Development of high Performance Concrete Beam Using Carbon Fiber Mat

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ABSTRACT

Lower tensile and high compressive strength are the basic qualities of Concrete. Even though the elasticity of concrete is relatively constant at low stress levels, at higher stress levels, following crack development, lower elasticity will be observed. Various methods have been reported in literature for strengthening concrete beams to overcome lower tensile strength and crack development. In this research work, Strengthening is carried out through external bonding of carbon fiber mat at the bottom of the concrete beam in U shaped manner till the neutral axis. Epoxy resin and hardener are used as a matrix for holding the fibers in place. Three rectangular concrete beams samples of dimension 100x225x1700mm are cast and experiments have been conducted to analyze, the effect of strengthening on, ultimate load, deflection, moment, curvature, stress and strain. Results of the investigations with single layer and double layer external wrapping of carbon fiber are reported. For this study M20 grade concrete is used as base for implementing strengthening. From the results of the experimental studies it has been concluded that the strength of the reinforced concrete beam can be increased by wrapping it up with single or double layer carbon fiber mat.

Key words: Carbon fiber Mat, strengthening, Stiffness, Epoxy resin, neutral axis, Deterioration

INTRODUCTION

Aims of repairing and strengthening processes are improving the performance of the concrete members, restoring and increasing the strength and stiffness of the concrete, improving the appearance of the concrete surface, increasing water tightness, preventing access of corrosive materials to the reinforcing and improving the overall durability of the concrete members.

Pioneering research carried out at the Swiss Federal Laboratories for Materials Testing and Research or EMPA (Meier, 1987 [1]) resulted in the application of fiber-reinforced polymer (FRP) composites for the rehabilitation of beams and slabs . Using FRP composites, as external tensile reinforcement, in the repair of beams and slabs, resulted in increase in the strength (ultimate limit state) and the stiffness (serviceability limit state) of the structure. Requirements for earthquake strengthening, higher service loads, smaller deflections, or simply to substitute for deteriorated steel reinforcement encouraged application of FRP Composites.

Increase in strength and stiffness is often accompanied by loss in ductility or in its capacity to deflect in elastically. Frequent brittle failures are normally due to de bonding or anchorage failure (Bonacci, 1996 [2]).

A satisfactory level of strengthened or damaged structures performance can be achieved by different methods. Commonly used method of repairing or strengthening is by applying additional layers on the tension face of the beam (Vide - using steel plates [3], reinforced concrete layer [4,5], Ferro cement layer [6,7], steel plates and FRP wrap laminates [8-11]) . Even though use of beneath layer results in increase of the load capacity of concrete beam, an increase in stiffness and strength is also obtained depending on the type of wrap layer used.

In this research work detailed experimental studies have been carried out on two samples of rectangular beams to analyze the effect of strengthening with carbon fiber mat on ultimate load, deflection, moment, curvature, stress and strain.

The issues addressed in this paper are:

1. Is there any flexural strength enhancement provided by Carbon Fiber mat externally bonded while using epoxy resin and hardener as matrix for holding the fibers in place?

2. What is the effect of strengthening on ductility?

3. Is there enhancement of anchorage by wrapping and curing?

4. Is there any inter-layer delamination occurring after reinforcement?

5. What is the effect of number of layers of wrapping on the performance of the strengthened beam?

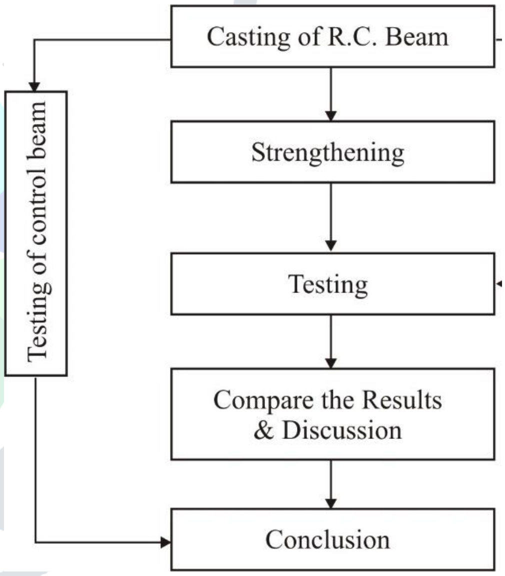
DETAILS OF SPECIMENS

Rectangular beam

Three beams of dimension 1700x 225x 100 mm are cast for testing purpose (Vide Fig. 1 for details). Control specimen cast are cubes of size 150 mm

Fig. 1: Dimensional detail of rectangular Beam

METHODOLOGY



PROCEDURE TO BOND CARBON FIBER MAT

Chipping and air blasting

The surface of the beam, where the mat has to be attached, is first chipped manually and then subjected to air blasting to remove the entire macro dust particles from the reinforced concrete beam (Vide Fig.2). In order to remove laitance, grease and loosely adhering particles a near rough surface on the tension face and two sides of the beam is created . It has been ensured that the smooth surface is kept contaminant free, with no air entrapment and unevenness areas.

Fig 2: Chipping

Wrapping and Curing

Concrete surfaces are prepared ensuring a thorough mixing of individual contents of R 3 E. A thorough mixing of Part B (Hardener) and Part A (Epoxy Resin) for at least three minutes, using a heavy duty slow speed drill with a spiral peddle, is carried out in the Epoxy Resin container. Activation of any residue is ensured by reintroducing some of the mixed components into the hardener container (Vide Fig 3.).

Fig 3: Application of epoxy resin and hardener

After pouring the activated residue into the larger mixing vessel, re-mixing takes place for 30 seconds. (Part-A and Part-B mixed at a proportion 2:1) Adhesive is applied on cleaned and prepared surface so that the carbon mat is bonded to the tension face (bottom) and two sides of the concrete beam. Excess epoxy on the sides of the sheets is pressed out by applying required pressure. Attaching the CF sheets is carried out starting at one end In order to ensure full curing of the epoxy adhesive the prepared specimens are tested after a minimum of 3 days after bonding (Vide Figs. 4 and 5).

Fig 4: Wrapping Of Single Layer Of Carbon Fiber MAT

For the beams FB-1L and FB-2L carbon fiber (CF) laminates are attached at the tension (i.e. bottom) face.

Fig 5: Wrapping Of Double Layer Of Carbon Fiber Mat

TEST PROGRAM

To evaluate the effect of externally bonded CF mat with different strengthening scheme for the entire beam length, all sample beams are tested. Sample reinforced concrete beams have been fabricated with different CF configurations in the laboratory for strengthening purposes[12]. First beam (designated as CB) has not been bonded with CF laminates. Other two beams (CF-1L and CF-2L) have been bonded with different layers of CF laminates (1 and 2–layers respectively)

Test scheme Specimen size and steel reinforcement details

All the beam specimens are 100 × 225 mm in cross section and 1700 mm in span length on a simply supported span. All beams have been reinforced with two T12 (12 mm in diameter) bars as tensile reinforcement at an effective depth of 194 mm and two T8 (8mm in diameter) bars as compressive reinforcement at 23 mm from the top surface. R6 stirrups are placed at a constant spacing of 30mm throughout the entire length of the beams[12]. The stirrups are designed to ensure that none of the beams would fail in shear. The longitudinal reinforcement ratio is about 0.62% of the beam cross section.

INSTRUMENTATION AND TEST PROCEDURE

The test procedure is to monotonically load the beams until the failure of the beams[14]. The specimens are tested in four-point static and dynamic loading over a 1700 mm simply supported span to investigate the strengthening performance at different level of CF laminates strengthening scheme (Vide Fig. 6. For experimental set up).

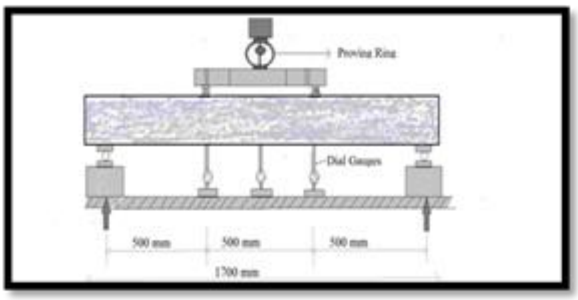


Fig. 6: Schematic representation of experimental test setup

The two point loads have been positioned using I-steel sections at one-third span length and loading has been under displacement control. The static loads are applied at a regular interval by loading frame until failure occurred on the beams. Deflections of all beams have been measured at mid-span and at the location of the applied loads using Dial gauges. The split levels are used to check the symmetrical nature of the loaded beams[15]. Load at first crack instance is recorded. Further, subsequent crack patterns are marked on the beam surface as and when they develop during the application of load from first crack appearance to the failure of the beam.

EXPERIMENTAL TEST AND RESULTS

A total of three reinforced concrete beams having different CF configurations have been fabricated in the laboratory for testing purposes. First beam (CB) has not been wrapped with CF mat. Two beams (CF-1L and CF-2L) have been wrapped with different layers of CF mat (1 and 2–layers respectively).

A beam of size 1700 mm x 225mm x 100mm, reinforced with 2 bars of 12mm diameter rod, cast with M20 grade concrete is taken as control beam. First 10 kN load is applied and the deflection and deformation are noted. Load is then increased gradually in steps of 10 kN till the ultimate load.

The control beam of size 1700mm x225mm x100mm is wrapped with single layer carbon fiber mat in the tension zone of the beam. It is subjected to the 2 point loading condition as that of the control beam. First 10 kN load is applied and the deflection and deformation are noted. Load is then increased gradually in steps of 10 kN till the ultimate load.

The control beam of above size is wrapped with double layer carbon fiber mat in the tension zone of the beam. It is subjected to the 2 point loading condition as that of the control beam. First 10 kN load is applied and the deflection and deformation are noted. Load is then increased gradually in steps of 10 kN till the ultimate load.

The control beam is cured for 28 days and tested under two point load using loading frame. The initial crack occurred at 30 kN. The failure is shear failure. The ultimate load recorded is 70 kN (Vide Fig. 10).

Fig 10 Crack pattern on control beam

The single layered Carbon fiber mat of the beam is cured for 28 days and tested under two point load using loading frame. The initial crack occurred at 90 kN. The ultimate load is 120 kN. The crack is compression crack due to flexure (Vide Fig. 11)

The double layered Carbon fiber mat of the beam is cured for 28 days and tested under two point load using loading frame. The initial crack occurred at 80 kN. The ultimate load is 90 kN. The crack is compression crack due to flexure.(Vide Fig.12)

Fig 11 crack pattern on CF-1L Beam

Fig 12 crack pattern on CF-2L Beam

Load-Deformation Response

The strength and deformation capacity of the tested specimens varied significantly depending on the number of carbon fibre layers wrapped around the beam till the neutral axis. Specimens strengthened with different number of layers are tested and the response measured.

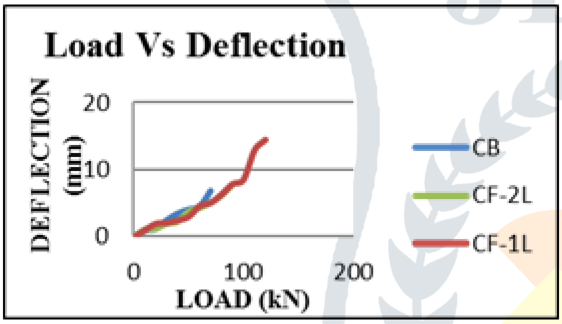


Fig 7: Load Vs Deflection

Although most of the strengthened beams failed at loads that exceeded the capacity of control beam, all the strengthened specimens failed at considerably less displacement levels as compared to the deflections of the control beams (Vide Fig.7 for Load vs Deflections graph).

Moment-Curvature Characteristics

Rectangular stress distribution for concrete is the base with which the moment-curvature curve has to be calculated. An accurate method to determine the behavior of a concrete section under load-deformation is Moment curvature analysis. Nonlinear material stress-strain relationships are used in this method. For a given load, an equilibrium stage of nonlinear stress distribution with the applied load occurs for a section curvature at an extreme compressor fiber strain. A unique bending moment is calculated at this section curvature from the stress distribution. A range of moment-curvature values are obtained for a set of section curvature and extreme concrete compression (Vide Fig. 8 for Moment vs Curvature variation graph).

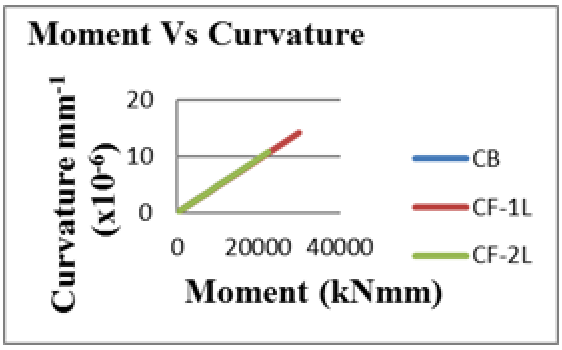


Fig 8: Moment Vs Curvature

At initial load as the moment increases, curvature also increases. When load is gradually increased moment and curvature of the beam are also increased.

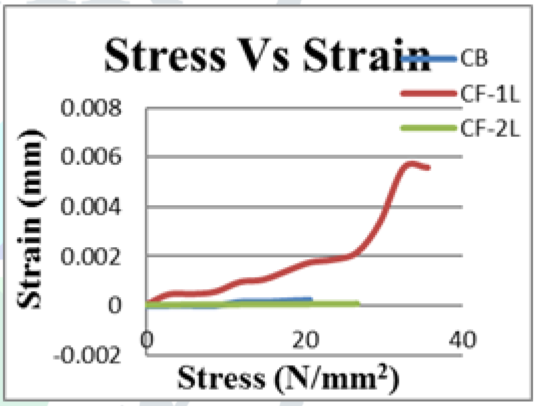


Fig 9 Stress Vs Strain

The moment has been increased up to 120 kN in beam which is externally bonded with carbon fiber mat till the neutral axis, and correspondingly curvature is also increased. (vide Fig 9 for Stress vs Strain graph.)

Shear failure

Shear failure of reinforced concrete, more properly called diagonal tension failure. Shear failure is difficult to predict accurately. In spite of many decades of experimental research and the use of highly sophisticated analytical tools, it is not yet fully understood. Furthermore, if a beam without properly designed shear reinforcement is overloaded to failure, shear collapse is likely to occur suddenly, with no advance warning of distress. This is in strong contrast with the nature of flexural failure. Typically, for under reinforced beams, flexural failure is initiated by gradual yielding of tension steel, accompanied by obvious cracking of concrete and large deflections, giving ample warning and providing the opportunity to take corrective measures. Because of these differences in behavior, reinforced concrete beams are generally provided with special shear reinforcement to ensure that flexure would occur before shear failure if the member should be severely overloaded.

Failure Mechanism Observed

Three different failure modes are observed in the tests.

Mode 1 : The ultimate load is reached at 70 kN. (Vide Table 2). This beam failed by yielding of internal tensile steel reinforcement followed by concrete crushing near the support section.

Mode 2 : Beam CF1 exhibited tensile rupture of mat at edge region. Rupture of CF sheets is sudden and accompanied by a noise indicating a rapid release of energy and total loss of load capacity. It has been observed that for CF mat one layer and two layer beams maximum loads that could be attained are 120 kN and 90 kN (vide Tables 2 and 3) respectively for CF mat.

Mode 3 : This type of failure occurs in between the load points at compression zone of beams CF2. It is sudden, explosion, accompanied with a loud noise and resulted in immediate premature beam failure.

Mode 4 : Shear and diagonal tension failure occurs in both beams such as CF1 and CF2, it is observed that the member failed immediately upon the formation of critical crack in the high shear region near the supports.

Opportunities and Challenges

CFRP has proven to be an effective material for strengthening reinforced concrete structural elements. A large number of researchers around the world are actively pursuing new potential applications and developing procedures for the analysis and design of various strengthening systems. Carbon fibers have high elastic modulus and fatigue strength than those of glass fibers. carbon fiber reinforced polymers have more potential than aramid and glass fibers. They possess high chemical resistance and high temperature tolerance with low thermal expansion and corrosion resistance.

CONCLUSIONS

Based on the experimental test results, following conclusion have been drawn:

1. Reinforced concrete beams can be effectively Strengthened by wrapping them externally with carbon fiber mat. All the strengthened beams didn't show any inter-layer de-lamination in any case.

2. The initial crack of the reinforced concrete rectangular beam wrapped with single layer carbon fiber mat has occurred at 90 kN (Vide Table 3.) which is nearly three times that of the control beam (30 kN).

3. Ultimate load of reinforced concrete rectangular beam wrapped with single layer carbon fiber mat is 120 kN which is nearly two times that of the control beam 70 kN (Vide Table 3).

4. The initial crack of the reinforced concrete rectangular beam wrapped with double layer carbon fiber mat has occurred at 80 kN (Vide Table 4) which is nearly three times that of control beam (30 kN).

5. Ultimate load of reinforced concrete rectangular beam wrapped with double layer carbon fiber mat is 90 kN (Vide Table 4) which is higher than that of the control beam 70 kN. (nearly 1.3 times)

Thus, it is concluded that the strength of the reinforced concrete beam can be increased by wrapping it with single or double layer carbon fiber mat.

REFERENCES

1. **Meier, U. (I 987),** "Bridge Repair with High Performance Composite Matcrials", Material and Technik , Vol. 15, pp. 125- 128.

2. **Bonacci, J.F. (l996),** "Strength, 1;ailure Mode and Deformability of' Concrete Bcains Strcngthcned Externally with Advanced Composites, " Proceedings of the Second International Symposium On " Advanced Composite Materials in Bridges and structures" Montral, Canada, pp. 419-426.

3. **Hussain M, Sharif A, Basunbul IA, Baluch MH, and Al-Sulaimani GJ,** "Flexural Behavior of Pre-cracked Concrete Beams Strengthened Externally by Steel Plates," ACI Structural Journal, Vol. 92, No. 1, 1995, pp. 14-22.

4. **Hamoud A, Islem A, Maslehuddin M, Jamil Ghazi, and Baluch M,** "Durability Performance of Repaired Concrete Beams," ACI Materials Journal, Vol. 91, No.2, 1994.

5. **Basunbul AA, Gubati GJ, Al-Sulaimani and Baluch MH,** "Repaired Reinforced Concrete Beams," ACI Materials Journal, Title No. 87-M37, 1990, pp. 348-354.

6. **Fahmy EH, Shaheen YBI, and Korany YS,** "Repairing Reinforced Concrete Beams by Ferrocement," Journal of Ferrocement, Vol.27, No.1, Jan. 1997, pp. 19-32.

7. **Fahmy EH, Shaheen YBI, and Korany YS,** "Use of Ferrocement Laminates for Repairing Reinforced Concrete Slabs," Journal of Ferrocement, Vol.27, No.3, July 1997, pp. 219-232.

8. **Bonacci JF, and Maalej M,** "Behavioral Trends of RC Beams Strengthened with Externally Bonded FRP," Journal of Composites for Construction, Vol.5, No.2, 2001, pp.102-113.

9. **Al-Amery R, and El-Mahaidi R,** "Coupled Flexural-Shear Retrofitting of RC Beams Using CFRP Straps," Composite Structures, Vol.74, 2006, pp.457-464.

10. **Esfahani MR, Kianoush MR, and Tajari AR,** "Flexural Behavior of Reinforced Concrete Beams Strengthened by CFRP Sheets," Engineering Structures, Vol.29, 2007, pp.2428-2444.

11. **Anil O,** "Strengthening of RC T-section Beams with Low Strength Concrete Using CFRP Composites Subjected to Cycle Load," Constr. and Building Mat., Vol. 22, 2008, pp.2355-2368.

12. **HabiburRahmanSobuz, Ehsan Ahmed, Noor Md. SadiqulHasan, Md. AlhazUddin** "Use of carbon fiber laminates for strengthening reinforced concrete beams in bending" International journal of civil and structural engineering volume 2, no 1, 2011.

13. **Mykolas Daugevičius, Juozas Valivonis, Gediminas Marčiukaitis** "Deflection analysis of reinforced concrete beams strengthened with carbon fibre reinforced polymer under long-term load action" Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering) ISSN.

14. **Giovanni Martinola , Alberto Meda , Giovanni A. Plizzari , ZilaRinaldi** "Strengthening and repair of RC beams with fiber reinforced concrete"

15. **M.B.S Alferjani, A.A. Abdul Samad ,Blkasem. S Elrawaff ,N. Mohamad, M.Hilton and AbdallaAbSinusiSaiah** "Use of Carbon Fiber Reinforced Polymer Laminate for strengthening reinforced concrete beams in shear"International Refereed Journal of Engineering

and Science (IRJES) Volume 2, Issue 2(February 2013), PP.45-53.

16. **Tom Norrise, Hamid Suadatmanesh, member, ASCE, and Mohammad R. Ehsani, member ASCE** "shear and flexural strengthening of RC beam with carbon fibre sheet"

Table 1 : Test Scheme

	Strengthening scheme		
	Control beam (not bonded)	1-layer bonded	2-layer bonded
Beam designation	CB	CF-1L	CF-2L

Table 2 : Control Beam Readings

S. No	Load in kN	Deflection in mm			Strain		Moment in kNmm	Curvature in mm^{-1}	Bending Stress in N/mm^2
		D1	D2	D3	Compression	Tension			
1	0	0	0	0	0	0.00001	0	0	0
2	10	0	0.97	0.8	0	0.00001	2500	1.19	2.96
3	20	1.82	1.22	1.9	0	0. 00001	5000	2.4	5.92
4	30	2.55	2.49	2.6	0.00001	0.00001	7500	3.5	8.89
5	40	2.89	2.5	2.9	0.00001	0.00002	10000	4.8	11.85
6	50	4.28	4.08	3.5	0.00001	0.00002	12500	5.95	14.81
7	60	4.59	4.56	4.6	0.00001	0.00002	15000	7.1	17.78
8	70	6.32	6.86	7.2	0.000005	0.000025	17500	8.3	20.73
Initial Crack = 30 kN							Ultimate load = 70 kN		

Table 3: Carbon fiber single layer wrapped beam readings (CF-1L)

S. No	Load in kN	Deflection in mm			Strain		Moment in kNmm	Curvature in mm^{-1}	Bending Stress in N/mm^2
		D1	D2	D3	Compression	Tension			
1	0	0	0	0	0	0	0	0	0
2	10	0.63	0.99	0.98	0.001575	0.00044	2500	1.19	2.96
3	20	1.31	1.94	1.89	0.00082	0.00045	5000	2.4	5.93
4	30	1.78	2.07	1.90	0.00080	0.00054	7500	3.5	8.9
5	40	1.9	2.46	2.1	0.000675	0.00094	10000	4.8	11.9
6	50	3.17	3	3.48	0.000587	0.00103	12500	5.95	14.8
7	60	3.58	4.58	3.87	0.000586	0.00139	15000	7.1	17.8
8	70	4.6	5.05	4.9	0.000562	0.00173	17500	8.3	20.7
9	80	5.3	6.31	5.2	0.00049	0.00185	20000	9.5	23.7
10	90	6.70	7.83	6.67	0.00047	0.00215	22500	0.1071	26.7
11	100	7.7	8.49	8.52	0.000305	0.00338	25000	0.119	29.6
12	110	11.5	12.8	11.8	0.00003	0.00557	27500	0.131	32.6
13	120	14.7	14.3	13.2	0.000005	0.00558	30000	0.1429	35.6
Initial Crack = 90kN							Ulimate Load =120kN		

Table 4: Carbon fiber double layer wrapped beam readings (CF-2L)

S. No	Load in kN	Deflection in mm			Strain		Moment in kNmm	Curvature in mm^{-1} $x10^{-6}$	Bending Stress in N/mm^2
		D1	D2	D3	Compression	Tension			
1	0	0	0	0	0	0	0	0	0
2	10	0.87	1.1	0.6	0	0.00002	2500	1.19	2.96
3	20	1.6	1.25	0.82	0	0.00003	5000	2.4	5.93
4	30	2.48	1.98	1.29	0.000006	0.00004	7500	3.5	8.9
5	40	2.65	2.29	1.8	0.000006	0.00005	10000	4.8	11.9
6	50	3.18	3.8	3.31	0.000005	0.00006	12500	5.95	14.8
7	60	4.38	4.34	3.42	0.000005	0.00006	15000	7.1	17.8
8	70	5.15	5.12	3.76	0.000005	0.00007	17500	8.3	20.7
9	80	6.39	6.17	5.50	0.000002	0.00008	20000	9.5	23.7
10	90	8.35	7.84	6.35	0.000001	0.00009	22500	0.1071	26.7
Initial Crack = 80 kN								Ultimate load = 90 kN	

Table 5: At initial crack of control beam (30 kN)

Beam designation	Load (30 kN)		
CB	2.55	2.49	2.6
CF 1L	1.78	2.07	1.9
CF 2L	2.48	1.98	1.29

Table 6: Ultimate of control beam (70 kN)

Beam designation	Load (30 kN)		
CB	2.55	2.49	2.6
CF 1L	1.78	2.07	1.9
CF 2L	2.48	1.98	1.29