Behavior of Composite Reinforced Concrete T-Beams having Different Combinations of Headed and Unheaded Shear Studs Embedded in tensioned Concrete Zone

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Abstract

Four simply supported composite reinforced concrete T-beams of webs partially cast in steel channels were manufactured and loaded till failure in the laboratory by four-point loading condition simulating approximately the control ١-m uniformly distributed load, to determine their load midzspan deflection and load-relative interface end slip relationships. Three of those beams were provided with effectively spaced headed studs. The main variables are the elimination of the heads of the studs shear connectors and the locations of such head- less studs. While the studs of the first of those three beams were all provided by enlarged heads, the heads of all studs of the second beam are removed. The remaining beam included exterior abundant headed studs and interior distant studs without heads. Additional digital- interpreted results evaluating parameters representing the flexural behavior and the "Integrity characteristics" of such beams were also determined to investigate the effects of such uses and distributions of unheaded studs on those two main characters of composite beams.

The present study showed that heads of the exterior abundant stud shear connectors have vital effect on the flexural stiffness and slight effects on the flexural resistance and ductility, and the relative end slip at interfaces. The study also verified that the heads of the interior distantly-spaced stud shear connectors have major positive effects on the ultimate deflection and the flexural stiffness

Key Words: Composite Reinforced Concrete, T-beams, Shear Studs, Headed Shear Studs, Unheaded Shear Studs

تصرف العتبات المركبة الخرسانية المسلحة ذات المقطع **T** والتي تتمتع بتوليفات مختلفة من روابط القص ضمن منطقة الشد الخرساني

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الخلاصة

تم اختيار أربع عتبات خرسانية مركبة بشكل حرف *T* بسيطة الإسناد وذات جذوع مصبوبة جزئياً في قنوات حديدية وحملت هذه العتبات في المختبر حتى الفشل وتحت حالة تحميل ذات أربعة نقاط وذلك لتشبيه النموذج المرجعي ذي التحميل المنتظم تقريباً. لقد كان الغرض من ذلك تحديد علاقات الحمل- الهطول لمنتصف العتبة والحمل- الزحف للطبقة الوسطية لهذه العتبات. وكذلك تم تجهيز ثلاث عتبات من هذه الأربعة بقضبان قص ذات رؤوس موزعة بشكل مؤثر. وكانت المتغيرات المدروسة ، وجود الرؤوس من عدمها في قضبان القص وكذلك تباعد القضبان من غير ذوات الرؤوس . بينما جهزت قضبان القص في النموذج الأول برؤوس موسعة رفعت هذه الرؤوس من النموذج الثاني كلياً. وضعت قضبان قص ذات رؤوس عند الأطراف والعديمة الرؤوس في الوسط في العتبة الأخرى. أخذت نتائج أخرى بقراءات رقمية لمتغيرات تعكس السلوك الانحنائي " وخصائص التكامل " لمثل هذه العتبات وذلك لدراسة تأثير توزيع القضبان ذوات الرؤوس على مثل هذه المتغيرات. أظهرت الدراسة الحالية أن لتوزيع قضبان القص عند الجهة الخارجية تأثيراً مهماً على جساءة الانحناء وتأثيراً ثانوياً على مقاومة الانحناء والمطيلية والانزلاق النسبي عند النهايات. كذلك أكدت الدراسة أن رؤوس القضبان الوسطية المتباعدة لها تأثيراً ايجابي واضح على الانحراف النهائي و الجساءة الانحنائية.

Introduction

One method of constructing composite sections so that both of the advantages of ordinary reinforced concrete and composite construction are gained is by casting a concrete beam into a steel channel.

It seems, as far as the author knows, the first researcher that dealt with this form of composite construction was **Taylor [١,٢،٣،٤،٥،٦]** .

This form of composite beam construction conserves the well established economical merits of composite construction but may be less flexible from the constructional point of view. However, it remains more flexible from the constructional point of view compared to ordinary reinforced concrete.

In spite of the fact that basic composite –action mechanics is well understood nowadays, it remains to fill in important gaps in understanding of the details of this action in existing and newly developed configurations of composite sections.

This task is to be undertaken by basic experimental and theoretical research. As for works closely related to the subject matter of the present work, one may mention.

Asaad **[٧]** who in ١٩٧٧ conducted tests on simply supported inverted composite reinforced concrete T-beams so as to simulate the hogging moment regions of continuous beams.

Taylor *et al.*[٨] presented in ١٩٧٨ the results of testing six beams containing prestressing as a part of tensile reinforcement.

Further investigations followed both experimentally and theoretically of which the following is a representative sample.

In ١٩٨٢, **Kettoola [٩]** tested four inverted T- beams with steel channels. The model used to simulate them was to consider them as parts of continuous beams. He studied their shear and hogging bending.

The study of composite action has been restrained to take that action between steel and concrete only.

As an example for this trend a mention may be made for the work of Tajnik *et al* [١٠] who the analyzed the composite action in T-beams composed of timber, concrete and carbon strips.

In ٢٠٠٩, Al-Hadithy and Al-Kerbooli [١١] performed laboratory tests and conducted finite element analyses on four reinforced concrete beams cast in steel channels and other four reinforced concrete beams without steel channels. The purpose endavoured for was to examine the flexural stiffnesses , ductility's and ultimate bending capacities of such beams .

Numerical studies were also conducted as exemplified by the finite element work done by **Al- Ta'ai [١٢]** in ٢٠٠٩ His work concentrated on T-beams with webs entirely enclosed by large steel channel .

Other subjects of relation was also studied as exemplified by the work of **Ooijevaar** *et al* [١٣] who in ٢٠١٠, devised a vibration – based damage identification method for composite T- beams.

Description of Beams and Experimental Program

In the present work, four composite T- beams were fabricated and tested in accordance with the details to follow.

Apart from details pertaining to composite sections all of these four beams were of the same sections, spans, reinforcing details and concrete type. See **Fig**.١.

All of those four beams were connected to web inside faces in steel channels of the same section and properties at the base of the web.

So far for the common properties of the tested four beams, a description of the details in which they differ is in order.

Those beams were designated by the letter combinations **TB-NS**, **TB-NUH D/R**, **TB-NHNU D/R** and **TB-MNHN D/R**.

The properties of each one of those four beams are presented in **Table ١** below, while the properties of their constituents are shown in **Table ٢**.

Table ١: Definitions of the four beams designations.

| No.	Tee-Beam designations	Presence of Studs	Type of Studs	Distribution of Studs
١	**TB-NS**	No Studs	-----	-----
٢	**TB-NU D/R**	Present	Headed Studs	Dense at ends of the beam and rarefied at the middle
٣	**TB-NHNU D/R**	Present	Not headed	Dense at ends of the beam and rarefied at the middle
٤	**TB-MN HN D/R**	Present	Un headed at the middle and headed at the ends	Dense at ends of the beam and rarefied at the middle

Plates ١, ٢, ٣ and ٤ contain photos illustrating shear stud different on the steel channel and ordinary reinforcements for the T-beams
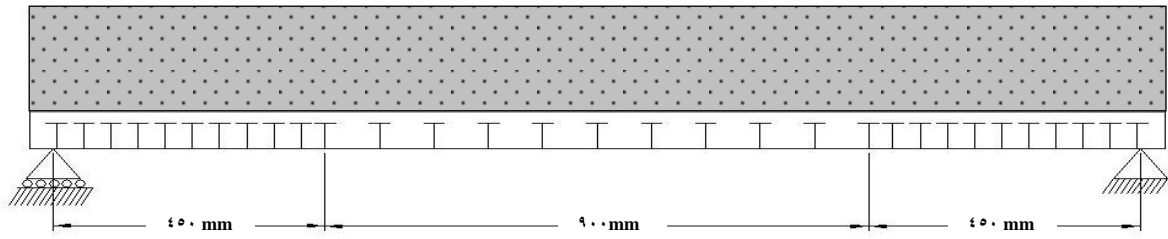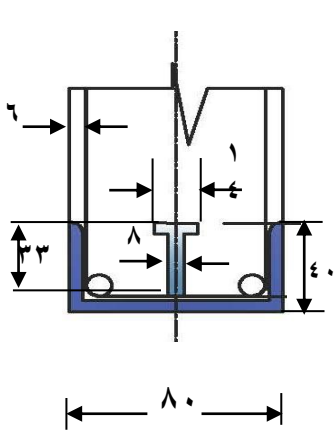
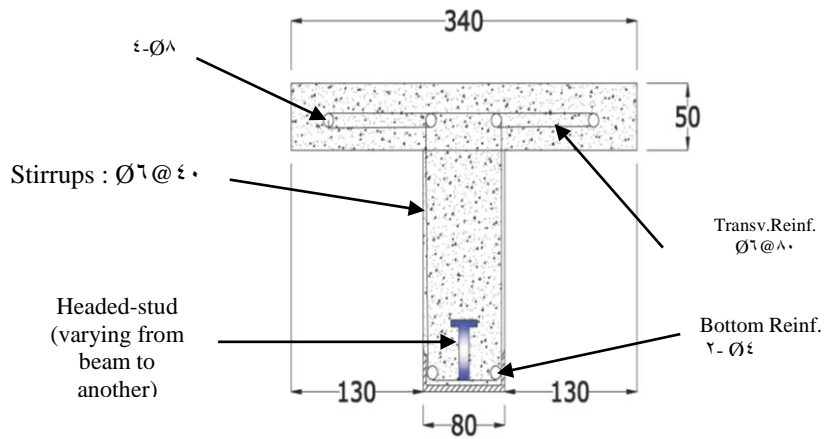**Beam TB-MNH NU D/R** (non-uniform distribution of headed studs)
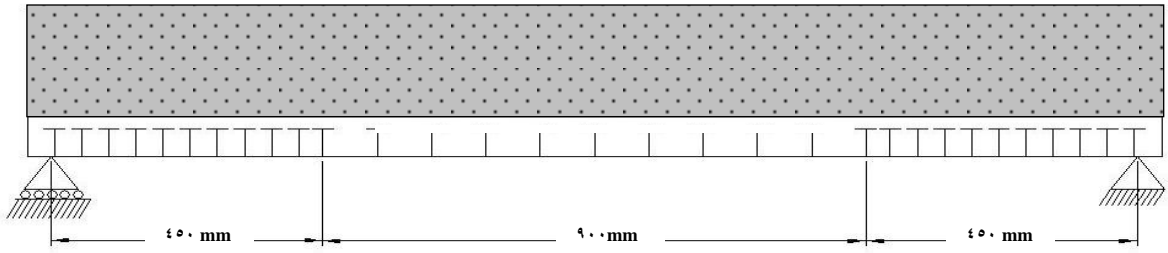
Beam TB-MNH NU D/R (non-uniform distribution of headed and unheaded studs; studs being in the middle and headed at the
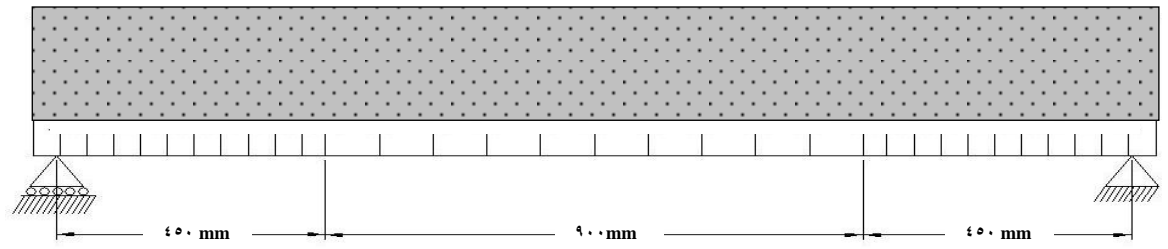
Beam TB-NHNU D/R ((non-uniform distribution of unheaded studs)

Details of the steel channel and the headed studs

Typical cross – section for each of the four beams

Fig.١: Details of the four tested beams.

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Plate ١: Steel channel destitute of studs for **TB-NS**

Plate ٢: Steel channel and studs for **TB-NU D/R**

Plate ٣: Steel channel and studs for **TB-NHNU D/R**

Plate ٤-a: Steel channel and stud for TB-MN HN D/R

Plate ٤-b: The steel reinforcing bar cage resting on the steel channel (with welded headed studs) for a typical test beam .

The test beams were kept during test under the action of a central ١٫٢ m uniformly distributed load using a universal test machine as shown in **Plate** ٥ . Three dial gauges having the smallest division of ٠٫٠١ were used to measure the central deflection of the tested beams and two slip values at the ends for each beam.

Experimentation and Test Set-up

For all the four tested beams, a uniform load was applied to the beam being tested using a specially fabricated plate ١٢ cms thick.

For all of the tested specimens, the material constituents were as presented [١٤،١٥] in **Table ٢**.

Table ٢: A ,B,C &D: Quantities and Properties of Materials for all Specimens

Table ٢A: Quantities for All Specimens

Quantities of Materials (Kg/ m³)				
Material	Water	O.P Cement	Ordinary Sand	Crushed Natural Gravel
Quantity	١٧٥	٧٢٠	٤١٠	٩٩٠
Ratio	٠,٤٢	١	١,٧٥	٦,٤٢

Table ٢B: Grading of fine aggregates #

No.	Sieve size (mm)	%Passing	
		Present work fine aggregate (%)	BS ٨٨٢:١٩٩٢ limits zone "M"
١	٥,٠	٩٣,٢٨	٨٩ – ١٠٠
٢	٢,٣٦٠	٨٠,٥٦	٦٥ – ١٠٠
٣	١,١٨٠	٦٨,٧٣	٤٥ – ١٠٠
٤	٠,٦٠٠	٥٦,٠٧	٢٥ – ٨٠
٥	٠,٣٠٠	٢٤,٩٩	٥ – ٤٨
٦	٠,١٥٠	٥,١٤٣	٠ – ١٥

Table٢C: Grading of coarse aggregate

No.	Sieve size (mm)	% passing	
		Present work coarse aggregate (%)	BS٨٨٢:١٩٩٢ limits
١	٢٠,٠	١٠٠	١٠٠
٢	١٤,٠	١٠٠	٩٠ – ١٠٠
٣	١٠,٠	٧٤,٥	٥٠ – ٨٥
٤	٥,٠	٣,٥	٠ – ١٠
٥	٢,٣٦	٠	

 # All testing are made at the laboratory of the Building and Construction Department of the University of Technology

Table ٢D: Physical properties of cement

Physical properties	Test result	Limit of IOS ٥:١٩٨٤
Fines using Blain air permeability apparatus (m²/kg)	٣١٠٠	> ٢٣٠٠
Soundness using Autoclave method	٠,١٩٪	< ٠,٨٪
Setting time using Vicat's instruments		
Initial (min.)	١٩٨	> ٤٥ min
Final (hrs : min)	٤:١٥	< ١٠ hrs
Compressive strength for cement paste cube (٧٠,٧ mm) at		

 # All Chemical and physical tests are made by Faloja cement

Those beams were all tested using a hydraulic type universal testing machine shown in **Plate ٥**. The capacity of that machine was ٢٥٠٠kN. The plate mentioned above was directly subjected to the action of the hydraulic jug of this testing machine while the plate itself was supposed to convert the action of the machine into a uniformly distributed load. This is illustrated in **Fig.٢** which illustrates the test setup.

All tests were carried out at the laboratory of the Building and Construction Department of the University of Technology.

Plate ٥: The universal testing machine (٨٥٥١M.F.L.system) with a typical test beam

Three mechanical deflectometers were used to measure vertical deflection at the middle of each beam and the horizontal relative end slips at steel – concrete interfaces.

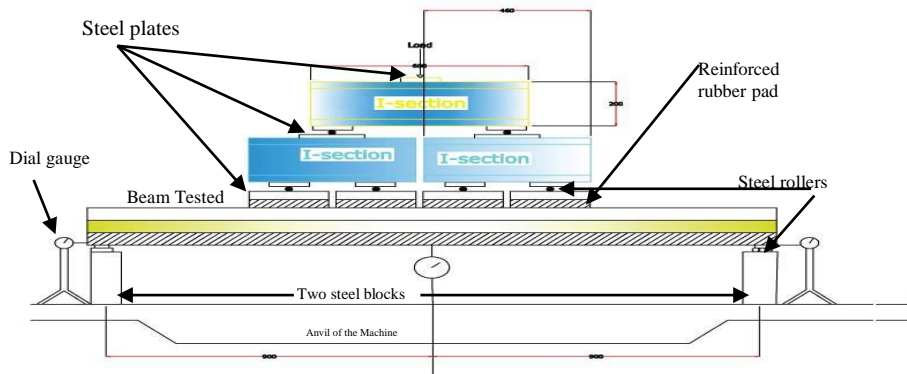The applied load was applied monotonically up to failure as shown in Fig.٢ illustrating the test setup.

Fig.٢ : Test set –up for loading of beams

Presentation and Analysis of Test Results

The consecutively growing midspan deflections and the relative longitudinal horizontal and slips at steel-concrete interfaces (measured by the ٠,٠١ mm –sensitivity dail gauges attached to the beams at the locations shown in the test set-up **Fig.٢** shown above) with the monotonically increasing loads applied up to failure have been recorded and shown in **Fig.٣** and **٤**, respectively.
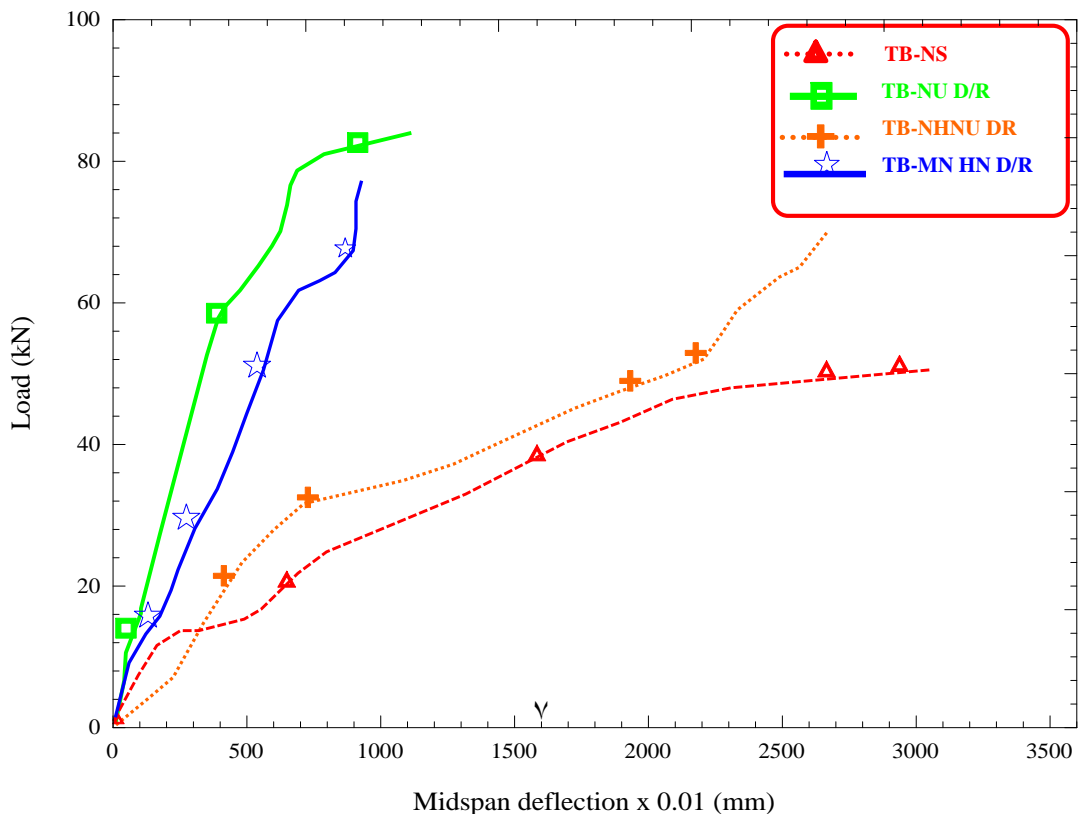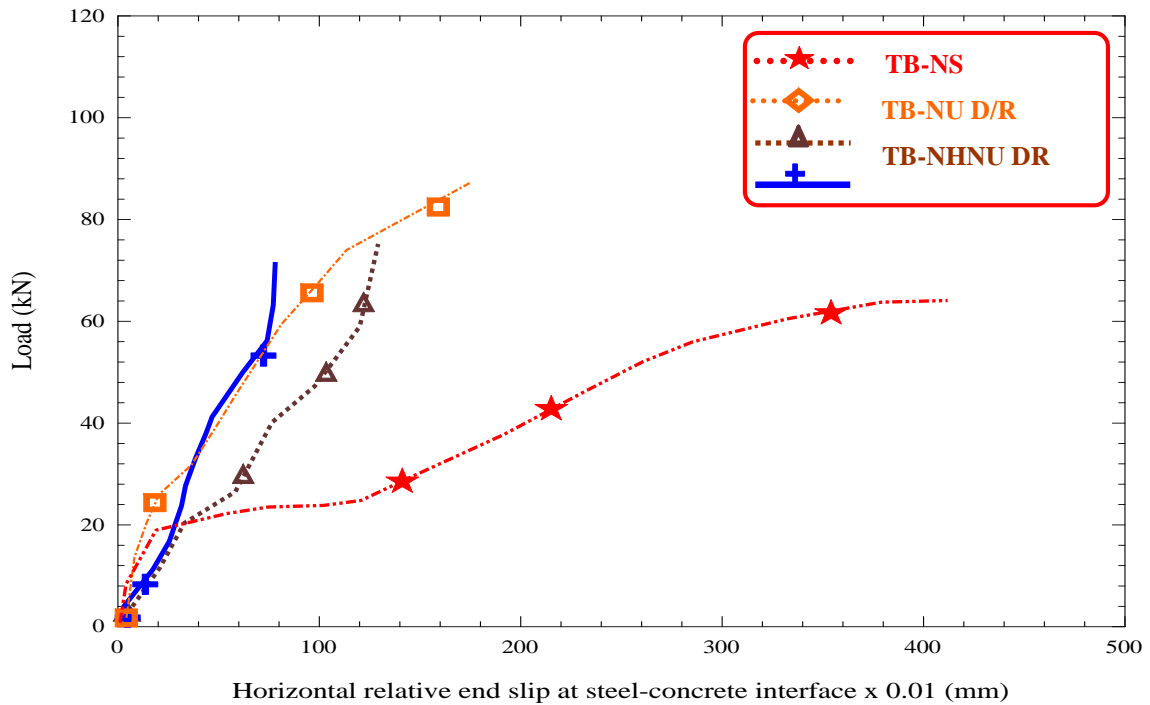

Midspan deflection x 0.01 (mm)

Fig. ٤: Load ~ relative horizontal end slip relationships obtained experimentally for the four prototypes

The test results presented in **Fig. ٣** and **٤** shown above have then been analyzed to demonstrate, first the enhancements achieved in the principal properties within the two main studied mechanical properties of **"*Composite Reinforced Concrete*** " beams –namely, " ***Flexural Behavior*** " and "***Integrity***" due to i*ntroducing perfectly headed –stud* shear connectors, and, *secondly*, to demonstrate the effects of eliminating un headed of studs – at various span wise locations – on the parameters associated with the two main properties defined above. Associated numerical valuations are given in **Table ٣** given below.

Table ٣: Contains the properties of the concrete, reinforcing steel bars and steel channels used to fabricate the tested beams

		Concrete (٢٨ days age)		Reinforcing Steel Bars			Steel Channel &Headed Stud		
		f$_{cu}$	Ec	f$_y$	f$_u$	E$_s$	F$_y$	F$_u$	E$_s$
Beam Designation	TB-NS	٣٦,٧	٢٦٨٨٣	٤١٦	٤٧٤	٢٠٧٠٠٠	٤٦٨	٥٠٠	٢٠٠٠٠٠
	TB-NU D/R	٣٨,٥	٢٨٢٠٢						
	TB-NHNU DR	٣٧,٢	٢٧٢٥٠						
	TB-MN HN D/R	٢٣,٤	١٧١٤١						

(All numbers are in MPa)

Loads values comprising measurements of the cracking, **Pcr**, and the ultimate, **Pu**, loads were also taken during the tests. Those load values are presented in **Table ٤**.

Remark:

Since the values of the ultimate crushing stress (characteristic strength, F_{cu}) of concrete are not the same for the four investigated beams (as given in **Table ١**), it has become necessary to modify the observed load values of any of the three concerned beams (provided by shear connectors) by multiplying them by the square root of the ratio of the characteristic concrete strength of beam **TB-NS** (destitute of shear connectors) to the corresponding strength of the beam concerned. This treatment has been first carried out then presented in Fig.٣ and ٤, and **Table ٣**).

Discussion of Test Measurements and Interpreted Parameters

(with references to **Fig.٣** and ٤, and **Table ٣**)

١) **Ultimate Load, P_u** :

When fully headed studs were added effectively to the composite reluf. concrete T-beam destitute of shear connectors (i.e. beam **TB-NS**) in the spanwise distribution illustrated in **Fig.١** to give beam **TB-NU D/R** a very large increase in the value of the applied load at ultimate stage, **Pu** have been gained . That increase was as large as ٦٨٪. Removed of enlarged heads from all shear connectors of beam **TB-NU D/R** thus producing beam **TB-NHNU D/R** has caused a substantially smaller but still effective decrease in the ultimate load, **Pu** value which is of order ٢٠٪ .

However, the provision of heads to the stud shear connectors of beam **TB-NHNU D/R** only at the two end quarters (to create beam **TB-MNHN**) have not brought a significant increase in the ultimate load, **Pu** value the other than ١٫٢٪.

These variations and behavior load to the fact that the heads of the stud shear connectors have a marginal positive effect on the ultimate load capacity (then the bending resistance) of such beams. However, the role of the heads of the interior studs is somewhat more significant as they are located at the region of maximum interior bending moment.

٢) **Average Flexural Stiffness, AFS:**

The provision of stud shear connectors (fully supplied by headed studs and effectively distributed in the spanwise direction) to the beam without headed studs, TB-NS (thus producing beam TB-NU D/R) have produced an extremely large increase in the flexural stiffness – in the rank of ٣٥٠٪. This in not surprising when we recall the fact that the degree of partial interaction at steel- concrete interfaces solely depends on the existence of shear connectors.

As a substitute of the studs provision stated above, when the provided stud connectors to beam TB-NS were without heads, the increase in the defined flexural stiffness – due to such stud shear connectors – was small and insufficient where the percentage increase in AFS value was ٢٢٪.

For the situation of the beam provided by fully –headed stud shear connectors – i.e. beam TB-NU D/R where the head of the interior studs (within the central half length of the beam were removed no decrease in the level of the average flexural stiffness have been attained. Instead a negligible increase of that parameter has taken place.

The argument reasoning arising from the behavior described above verifies the major role of the heads of the exterior studs (near supports where shearing and accordingly interface action is definitely high) in creating high partial interaction, whereas the heads of the interior studs play a marginal role.

	Beam Mark (١)	Flexural Behavior								Integrity Characteristics		
		P_cr (٢) kN	P_u (٣) kN	P_cr / P_u	Δ_cr (٤) mm	Δ_u (٤) mm	AFS (٥) N/mm	FD (٦) ratio	%ΔFD (٧)	δ_cr (٨)	δ_u (٩)	%PCS (١٠)
١	TB-NS	٤٢,٤	٤٩,٨	٠,٨٥	٢,٧	٢١	١٦٠٦	١,٥	---	٢,٥	٤	١٢,٥٪
٢	TB-NU D/R	٤٧,٢	٨٢,٨	٠,٨	٣,٢	١١,٥	٧٢٨٧	١,٨٣	٢٢٪	١,٠٢	١,٨	٤٢,٨٧٪
٣	TB-NHNU	٥٦,١	٦٩,٧	٠,٨٠٤	٢٤	٢٨,٦	١٩٣٢	١,٨	٢٠٪	١,١	١,٢٧	١٢,٤٨٪
٤	TB-MNHN	٥٤,٤	٧٠,٥	٠,٧٧	٦,٩	٩,٦	٧٣٤٤	١,٢١	١٩٪	٠,٥٧	.٦٥	١٢,٣٢٪

(١) with reference to Fig ١ .
(٢) Applied load and midspan deflection at stage of crack appearance above level of the steel channel.
(٣) Applied load and midspan deflection at ultimate stage
(٥) Average flexural stiffness = P_u/Δ_u .
(٦) Flexural ductility ratio = Δ_u/Δ_{cr} .
(٧) Percentage of increase in the FD ratio with introducing headed-stud shear connectors.
(٨) Relative horizontal end slip at steel-concrete interface at stage of crack appearance above level of the steel channel.
(٩) Relative horizontal end slip at steel – concrete interface at ultimate stage.
(١٠) Percentage of relative end slip at steel –concrete interface at post –cracking stage = %(δ_u - δ_{cr})/ δ_u .
(١١) Average anti-slip stiffness = P_u/ δ_u .

٣) Flexural Ductility, FD and its increase Percentage % Δ FD :

Observing values of those two parameters demonstrates the fact that the extance of effectively spaced shear connectors in the longitudinal direction (kegardless of the shear connector head supply) increases effectively the flexural ductility of the composite beam.

It is seen that the percentages of increase in values of that major parameter (for the three stud–contains beams) are close to each other ٢٢٪, ٢٠٪ and ١٩٪ , indicating to the positive

role of shear connector in relatively delaying the flexural failure somewhat beyond the cracking stage .

٤) Relative end slip at steel-concrete interfaces; δu at failure:

Attentively considering the numerical values in the tenth column of **Table ۲** danifieg the effective role of shear connectors in reducing the relative longitudinal end slip at steel concrete interfaces of the three stud-contain composite beams; **TB-NU D/R**, **TB-MN HN**, and **TB-NHNH**. Those three beam lay in the same level of the horizontal (i.e. antislip) " Integrity " announced by the **δu** values.

٥) Relative and Slip at steel –concrete interface at the Post-cracking stage:

This is the unique indicator of the "procrastination " level in undergoing ductile relative – slip behavior after cracking and prior to failure. Anyway, it is also a main parameter of horizontal integrity observation of the numerical values of this specified parameter (for the four tested beams) presented in the eleventh column of **Table ۲** shows that beam **TB-NU D/R** of fully head –provided stud shear connector extremely surpasses the two other beams provided by shear connectors by percentages not less than ۲۲۰٪.

Conclusions

The main conclusions are given below:

۱- Primarily, the shear connectors (whatever their constituents are) perform the unique major role increasing the bending strength, ultimate bending stiffness, flexural ductility and Integrity phase controlled by flexural action in composite reinforced concrete T-beam cast in steel channels .

۲- In spite of the slight effect of the heads of the abundant stud shear connectors at ends of beams (near supports) on the bending strength and the flexural ductility of the studied beams, those stud heads have the "vital " on increasing the flexural stiffness and the midspan deflections at failure . Certainly, this is attributed to their uplift resistance at their locations where the splitting tendency is large .

۳- The main role of the heads of the more distantly spaced stud shear connectors at end near beams midspans is decreasing the ultimate midspan deflection **Δu** and increasing the flexural stiffness to a far favorable extent. This is because that stiffness depends mainly on the flexural rigidity of the composite simply supported beam section at interior zones where such stud heads are provided.

٤- In principle, the stud shear connectors (whether provided by heads or not), when they are effectively spaced have the extremely major effect on reducing the relative horizontal end slip at steel –concrete interfaces.

٥- While the effect of the heads of the stud shear connectors   has been found to be of major positive effect on the vertical integrity (announced by the uplift –resistance), their effect in increasing the horizontal –or longitudinal –integrity (announced by the relative end slip at steel –concrete interfaces) is quite marginal.

٦- Heads of the distant interior stud shear connectors and those of the abundant exterior ones have slight effects on reducing the longitudinal relative end slip at steel –concrete interfaces, Moreover, the each others.

٧- The positive vital role of the heads of the distance interior stud shear connectors in developing the favorable ductile behavior regarding the relative end slip at steel-concrete interfaces (appearing in the "procrastinate" manner post to cracking) is indispensible. This is contradictory the slight effect of the heads of the abundant exterior stud shear connectors in composite reinforced concrete T-beams cast channels.

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