Mansoura Engineering Journal (MEJ) Vol.19, No.4, December,1994 C.5L

EXPERIMENTAL INVESTIGATION OF COMPOSITE BEAMS USING BENT BARS AS SHEAR CONNECTORS (Part II)

By
Saad Eldeen M. Abd-Rabou
Lecturer, Structural Eng. Dept.
El-Mansoura University, El-Mansoura, Egypt

الفحص العملى للكمرات المركبة (القطاعات الحديد والبلاطه الخرسانية) مستخدما الحديد المائل كرابط بينهما (جزء II)

الخلاصة : يمتد الفحص لعملى للكمرات المركبة بإستخدام نوع أخر من الرابط بين الكمرة الحديد والبلاطه الخرسانية ودراسة السلوك الإنشائى للكمرات المركبة بإستخدام المتغيرات الأتية : ❶ تغيير زاوية ميل الرابط داخل البلاطه الخرسانية (٤٥ °، ٦٠ °، ٩٠ °) ، ❷ تغيير الخطوة بينهما (١٥، ٢٠ ، ٢٥ سم) على طول الكمرة الحديدية ، والبرنامج العملي يتكون من : ❶ خمس تجارب من الكمرات المركبة ببحر ٢ متر صافى ، ❷ ثلاثة تجارب Push out tests ، ❸ إختبارات مكملة لتحديد خواص المواد المستعملة مثل إختبارات الشد لعينات الحديد المأخوزة من الشفة والعصب للكمرة الحديد وإختبارات الضغط لمكعبات الخرسانة.

وقد أوضحت النتائج العملية أحمال الشروخ الشعرية وأحمال الإنهيار والترخيم للكمرات المركبة وعمل مقارنة بينهم ومدى تأثير هذه المتغيرات على أحمال الشروخ الشعرية وأحمال الإنهيار. وأوضحت أيضا أنواع الشروخ وتوزيعها وكثافتها كما بينت مقاومة القص للرابط بإستخدام الـ Push out test لزاوية الميل (٤٥ °، ٦٠ °، ٩٠ °).

1. ABSTRACT

A previous experimental study on composite beams provided with spiral shear connectors [11] is extended to include other types of shear connector constructed of round steel bars. The shear connectors are represented as open bent-up bars having one end welded to the upper flange of the steel beam and the other end embedded in the concrete slab.

The purpose of this paper is to study experimentally the behaviour of composite steel-concrete beams provided with dowels constructed of bent bars due to : (i) the change in the pitch between the shear connectors along the beam (p = 15, 20 & 25 cm), and (ii) the change in the slope angle of the shear connector $\theta = 45^\circ, 60^\circ \& 90^\circ$.

The experimental program includes the following tests : i) 5-tests of composite steel concrete beams of span 200cm: ii) 3-push-out tests: iii) tensile tests for 4-specimens taken from the cross section of the steel beam and. vi) cubic compression tests for the concrete.

The cracking loads, the failure loads as well as the types of crack patterns were recorded together with the failure shear strength for the various spacings and slopes of the bent-bars shear connectors. An investigation of the effect of bent-bar shear connectors on the previous parameters is presented.

2. INTRODUCTION

Much work has been published on the theoretical methods of analysis of composite beams such as the effective modulus method ,EM, mean stress method ,MS, age- adjusted effective modulus method ,AAEM, and numerical exact solution ,general method, [1,2,3,4,5,6,7,8,9]. Experimental work is needed in order to investigate the exact behavior of these beams. Comparison between theoretical and experimental results on the behaviour of prestressed composite beams under the effects of creep and shrinkage of concrete has been done [10].

The effective variables on the behavior of the shear connectors in composite beams are the welded length of the connector to the steel beam, the size of this weld, the pitch between connectors, the diameter of the bent-up bar and its length.

The purpose from the research reported in this paper is to determine ,experimentally, the cracking and failure loads, the types of cracks and the deflection of composite beams. The variables used in this study were the pitch between connectors (15, 20 & 25cm) and the slope angle of the bent-up shear connector bars as shown in Fig.(1). Also, the shear resistance of the different types of shear connectors with different slopes is investigated using the Push-out test .

3. SCHEME OF THE EXPERIMENTAL PROGRAM.

The main parameters investigated in this study are the effect of changing the slope angle of the shear connector in concrete (45° , 60° & 90°) as well as the pitch between the shear connectors on the behaviour of the composite beams. Also, the strength of shear connectors with different slopes is investigated using Push-out tests.

The program is divided into two main parts: the first part contains six simply supported beams (B1,B2,B3,B4,B5 & B6) representing the cases of free and different values of pitches (25, 20 & 15cm) with constant slope of the connector 45° , as well as with various slopes of the connectors of 60° & 90° at a constant pitch (15cm) as shown in Fig.(1). The second part contains Push-out test for three different cases of shear connectors (cases 1,2 & 3) as shown in Fig.(2). Push-out tests are used to determine the strength of the shear connectors welded in the flanges of the steel beam and imbedded in the reinforced concrete column.

Each beam has a total length of 230 cm and a clear span 200 cm as shown in Fig.(1). The steel reinforcement of the concrete slab in longitudinal and transverse directions are constant for all beams and equals 5ϕ10mm and 7ϕ10mm/m respectively as shown in Fig.(1). The width of the concrete slab is equal to (L/4), 50cm, according to Egyptian Code [11] and it's thickness is 10cm. The steel beam used in the composite section is S.I.B.No.120.

The program includes also other complementary tests to determine the properties of the materials used viz :(i) the concrete mix used in the composite beams and columns of the Push-out tests and which has the following basic data :

Concrete Cube strength after 28 days = 250 Kg/cm^2

Cement Content	*= 400 Kg/m^3*
Sand / gravel ratio (by weight)	*= 35/65*
Water/Cement ratio (by weight)	*= 0.5*
Weight of gravel	*= 1.65 t/m^3 ; and*

(ii) the properties of the steel beams have been determined from tensile tests from specimens taken from the web and flanges. The yield and ultimate loads and stresses for the steel beam specimens are given in Table (1).

4. TEST PROCEDURE

The composite beams were placed as simple beams and the load was applied through one concentrated load at mid-span in equal incremental (300 Kg) using a Hydraulic Pump till failure as shown in Fig.(3). For deflection measurements, dial gages of 0.01mm accuracy were placed at the upper surface of the concrete slab on both sides of the jack and another dial gauge was placed at the bottom flange of the steel beam at mid-span. Two dial gauges were also used on the upper surface of the concrete slab to record the settlement of the supports as shown in Fig.(3).

Push-out test specimens were placed on the same testing frame and subjected to direct load till failure as shown in Fig.(2). In each test, the specimen is secured from all sides before starting the test.

5. ANALYSIS OF EXPERIMENTAL RESULTS.

Based on the experimental results treated, the behaviour of the tested composite beams is discussed with respect to initial cracking and failure loads, the load deflection relationships, the crack pattern and the shear strength of the different types of shear connectors.

I. DEFLECTION.

Figures (4) to (9) show the relation between the applied load and the recorded deflection till failure for all the beams tested. The settlement at supports has been taken into account in the calculation of the actual deflection. The maximum deflections corresponding to the failure loads for all the beams tested are given in Table (2).

The deflection curve for beam B1, Fig.(4) includes two curves, one corresponding to the deflection measured at the concrete slab surface on both sides of the jack while the second corresponding to the deflection measured at the bottom flange of the steel beam at mid-span. At the failure loads of beams B3,B4 & B5, the maximum deflection was 91%,88% and 78% of the maximum deflection of beam B1 respectively although the failure loads of these beams were 2.08, 2.1 and 2.7 times that of beam B1. The maximum deflections of beams B2 & B6 are higher than the maximum deflection of beam B1 although the failure loads of beams B2 & B6 were 2 to 2.16 times that of beam B1. It was noticed that the maximum deflection is proportional to the pitch between the shear connectors. Also, for beam B5 where the slope of *the shear connectors is 60, the recorded deflection is the least compared with those of beams B2,B3,B4 & B6, (although the failure load of B5 is greater than those of beams B2,B3,B4 & B6).*

The difference between the deflection recorded at the bottom flange of the steel beam and those on the upper surface of the concrete slab reaches 3 to 5%.

II) CRACKING :

II-i) Crack Initiation.

Crack initiation is affected by the pitch between the shear connectors along the steel beam as well as by their slopes. The initial crack load recorded for beams B2,B3 & B4 increased with the decrease of the pitch between the shear connectors. It increased by 10% and 22.2% due to a decrease in the pitch from 25cm to 20cm and from 20cm to 15cm respectively. The cracking load of beam B5 with slope angle of shear connector 60 is higher than those of beams B4 & B6 with shear connector slope angle 45 & 90 respectively. The cracking load of beam B5 increased by 27.2% and 16.6% over those of beams B4 & B6 respectively. The values of the cracking loads for all beams are given in Table (2). The cracking loads for beams with shear connectors (B2,B3,B4,B5 & B6), increased from 7 to 12 times the value of beam B1 free of shear connectors.

II-ii) Crack Distribution.

Fig.(10) shows the types of cracks in the composite beams tested (B1,B2,B3,B4,B5 & B6). It is noticed from the shape of cracks of these beams that : for beams B3,B4 & B5, the spread of cracks is concentrated at the middle fourth under the applied load. Also, there is a separated region at mid-span only between the concrete slab and the steel beam for beams B2 & B4. For beams B2 & B6, the cracks are distributed at a nearly constant slope of 60 along the haunch of the concrete slab. For beam B1 free of shear connectors, there is a complete separation between the steel beam and the concrete slab along the whole span and the concrete slab crept outside the upper flange of the steel beam as shown in Fig (12). Yielding in the steel beam at mid-span occurred for all beams tested.

II-iii) Crack Width.

The maximum width of cracks occurred at the middle region of the span in all beams. Also, the cracks intensity in the middle region is bigger than those recorded at other regions along the beam length.

III. FAILURE LOADS.

From the experimental results, it is noticed that the failure load for beam B5 is greater than those of the other beams (B2,B3,B4 & B6). Also, the failure loads of beams B2,B3,B4,B5 & B6 increased from 2 to 2.7 times the value of beam B1. The failure loads for all the beams are given in Table (2). The modes of failures were wide cracks in the middle fourth of the concrete slab, hair cracks in the concrete slab along the beam length and yielding of the steel beam at mid-span.

6. ANALYSIS OF PUSH-OUT TEST RESULTS.

The push-out tests are carried out to examine the shear strength of welded bent bar connectors of different slopes (45, 60 & 90 cases 1, 2 & 3) with the concrete column. Fig.(2b) shows a typical specimen used in the Push-out tests. Typical load-slip curves for cases 1,2 & 3 are plotted in Fig. (11). The failure shear strength and the corresponding modes of failure for cases 1,2 & 3 are given in Table (3). The failure shear strength of case 3 increased by 29.7% and 32% over those of cases 1 & 2 respectively.

7. CONCLUSIONS

From the experimental test results on the composite concrete-steel beams carried out in this research with the different slopes and pitches of shear connectors, the following conclusions are drawn :

1- The cracking and failure loads are highly affected by bent-bar shear connectors.
2- The failure and cracking loads increase with the decrease of the pitch between the shear connectors.
3- The cracking and Failure loads of the composite beam with shear connectors of slope 60 are the highest values of all composite beams.
4- The cracking and failure loads increased from 7.7 to 12 times and from 2 to 2.7 times over those of the beam free of shear connectors respectively.
5- The failure strength of shear connectors having a slope of 90° increased by 29.7% and 32% over those of shear connectors having slopes of 45° & 60° respectively.
6- The modes of failure for the composite beams were cracking in the concrete slab and yielding of the steel beam.
7- The failure shear strength of spiral shear connectors are higher than those of bent-bar shear connectors.

REFERENCES

1- "Composite Steel and concrete Construction" Butterworth & Co. Ltd, London, 1988, Edited by P.R.Knowles.
2- "Composite Steel Structures" Advanced, Design and Construction. Printed in Great Britain Edited By R.Narayanan, Cardiff, U.K. 1987.
3- "Shear connectors in composite beams with longitudinally cracked slabs" D.Oehlers & S.Park ASCE, Vol.118, Aug. 1992.
4- "Behavior of prestressed composite beams under the effect of shrinkage and creep" M. Zidan, K. Abdel-Aziz, A. Moktar & M. El-shaer, second Alex. Con. Str. & Geotech. Eng. April 1994.
5- Steel in Tall Buildings" 14-Edition, Part 1, Band II, Stahlleisen GmbH, 1987, Duesldorf, West Germany.
6- "Creep effects in composite beamswith flexibleshear connectors" L. Dezi

& A. Tarantino, ASCE, Vol. 118, No. 8, Aug. 1992.

7- "Simplified creep analysis of composite beams with flexible connectors" L. Dezi, C. Ianni & A. Tarantina , ASCE, Vol.119, No.5 , May 1993.

8- "Creep in composite beam beams" "Part 1: Theoretical treatment" By L. Dezi and A. Tarantino, ASCE, Vol. 119, No.7, July 1993.

9- "Creep in composite beam beams" "Part 2: Parametric study By L. Dezi & A. Tarantino, ASCE, Vol. 119, No.7, July 1993.

10- "Egyptian Code for Steel Construction and Bridges" Ministerial Decree No.451, 1989, Permenant Committee for Code of Practice for Steel Constructions and Bridges, Reseacch Center for Housing, Building and Physical Planning.

11- "Experimental investigation of composite beams using spirals as shear connectors" Part I, Vol.19, No.4, MEJ, El-Mansoura uni., Dec.1994. under publication.

Table (1) : Properties of the steel beams used in the tests.

Specmein, No.	Dimensions, cm			Area cm2	Py Kg	σy t/cm2	Aver. σy	P_{ult} Kg	σ_{ult} Kg/cm2	Aver. σ_{ult}
	a	b	L_o							
1	0.6	2.0	8.0	1.2	3000	2.5	2.86 t/cm2	4200	3.5	3.8 t/cm2
2	0.6	2.0	8.0	1.2	3500	2.92		4600	3.83	
3	0.6	2.0	8.0	1.2	3650	3.04		4770	3.98	
4	0.6	2.0	8.0	1.2	3620	3.02		4710	3.93	

Table (2) : Summary of test results for composite beams with bent-bars shear connectors.

Beam No.	Pitch between connector	slope of connector	Initial $P_{cracking}$ ton	$P_{Failure}$ ton	Maximum Deflection recorded	
					Concrete slab ,mm	steel beam ,mm
B1	----	----	1.46	7.86	15.80	15.20
B2	25cm	45	11.32	15.72	18.71	18.84
B3	20	45	12.58	16.35	14.43	14.80
B4	15	45	13.83	16.70	13.94	13.32
B5	15	60	17.61	21.07	12.34	12.00
B6	15	90	15.10	17.00	20.90	20.80

Table (3) : Shear strength of bent-bar connectors.

Slope angle of connector	Failure shear strength	Mode of Failure
45^o	5.33 ton	Vertical seperation between steel beam and concrete columns in all connector.
60^o	5.25 ton	
90^o	6.92 ton	

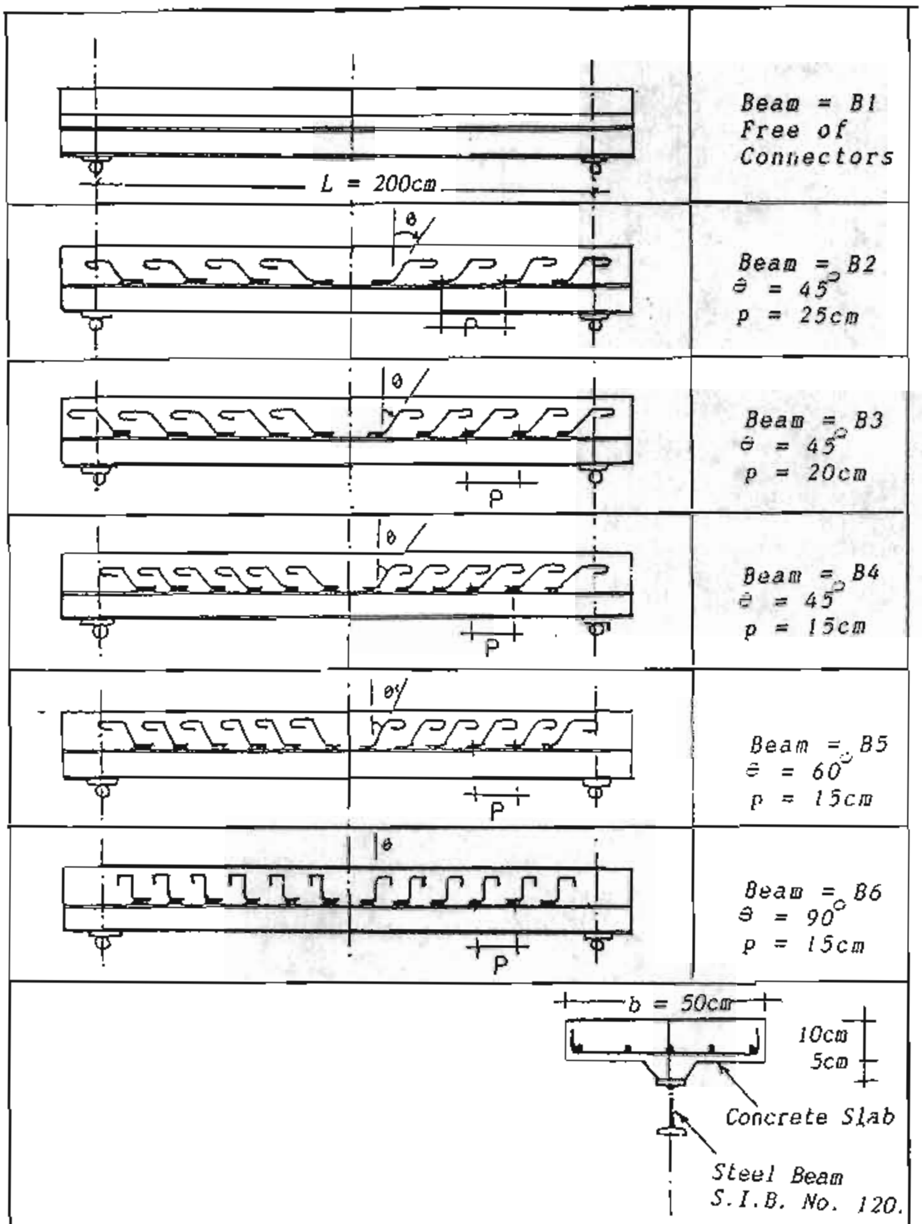
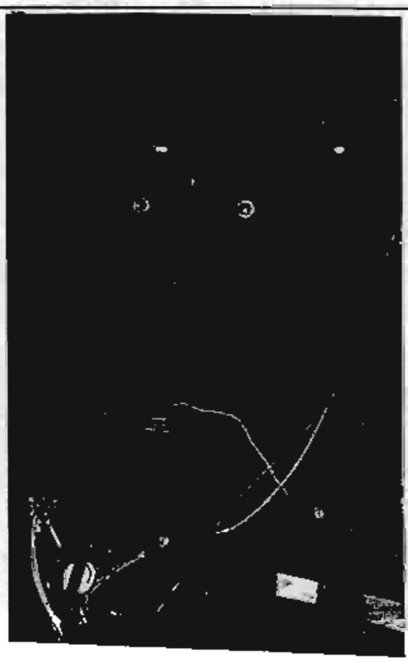
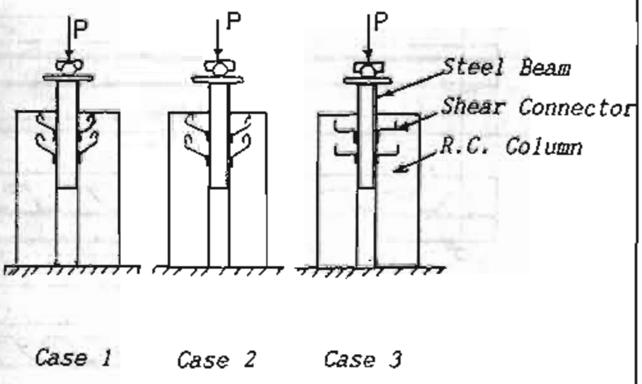


Fig.(1) : Types of the composite beams used in the experiments.





(a) Push-out test specimens

Fig.(2) : Details of Push out test.

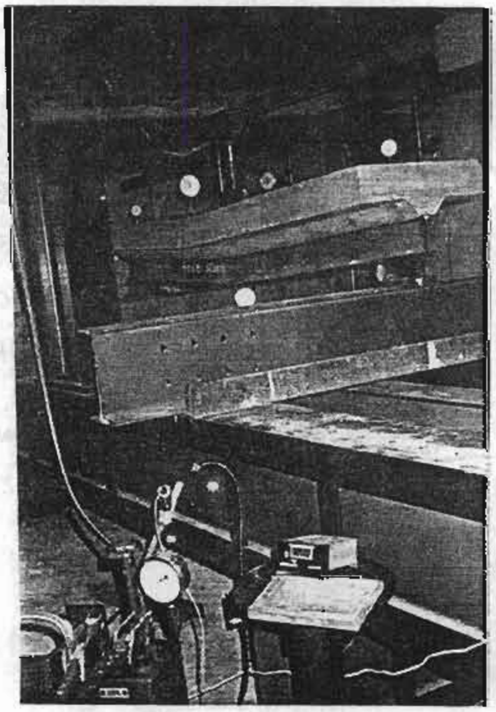


Fig.(3) : Typical arrangement for loading test.

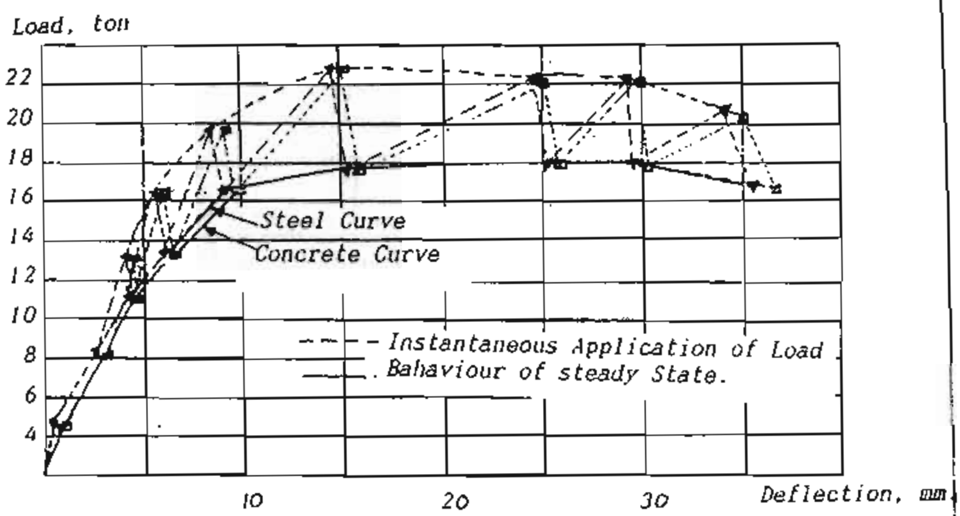


Fig.(4) : Load deflection curve of composite beam free of shear connectors.

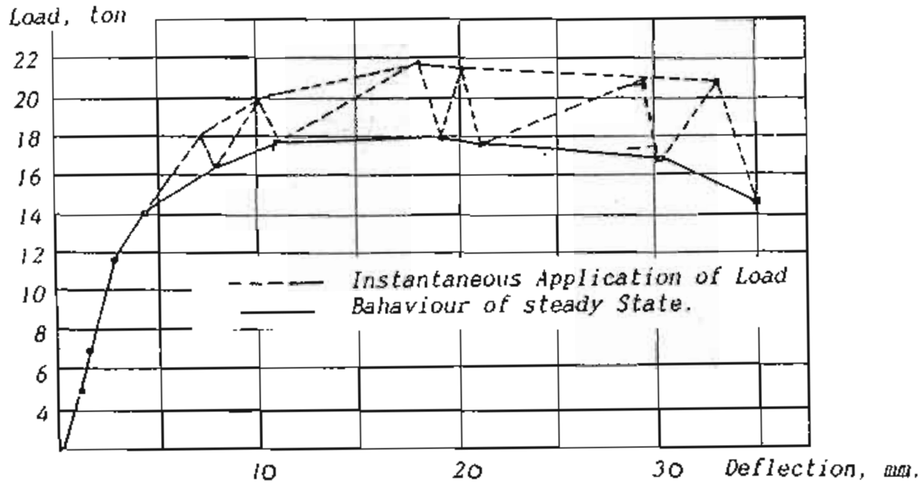


Fig.(5) : Load deflection curve of composite beam with connectors of slope 45° and pitch = 25cm.

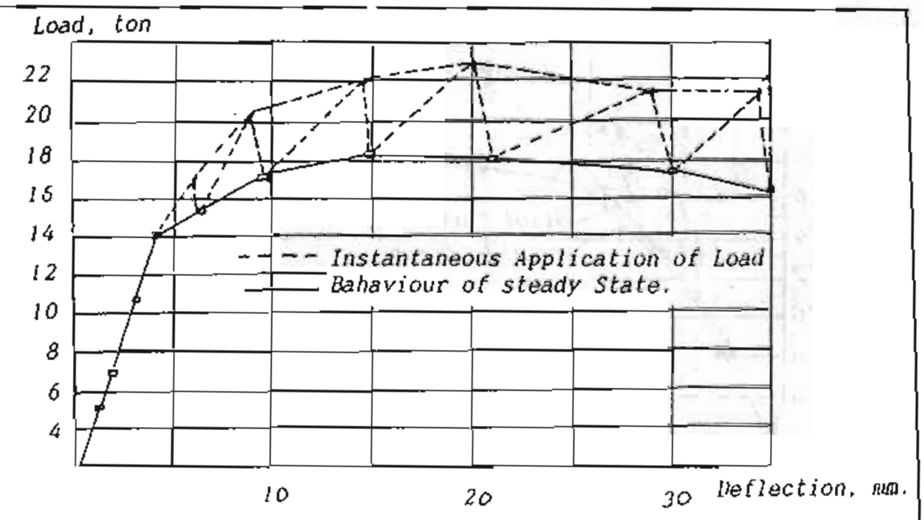


Fig.(6) : Load deflection curve of composite beam with connectors of slope 45° and pitch = 20cm.

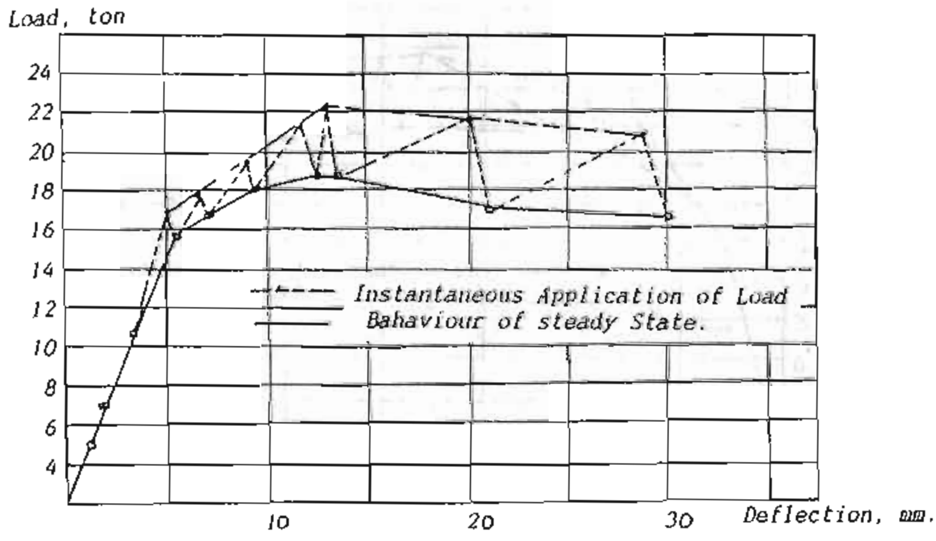


Fig.(7) : Load deflection curve of composite beam with connectors of slope 45° and pitch = 15cm.

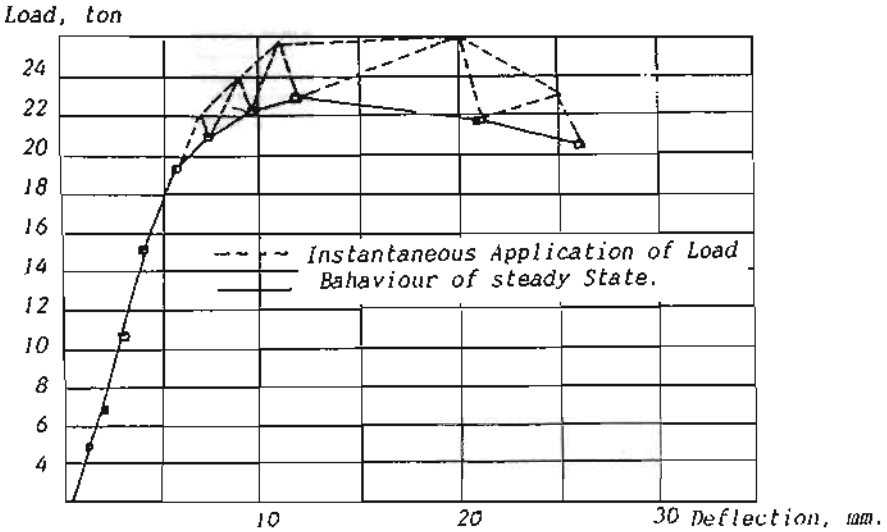


Fig.(8) : Load deflection curve of composite beam with connectors of slope 60° and pitch = 15cm.

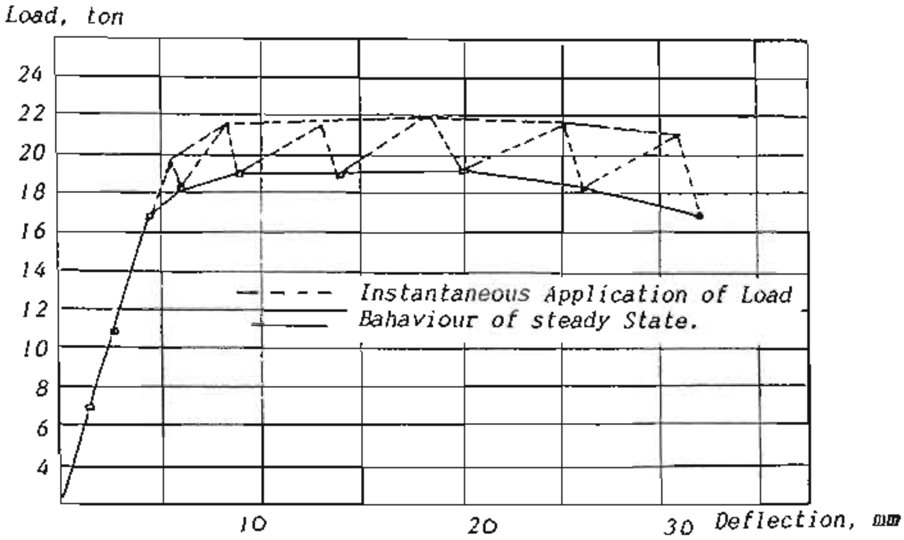


Fig.(9) : Load deflection curve of composite beam with connectors of slope 90° and pitch = 15cm.

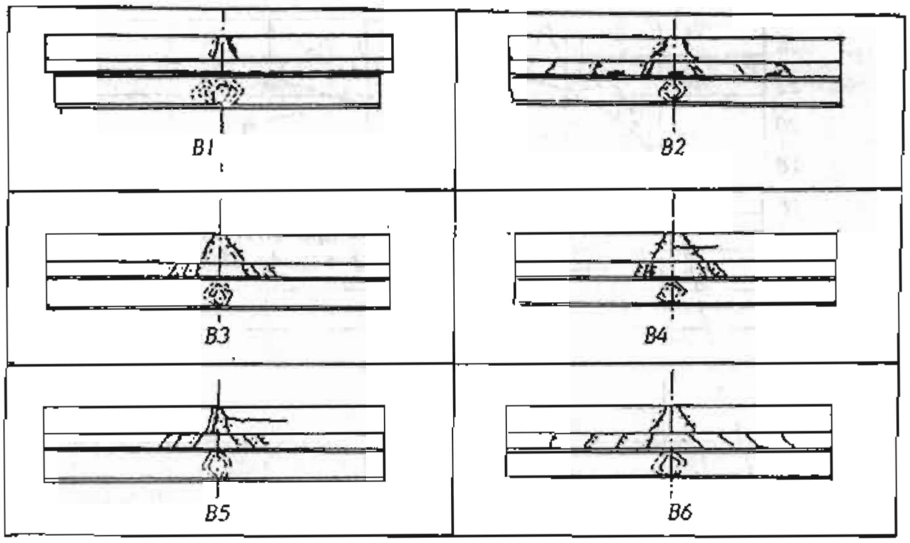
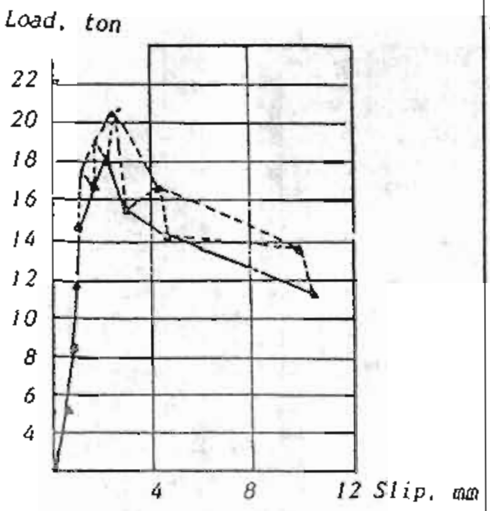
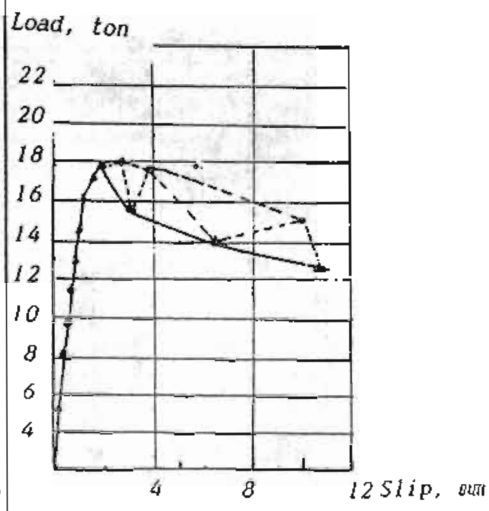


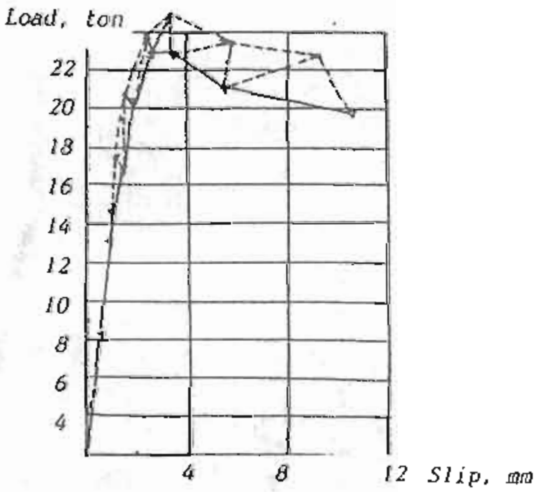
Fig.(10) : Patterns of cracks in the composite beams tested.



Case 1 : Shear Connector with slope 45°.

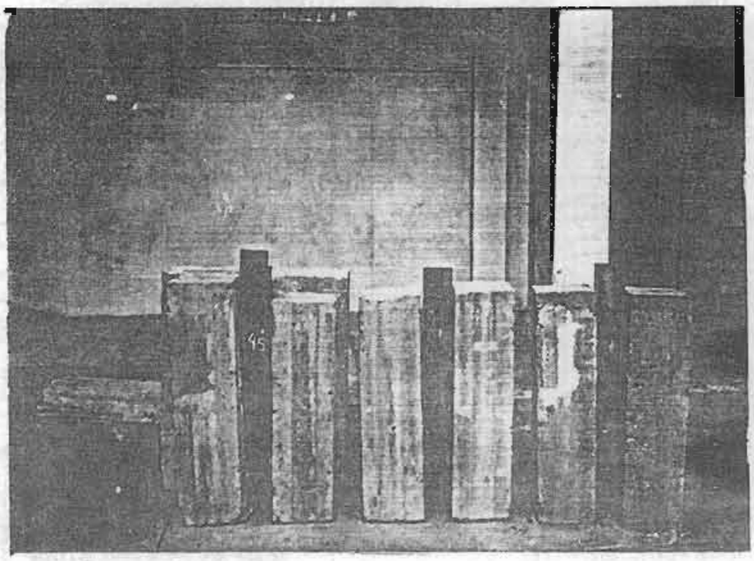


Case 2 : Shear Connector with slope 60°.

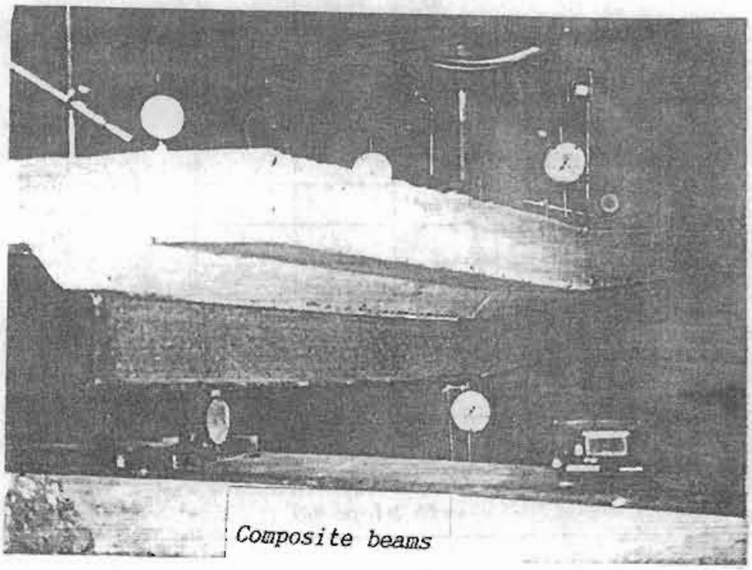


Case 3 : Shear Connector with slope 90°.

Fig.(11) : Load-slip curves for different types of shear connectors.



Push-out specimens



Composite beams

Fig.(12) : Modes of failures.