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EXPERIMENTAL INVESTIGATION OF COMPOSITE BEAMS USING SPIRALS AS SHEAR CONNECTORS (Part I)

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الفحص العملى للكمرات المركبة (القطاعات الحديد والبلاطه الخرسانية) مستخدما حلقات كرابط بينهما (جزء I)

الخلاصة : فى المنشآت الهامة مثل الكبارى والمبانى العالية والمخازن الثقيلة كثيراً مايلجأ المهندس الإنشائى إلى إستخدام هذا النوع من الكمرات. والغرض من هذا البحث هو الدراسة العملية للسلوك الإنشائى للكمرات المركبة من قطاعات الحديد والبلاط الخرسانية بإستخدام حلقات من حديد التسليح ملحومة فى الشفة العليا من الكمرات الحديدية ومدفونة فى البلاطه الخرسانية كرابط بينهما ، يوضع هذا الرابط فى أربع مجموعات متساوية على طول الكمرة بالأشكال الأتيــة ❶ كمـرة دون رابط ، ❷ كمرة بأربع وحدات كل وحدة تتكون من ثلاث حلقات، ❸ كمرة بأربع وحدات كل وحدة من اربع حلقات ، ❹ كمرة بأربع وحدات كل وحدة من خمس حلقات ، ❺ والكمرة الأخيرة بها حلقات مستمرة على طولها

والبرنامج العملى يتكون من : ❶ خمس تجارب من الكمرات المركبة ببحر ٢ متر صافى ، ❷ ثلاثة تجـارب Push out tests ، ❸ إختبارات مكملة لتحديد خواص المواد المستعملة مثل إختبارات الشد لعينات الحديد المأخوذة من الشفة والعصب للكمرة الحديد وإختبارات الضغط لمكعبات الخرسانة.

ونتائج الإختبارات أوضحت أحمال الشروخ الشعرية وأحمال الإنهيار والترخيم حتى أحمال الإنهيار للكمرات المركبة والمقارنة بينهم وأنواع الشروخ على طول الكمرة وكذلك مقاومة القص للرباط فى أشكاله الثلاثة (٣ حلقات - ٤ حلقات - ٥ حلقات) بإستخدام Push out tests.

1. ABSTRACT

The purpose of this paper is to study the experimental behaviour of composite steel-concrete beams when using welded round bar spirals as shear connectors. The spiral shear connectors are placed on four segements along the composite beam length in the following forms :1) beam free of spirals: 2) beam with 4 units of three spirals each , 3) beam with 4 units of four spirals each 4) beam with 4 units of five spirals each and, 5) beam with continuous spirals.

The cracking of concrete, the failure loads and the longitudinal shear flow in composite beams are highly affected by the arrangement of the spiral shear connectors. Moreover, there occurs an improvement in the shear resistance of the shear connectors along the interface between the steel beam and concrete slab.

The experimental program consists of 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 of the steel beam and, vi) cubic compression tests for the concrete.
The test results give the cracking loads, the failure loads, the types of crack patterns for the composite beams as well as the shear strength for

the various shear connectors. Also, the results have shown the effect of the spiral shear connectors on the previous parameters.

2. INTRODUCTION

Composite steel-concrete flooring systems are wide spread in modern building construction. The concrete provides the compressive strength, fire resistance, and floor surface, while the steel possesses high tensile strength and has the advantage of rapid erection. When acting compositely through the provision of shear connectors, the composite beam is stiffer and stronger than if the the steel and concrete acted separately in a non composite fashion [1,2,3].

The effective variables on the behavior of the spiral shear connectors in the composite beams are the welded length of the shear connector to the flange of the steel beam, the size of this weld, the diameter of the spiral bars, the pitch between spirals as well as the diameter of the spiral's circle.

Previous investigations [3,4] had been conducted to study the effect of transverse and longitudinal steel reinforcement in the concrete slab on the resistance of the shear connectors. Comparison between theoretical and experimental results on the behaviour of prestressed composite beams under the effects of creep and shrinkage of the concrete had been performed [5]. The purpose of this research is to determine ,experimentally, the cracking and failure loads, types of cracks and the deflection of composite beams shown in Fig.(1). Also, the shear resistance for using different numbers of spiral shear connectors (3 spirals, 4 spirals, 5 spirals - cases 1, 2 & 3 respectively) is investigated using Push out tests.

3. SCHEME OF THE EXPERIMENTAL PROGRAM.

The main parameter investigated in this study is the effect of increase of the number of spiral shear connectors in each unit (3 spirals, 4 spirals, 5 spirals and continuous spirals) on the behaviour of the composite beams. Moreover, the shearing resistance of the different shear connectors at the interface between the steel beam and the concrete slab is also examined.

The experimental program is divided into two main parts; the first part contains testing of five simply supported composite beams (B1,B2, B3, B4 & B5) without shear connectors or having 3 spirals, 4 spirals, 5 spirals and continuous spiral shear connectors respectively; as shown in Fig.(1). The second part includes three Push-out tests for three different lengths of spiral shear connectors (cases 2,3 &4) as shown in Fig.(2). Push out tests are used to determine the strength of the shear connectors welded to the upper flange of the steel section and imbedded in the reinforced concrete.

Each beam has a total length of 230 cm and a clear span 200cm. The steel reinforcement of the concrete slab in the longitudinal and transverse directions are the same for all beams and equals 5Φ10mm and 7Φ10mm/m respectively as shown in Fig.(1). The width of the concrete slab is taken equal to L/4 (50cm) according to Egyptian Code [6] 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 as well as in the columns of the Push-out tests 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

Volume weight of gravel = 1.65 t/m^3 ; and

(ii) the properties of the rolled steel I-section used have been determined from tensile tests of 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 simply supported at both ends and the load was applied through one concentrated load at mid-span in equal increments of (300 Kg) till failure using a Hydraulic Pump 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. Another dial gauge was placed at the bottom flange of the steel beam at mid-span. To record the settlement at the supports, two dial gauges were used on top of the concrete slab as shown in Fig.(3).

Push-out test specimens were placed on the same testing frame and were subjected to compressive load which produces direct shear till failure occurs Fig.(2b). In each test, the system was secured from all sides before starting applying the load.

5. ANALYSIS OF EXPERIMENTAL RESULTS.

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

I. DEFLECTION.

Figures (4) to (8) show the relation between the applied load and the recorded deflection till failure for all the beams. The settlement at supports has been taken into account in the calculation of the actual deflections. The maximum deflection corresponding to the failure load for beams B1,B2,B3,B4 & B5 are given in table (2).

The deflection of beam B1, Fig.(4) includes two curves, one corresponding to the deflection measured at the concrete slab surface on both sides of the jack and the other for the deflection measured at the bottom flange of the steel beam at mid-span. The maximum deflection at *failure load for beams B2 & B3 are 59% and 74% of the corresponding deflection of beam B1 respectively. For beam B4, the maximum deflection is equal to maximum deflection of beam B1 although the failure load of B4 was 2.7 times that of B1. For beam B5, the maximum deflection is greater than that of B1 by 15.5%, while the failure load of B5 is 2.85 times that of B1.*

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

II) CRACKING :

II-i) Crack Initiation.

Crack initiation is affected by the number of the spiral of the shear connector units along the beam length. The initial crack load recorded for all beams is proportional to the number of spirals distributed along the tested beam (these values are given in table (2)). For beam B2, which has 3 spiral units, the initial cracking load exceeded 5 times the value of beam B1 which has no spirals. The values of this load for beams B3 and B4 increased by 33% and 72% over the value of beam B2 respectively. Also, the cracking load for beam B5 increased 108% over that of beam B2.

II-ii) Crack Distribution.

Fig.(9) shows the types of cracks in the beams tested. It is noticed from the shapes of cracks of these beams that for beams B3 & B4 , the spread of cracks occurs in the middle fourth under the applied load. Moreover, there is a separated region between the concrete slab and the steel beam for B3 & B4 at mid-span only. For beams B2 & B5, the cracks were distributed at a constant slope of nearly 45 along the haunch of the concrete slab. For beam B1, 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 (10).

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 that noticed at other regions along the beam length.

III. FAILURE LOADS.

From the experimental results obtained, it is noticed that the failure load is affected by the spiral shear connectors and is proportional to the number of spirals. The failure loads for the beams tested are given in table (2). It can be seen that the failure loads of beams B2, B3, B4 & B5 increased by 2.44, 2.60, 2.68 and 2.84 times that of B1.

The modes of failures were wide cracks in the middle quarter 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 spiral connectors (3 spirals, 4 spirals and 5 spirals) in direct contact with the flange of the steel section and the concrete column. Fig. (2) shows a typical specimen used in Push-out test. 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 the three cases are given in table (3). The failure shear strength of connector is highly affected by the number of spirals. The strength of cases 2 & 3 increased by 44% and 84.2% over that of case 1 respectively.

7. CONCLUSIONS.

From the experimental test results of the composite concrete steel beams carried out in this research with spiral shear connectors having 3 spirals, 4 spirals and 5 spirals, the following conclusions are drawn :

1- The cracking and failure loads are highly affected by the arrrangement of spiral shear connectors.
2- The failure and cracking loads increase with the increase of the number of spirals in the shear connector.
3- Failure loads of the composite beams with spiral shear connectors increased from 2.4 to 2.8 times those of beams free of shear connectors.
4- The failure strength of shear connectors increases with the increase of the number of spirals.
5- Due to the increase of the spiral connectors from 3 spirals to 4 spirals and from 4 spirals to 5 spirals, the shear strength of connectors has increased by 44% and 28% respectively.
6- The modes of failure of the composite beams tested were cracks in the concrete slab and yielding of the steel beam.

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Table (1) : Properties of the steel I-Section used in the tests.

Specmein, No.	Dimensions, cm a	b	L_o	Area cm2	Py Kg	σy t/cm2	Aver. σy	P_{ult} Kg	σ_{ult} Kg/cm2	Aver. σ_{ult}
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 spiral shear connectors.

Beam No.	Case of Spirals Group	Initial P ton Cracking	$P_{Failure}$, ton	Maximum Deflection recorded concrete slab, mm	steel beam, mm
B1	Free	1.46	7.86	15.80	15.20
B2	3-spirals	7.55	19.18	9.34	9.26
B3	4-spirals	10.06	20.44	11.65	11.40
B4	5-spirals	13.00	21.07	15.60	15.30
B5	continuous	15.72	22.33	18.25	17.80

Table (3) : Connector's shear strength.

Type of connector	Failure shear strength	Mode of Failure
3 spirals	26.41 ton	Failure of welded connection
4 spirals	38.05 ton	Failure of welded connection
5 spirals	48.74 ton	Yielding of steel beam

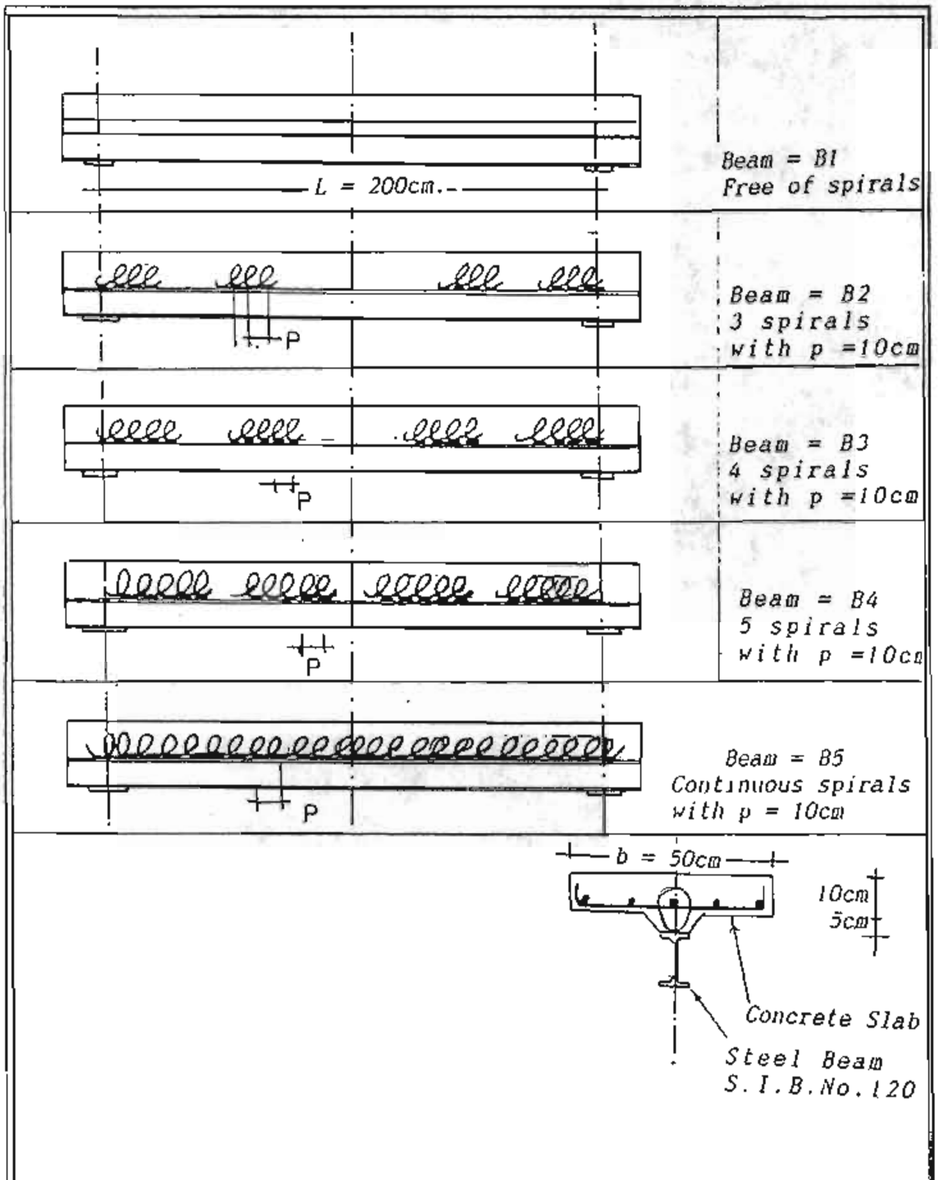
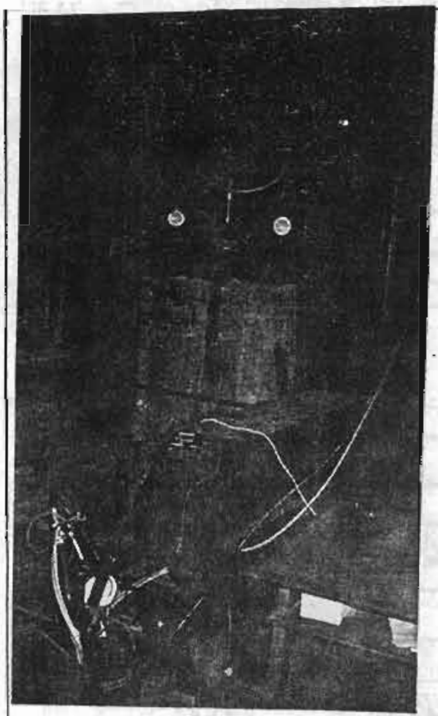
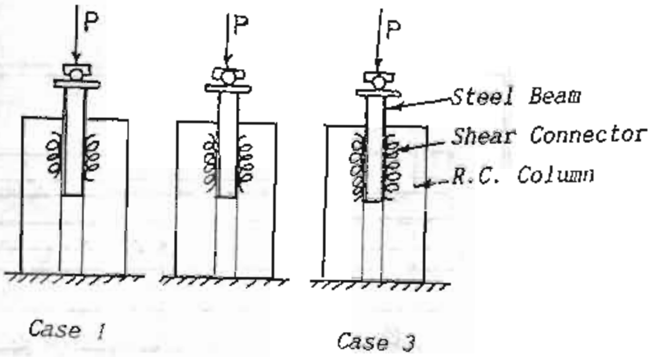


Fig.(1) : Types of the composite beams used in the experiments.





(a) Push-out test specimens

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

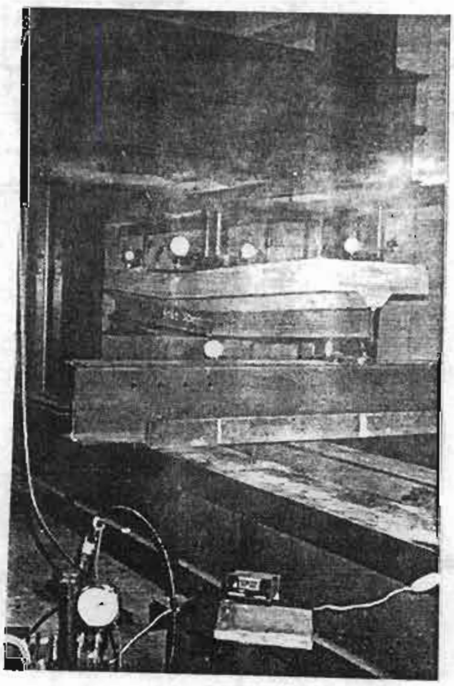


Fig.(3) : Typical arrangement for loading test.

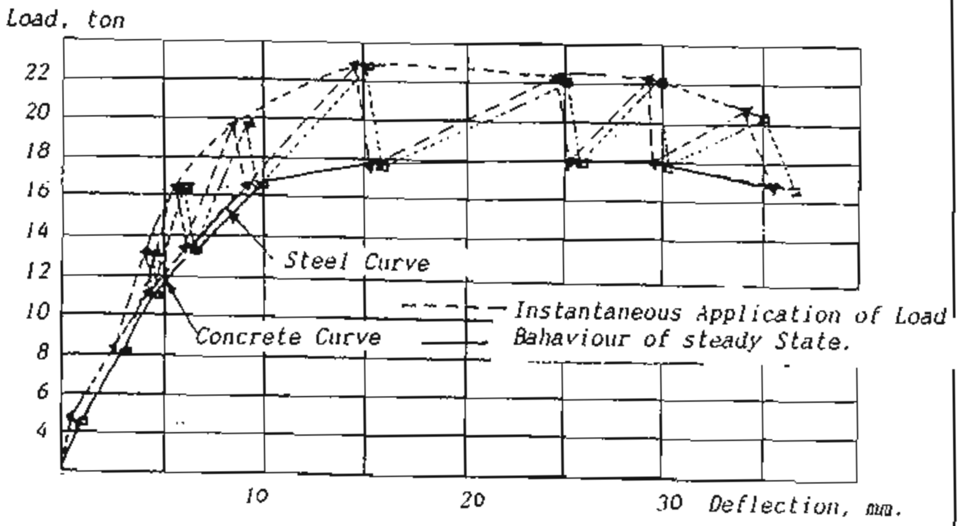


Fig.(4) : Load deflection curve of composite beam free of connectors.

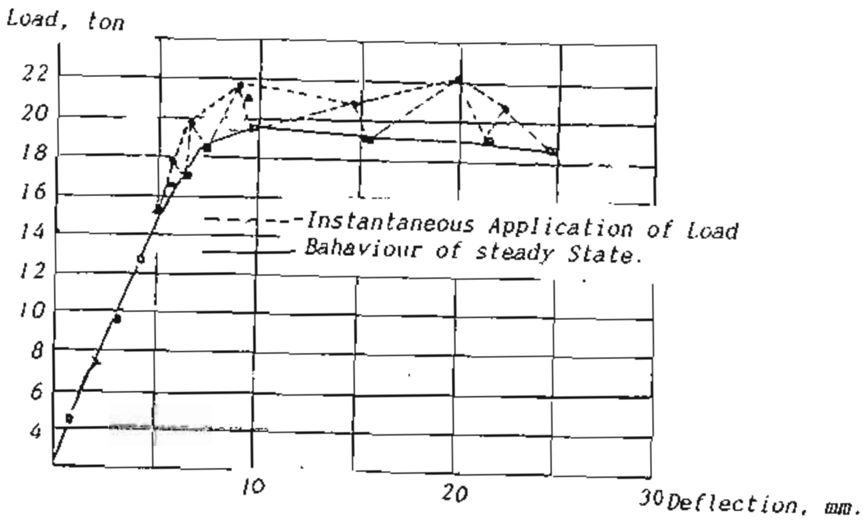


Fig.(5) : Load deflection curve of composite beam with 3 spiral shear connector units.

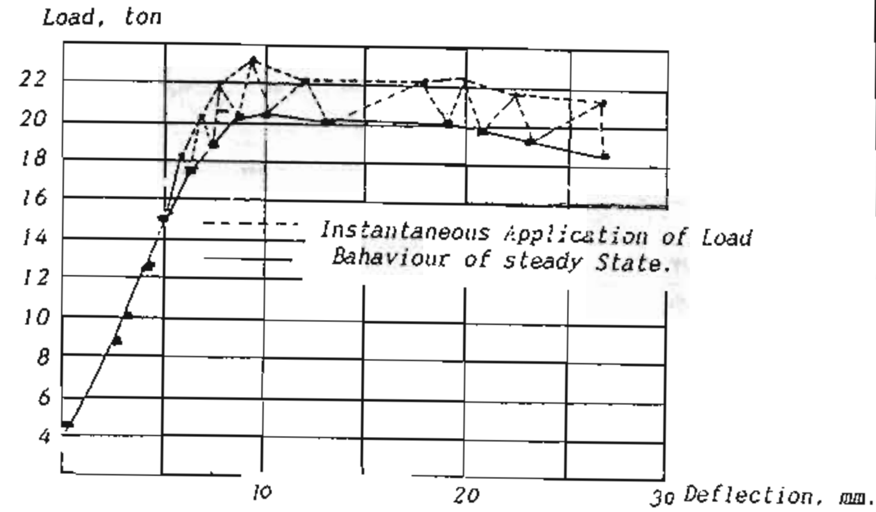


Fig.(6) : Load deflection curve of composite beam with 4 spiral shear connector units.

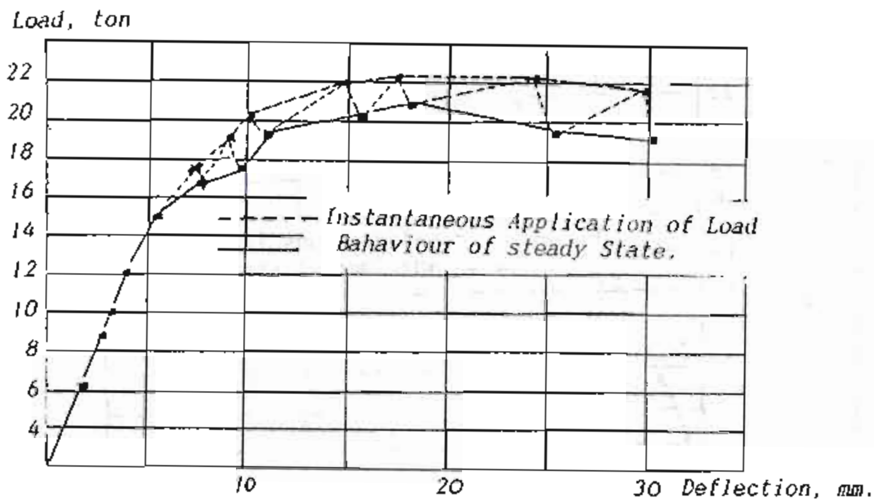


Fig.(7) : Load deflection curve of composite beam with 5 spiral shear connector units.

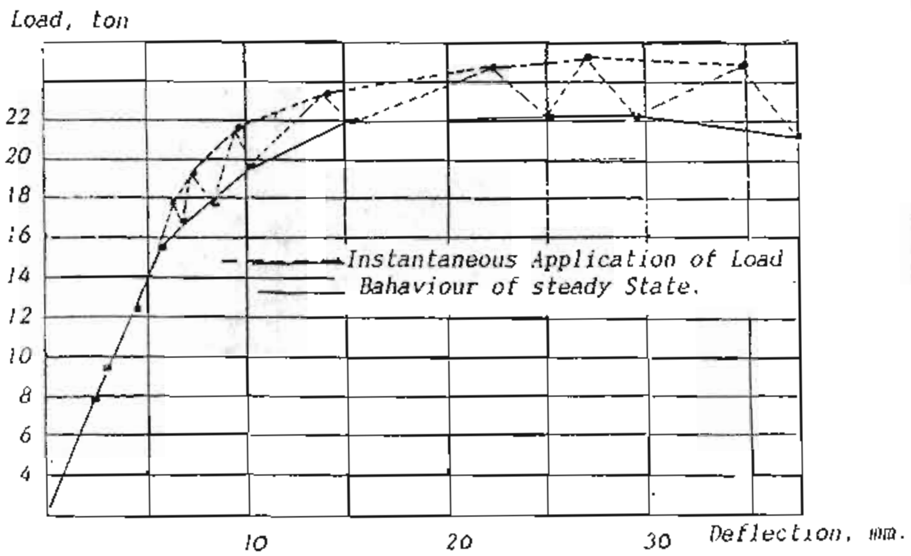


Fig.(8) : Load deflection curve of composite beam with continuous spiral connectors.

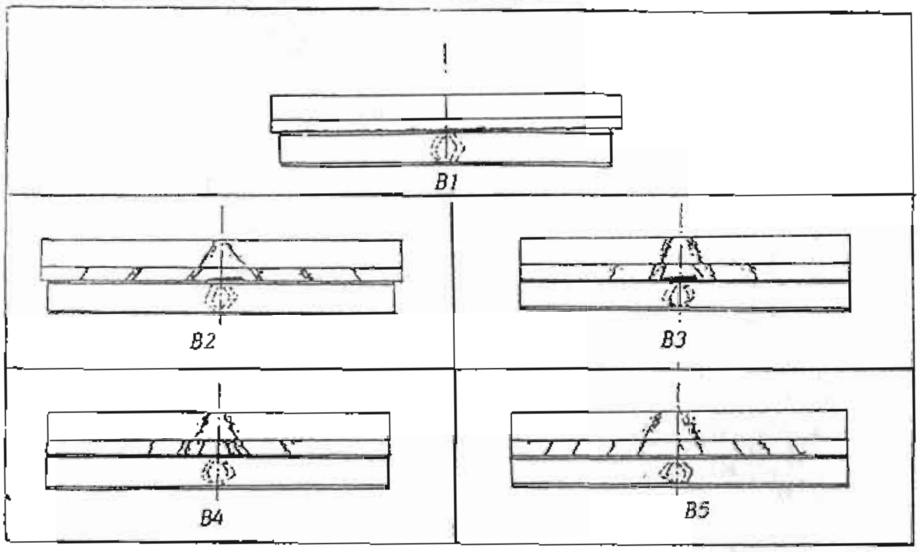
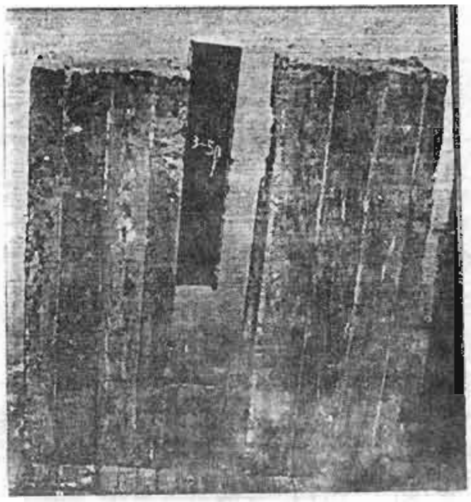
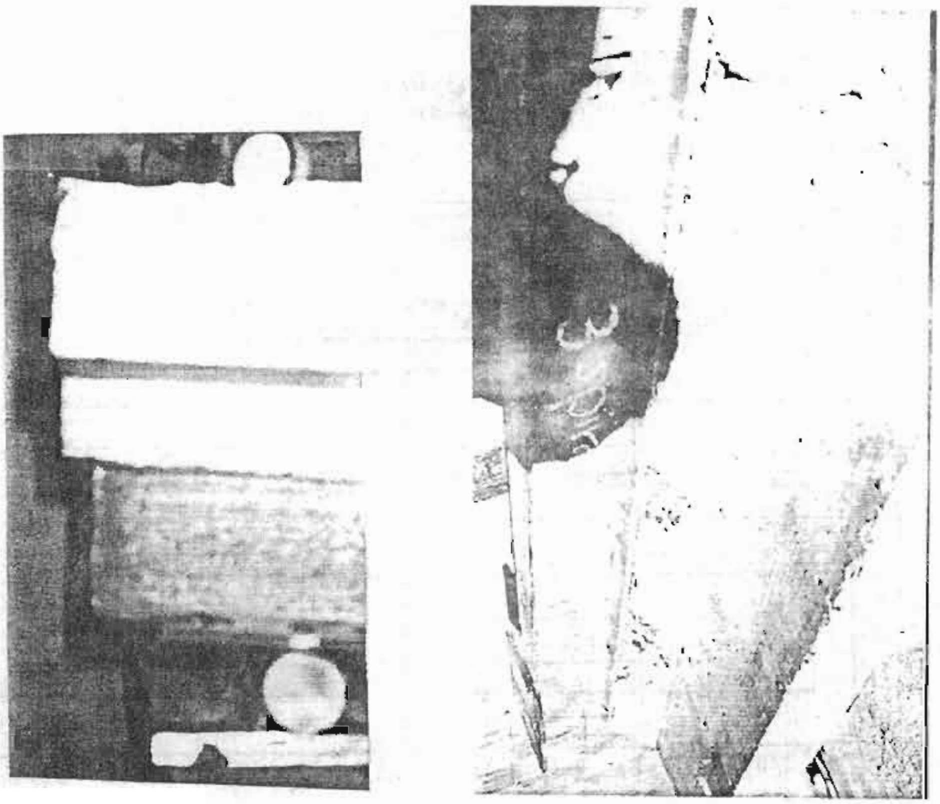


Fig.(9) : Crack patterns in the composite beams tested.

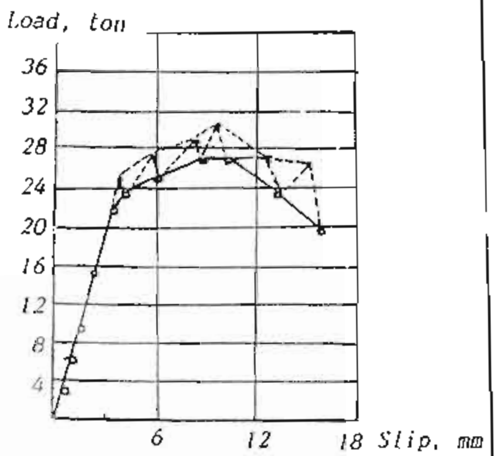


Push-out specimens

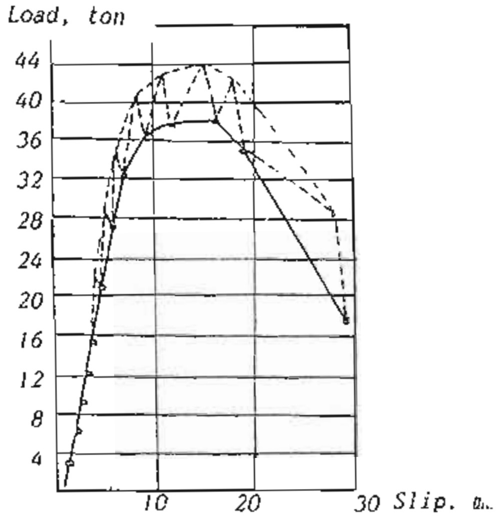


Composite beams

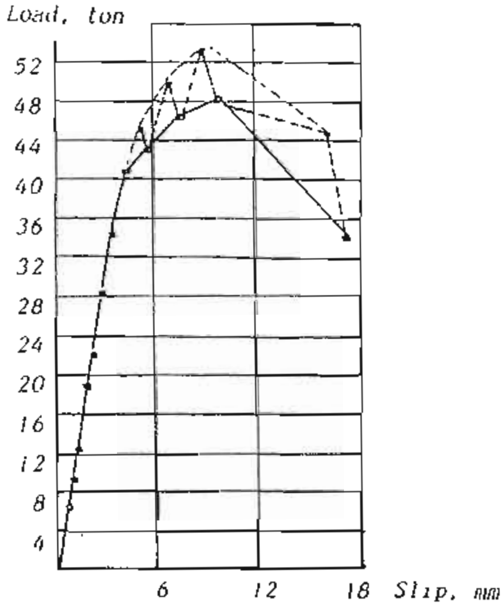
Fig.(11) : Modes of failures.



Case 1 : 3 spirals.



Case 2 : 4 spirals



Case 3 : 5 spiral:

Fig.(12) : Load-slip curves for different types of spiral shear connectors.