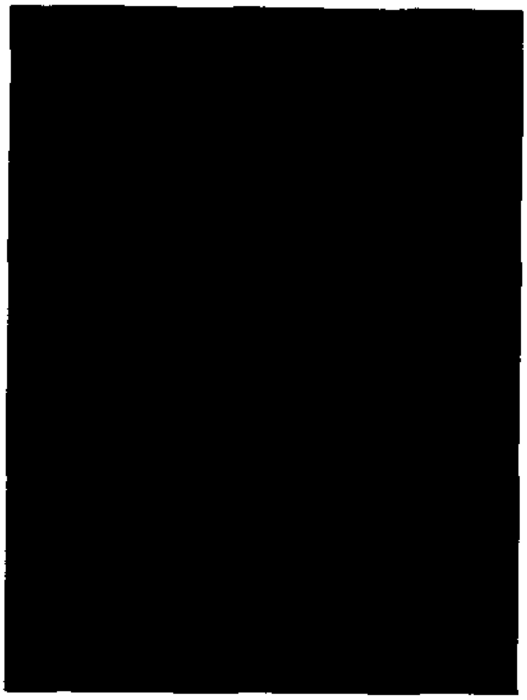


Fig. 6 Concrete cube after test

2.3. Behavior and Failure Mode

For both specimens, flexural cracks initially occurred at load of 40 kN; afterwards, the cracks progressively grew. The response of the specimens is presented in the load–displacement curves of Fig. 10.

It can be seen that the beam is showing linear behavior until 60 kN load; afterwards, the nonlinearity of the curve began and the beam will behave plastically as a plastic hinge occurring at the mid-span at loads of 110 kN and 100 kN for specimens 1 and 2, respectively. Ductility of the beam is very high that because of the high percentage of steel area and this is one of the favorable features for seismic construction.

The failure in the concrete is first by cracking of the tension zone and later by crushing of the compression zone. The steel shape and reinforcement continue in the plastic region and high deflection will be produced. The failure phenomena were similar for both specimens.

2.4. Analysis

The LRFD Specification [AISC, 2001] permits two methods of design for encased steel beams. In the first method, the design strength of the encased section is based on the plastic moment capacity, $\varphi_b M_p$, of the steel section alone. In the second method, the design strength of the encased section is based on the first yield of the tension flange assuming composite action of the concrete that is in compression and the steel section. Either way, there is no need to consider local buckling or lateral-torsional buckling of the steel beam because such buckling is inhibited by the slab encasement.

There are no design aids specifically for encased beams in the *Manual of Steel Construction LRFD Method* [AISC, 2001]. The process involves finding the moment of inertia of the shape manually. It is important to remember that the moment of inertia of an object is based on several components: 1) its moment of inertia about its own centroidal axes, and 2) the area of the object times the square of the distance between its own axis and the axis of the whole shape. In addition, it is important to know that one material must be transformed into the other material. Typically, the area of the concrete is transformed into the equivalent area of steel.

The properties of the materials are as following:

1. Structural steel

I-section beam is used with the following properties:

$d = 100$ mm

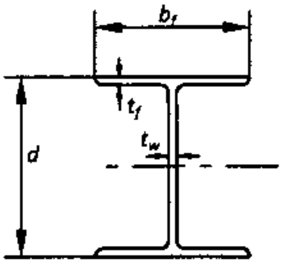
$b_f = 50$ mm

$t_f = 5.7$ mm

$t_w = 3$ mm

$F_y = 273.5$ MPa

$F_u = 461$MPa



2. Concrete

Concrete strengths are specified in terms of the characteristic cube strengths, f_{cu}, measured at 28 days. To convert to cylinder compressive strength f_c' a factor of 0.8 is used here. So,

$$f_c' = 0.8\, f_{cu}$$

3. Reinforcing steel

It is used four 12 mm-diameter bars as longitudinal reinforcement of f_y = 592 MPa and tied with undeformed 6 mm-stirrups as shown below.

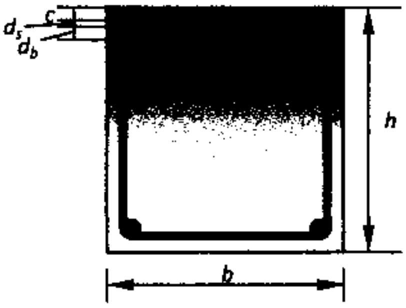
$h = 150$ mm

$b = 150$ mm

$c = 7$ mm

$d_s = 6$ mm

$d_b = 12$ mm



2.5. Elastic Stresses in Composite Beams

Although the available strength of composite beams is usually based on conditions at failure, an understanding of the behavior at service loads is important for several reasons. Deflections are always investigated at service loads, and in some cases, the available strength is based on the limit state of first yield.

Flexural and shearing stresses in beams of homogeneous materials can be computed from the formulas [Rokach, 1991]

$$f_b = \frac{Mc}{I} \text{ and } f_v = \frac{VQ}{It}$$

A composite beam is not homogeneous, however, and these formulas are not valid. To be able to use them, the transformed section is employed to convert the concrete into an amount of steel that has the same effect as the concrete. This procedure requires the strains in the fictitious steel to be the same as those in concrete it replaces. Fig. 9 shows a segment of a composite beam with stress and strain diagrams superimposed. Assuming full interaction between concrete and steel, the strains will be as shown, with cross sections that are plane before bending remaining plane after bending. However, a continuous linear stress distribution as shown in part *c* of the figure is valid only if the beam is assumed to be homogeneous.

The first requirement is that the strain in the concrete at any point be equal to the strain in any replacement steel at that point:

$$\varepsilon_c = \varepsilon_s \text{ or } \frac{f_c}{E_c} = \frac{f_s}{E_s} \quad Eq.1$$

and

$$f_s = \frac{E_s}{E_c} f_c = n f_c \quad Eq.2$$

where

E_c = modulus of elasticity of concrete, and

$$n = \frac{E_s}{E_c} \quad Eq.3$$

The ACI Building Code [ACI, 2008] gives the value of E_c as $w_c^{1.5} 0.043\sqrt{f_c'}$ (in MPa) for values of w_c between 1440 and 2560 kg/m^3 and for normal concrete it may be taken as $4700\sqrt{f_c'}$ where

w_c = unit weight of concrete (kg/m^3) (normal weight concrete weighs approximately 2400 kg/m^3).

f_c' = 28-day compressive strength of concrete (MPa).

Eq. 2 can be interpreted as follows: n square millimeters of concrete are required to resist the same force as one square millimeter of steel. To determine the area of steel that will resist the same force as the concrete, multiply the concrete area by n. That is, replace A_c by A_s/n. The result is the *transformed area*.

Depending on converting concrete to steel, the procedure will be as following [Segui, 2007]:

1. Computing the total area of steel beam and concrete, as

$$A_{total} = A_s + \frac{hb}{n} \qquad Eq.4$$

where A_s = area of steel, mm^2.

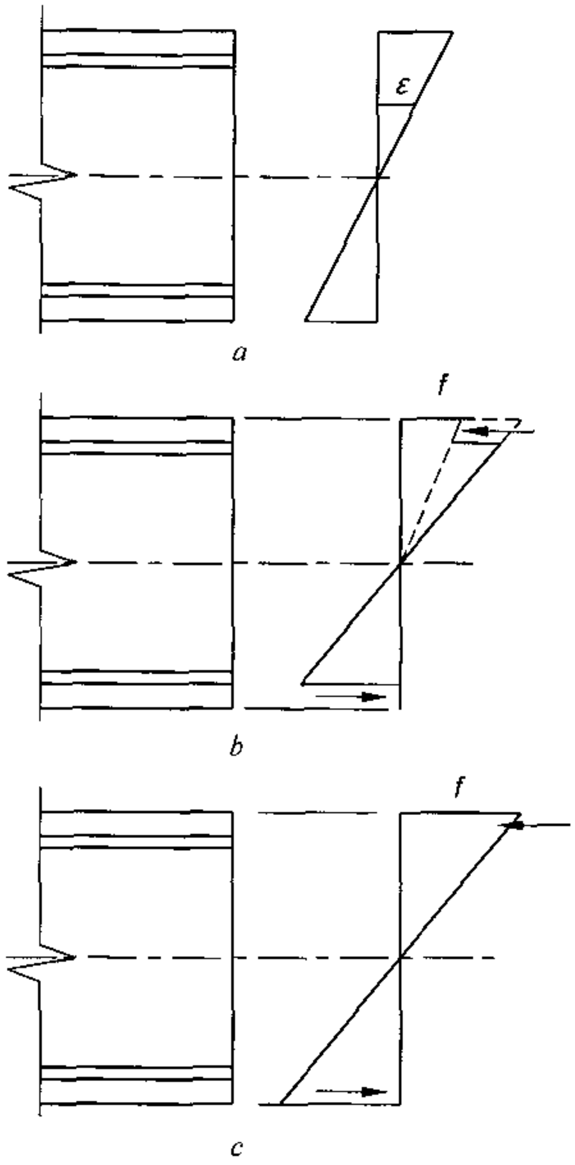


Fig. 9 Strain and stress distribution

2. Determining the distance y_b. this is the distance from the bottom of the beam to the neutral axis of the whole beam,

$$y_b = \frac{A_s y_s + A_{c(trans)} y_c}{A_{total}} \quad Eq.5$$

where y_s = distance between the steel's neutral axis and the bottom of the beam, $A_{c(trans)}$ = the transformed area of the concrete = hb / n, and y_c = distance between the neutral axis of the concrete and the bottom of the beam.

3. Computing I_x the moment of inertia about the x-axis of the whole beam,

$$I_x = I_0 + A_s(y_b - y_s)^2 + \frac{1}{12}\left(\frac{b}{n}\right)(d_c)^3 + A_{c(trans)}(y_b - y_c)^2 \quad Eq.6$$

In this formula: I_0 = moment of inertia of steel about its own axis, d_c = depth of concrete.

4. Calculating the stresses in the bottom of steel beam,

$$f_s = \frac{M(y_b - t_b)}{I_x} \quad Eq.7$$

where t_b = distance from the bottom of the steel to the bottom of the beam.

5. Verifying stresses.
They should satisfy $f_s \leq \varphi_b F_y$ where $\varphi_b = 0.9$ (AISC).

Now applying the previous steps, having:

b_f = 50 mm, d = 100 mm, t_f = 5.7 mm, t_w =3 mm

h = 150 mm, b = 150 mm, c = 7 mm, d_b = 12 mm, d_t = 6 mm

f_c' = 25 MPa, $f_{y,bar}$ = 592 MPa, F_y = 273.5 MPa, E_s = 200 000 MPa

$E_c = 4700\sqrt{f_c'}$ = 23 500 MPa

$n = \frac{E_s}{E_c} = \frac{200000}{23500} = 8.5$

A_s = 836 mm^2, $A_{c(trans)}$ = 2647 mm^2

A_{total} = 3483 mm^2

$y_b = 75$ mm

$I_0 = 1424333\ \text{mm}^4$

$I_x = 6387568\ \text{mm}^4$

The analytical solution to find the load that will cause yielding at the bottom flange neglecting the effect of the longitudinal reinforcement was $P_y = 99.8$ kN.

2.6. Deflections

A serviceable structure is one that performs satisfactory, not causing any discomfort or perceptions of unsafetey for the occupants or users of the structure. For a beam, being serviceable usually means that the deformation, primarily the vertical sag, or deflection, must be limited. Excessive deflection is usually an indication of a very flexible beam, which can lead to problems with vibrations. The deflection itself can cause problems if elements attached to the beam can be damaged by small distortions. In addition, users of the structure may view large deflections negatively and wrongly assume that the structure is unsafe.

Because of the large moment of inertia of the transformed section, deflections in composite beams are smaller than in noncomposite beams. Deflections caused by loads applied before the concrete cures must be computed with the moment of inertia of the steel shape. An additional complication arises if the concrete beam subject to sustained loading, such as the weight of partitions, after the concrete cures [Segui, 2007]. The concrete will be in compression continuously and is subject to a phenomenon known as *creep*. For the case of concrete-encased steel beam, the steel section is well distributed in the concrete; this will reduce the effect of creep.

Deflection is a serviceability limit state, not one of strength, so deflections should always be computed with service loads.

The appropriate limit for the maximum deflection depends on the function of the beam and likelihood of damage resulting from deflection. The AISC Specifications furnishes little guidance other than a statement in

CHAPTER 3: CONCLUSION AND RECOMMENDATIONS

3.1. Conclusions

Steel beams encased in concrete do offer several advantages that may justify the increased cost of construction, however: 1) Concrete encasement makes beams much stronger than they are on their own because the concrete resists the compression portion of the bending load and because the unbraced length of such a beam is zero; 2) Concrete can serve as the fireproofing for the beam thereby eliminating costs associated with those products; and 3) Buildings made of concrete and steel can be made to resist lateral loads of much greater magnitudes because of larger steel area strengthening . They are also stronger in resisting impact loads due to higher ductility as shown in figures in previous chapter.

It can be concluded that using steel shapes within slabs to form hidden beams or even projected beams will increase the strength of the beams and increase safety by increasing ductility of the beams.

3.2. Recommendations

The following recommendations may be suggested for future work:

1. Testing slabs with I-shape steel section.
2. Using shear connectors by welding studs or channels to steel shapes to increase bond between steel and concrete.
3. Nonlinear material or geometrical analysis of the composite beams for comparison purposes.
4. Applying cyclic loading to simulate loads on bridges.
5. Testing continuous beams to study the effect of indeterminacy in structures.

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