Design of Reinforced Concrete Beams Using Two Different Specification

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ABSTRACT

Nowadays, reinforced concrete beams are designed using traditional specification, such as BS8110 and Eurocode2 based on truss action. In this research BS8110 and Eurocode2 specification of designing a beam for flexure and shear are studied and compared with each other, to provide an in depth understanding of the two approaches. Two beams are designed, the first beam using BS8110 and the second beam using Eurocode2. The designs based on BS8110 and Eurocode 2 at the ultimate and serviceability limit states are discussed and the approach used to predict deflections is described and checked using standard relationship based on statics. Secondly the BS8110 and Eurocode2 approaches to designing a beam for shear and deflection are compared with each other. the two test beams are tested and the test results are compared with predicted results. The results from the laboratory tests have shown that the Eurocode2 beam carried a higher load and gave a higher central deflection compared to BS8110.

Keywords: Reinforced Concrete, Beam analysis, shear and deflection.

1 Introduction

Concrete is the most important construction material in the construction industry [1, 2]. There are approximately 2,000,000 billion tonnes of concrete being produced yearly [2]. Although concrete is good in compression and a durable material, it is weak in tension, where its tensile strength is approximately 10% of its compressive strength [3]. Concrete fails in tension when it is exposed to tensile stresses that are greater than its tensile strength capacity. So concrete on its own cannot resist these tensile stresses and it needs to be reinforced with another material that is good in tension, such as steel bars, to prevent failure of concrete in tensile region. Current design approaches for structural concrete beams are based on truss action [4]. In these design approaches the beam is designed firstly for flexure and then forshear independently of each other.

2 Comparison Between Provisions for Shear in BS8110 And Eurocode2

2.1 Shear

In the design for shear the basic principles behind the approaches in BS8110 and Eurocode2 are the same [5], and they are as follows

If the applied shear is less than the shear resistance of the concrete, minimum shear reinforcement should be provided, If the applied shear is higher than the concrete shear strength and less than the maximum design shear, designed shear reinforcement should be provided and if the applied shear is higher than the maximum design shear then a larger section must be chosen.

2.1.1 Shear Strength of Concrete

vc in BS8110 is equivalent to $\frac{VRd}{bd}$ in Eurocode2, where vc is design shear stress for concrete, VRd is the shear stress in concrete, b is the width of the section, and d is the effective depth of tension reinforcement

In BS8110 and Eurocode2 the strength of the concrete without shear links is dependent on the percentage of tensile reinforcement steel, the concrete grade and the effective depth of section and any axial forces are ignored [5, 6, 7].

Expression In BS8110

$$\mathrm{vc} = \frac{0.79[\left(100\frac{\mathrm{As}}{\mathrm{b.d}}\right)^{\frac{1}{3}}\times\left(\frac{400}{\mathrm{d}}\right)^{\frac{1}{4}}\times\left(\frac{\mathrm{fcu}}{25}\right)^{\frac{1}{3}}]}{\gamma_{\mathrm{m}}} \quad (1)$$

where vc is Shear stress in concrete, As is Area of tensile reinforcement, fcu is Characteristic strength of concrete, and γ_m is Factor of safety

Expression In Eurocode2

$$v_{Rd,c} = 0.18 \times \left(1+\sqrt{200/d}\right) \times (100\rho_1 \times fck)^{1/3}/\gamma_m \quad (2)$$

where ρ_1 is Longitudinal reinforcement ratio, and fck is Characteristic of concrete

The limitations associated with each of these equations are as follows:

Expression In BS8110:

The percentage of tensile reinforcement should not be greater than 3% [BS8110]

The effective depth d should not be greater than 400 mm [8]. According to BS8110 the concrete shear capacity increase with depth less than 400 mm.

The ultimate concrete strength f_{cu}should not be greater than $40N/mm^2$[BS8110, 8]

The factor of safety is 1.25 [BS8110, 8]

Expression In Eurocode2:

The percentage of tensile reinforcement should not be greater than 2% [7, 8]

The effective depth d should not be greater than 600 mm

There is no limit placed on the concrete strength (f_{ck}) [8]

The factor of safety is 1.5 [7, 8]

Tables 1 and 2 show the shear stresses for a concrete with a cube strength of $30\ N/mm^2$using BS8110 and Eurocode2

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Table 1: *Shear Strength of Concrete BS8110 [8]*

	d (mm)				
100As/bd	150	250	300	400	600
0.15%	0.46	0.4	0.38	0.36	0.36
0.3%	0.57	0.51	0.48	0.45	0.45
1%	0.86	0.76	0.72	0.67	0.67
3%	1.24	1.09	1.04	0.97	0.97

Table 2:*Shear Strength of Concrete Eurocode2 [8]*

	d (mm)				
100As/bd	150	250	300	400	600
0.15%	0.40	0.35	0.34	0.32	0.29
0.3%	0.51	0.44	0.43	0.40	0.37
1%	0.75	0.66	0.63	0.60	0.55
3%	1.09	0.96	0.92	0.86	0.80

2.1.2 Strength of Concrete Section With Shear Links

Designing concrete beam in shear using Eurocode2 can lead to significant economies in shear links compared to a beam designed using BS8110 [5, 7]

BS8110 – Assumptions:

- The angle between the notional compressive struts and the axis of the beam is constant and fixed at an angle $45°$ [5]
- The lever arm is assumed to be equal to the effective depth of the section [5]

Eurocode2 – Assumptions:

- The angle $\theta°$ between the notional compressive struts and the axis of the beam has a value within the range of 22° to 45° [5, 7].
- The lever arm is assumed to be equal to $0.9d$ [5, 7].

The resulting equations are as follows:

BS8110

$$\frac{Asv}{b \times Sv} = \frac{(v - vc)}{fyv/\gamma_m} \quad (3)$$

where Asv is the area of shear reinforcement, v is the Shear stress, Sv is the Spacing between links and fyv is Characteristic strength of links

Eurocode2

$$\frac{Asw}{b \times S} = \frac{\gamma_m \times v_{Ed}}{0.9.fyk.\cot\theta} \qquad \text{where } v_{Ed} = \frac{V_{Ed}}{b.d} \quad (4)$$

where v_{Ed} is the Shear forces at the ultimate limit state, fyk is the Characteristic strength of reinforcement and S is the Spacing between links it should be noted that in BS8110 the shear reinforcement does not resist the total applied shear but only resists the shear in excess of that which can be resisted by the concrete $(v - vc)$ [7], where v is the design shear stress and vc is the design concrete shear stress. In Eurocode2 all the shear must be carried by the shear links, when shear links are required [5, 7]

2.1.3 Maximum Shear Strength of Section

The maximum allowable shear force is limited by placing a limit on the crushing strength of the diagonal compression member to prevent excessive stress from occurring in the diagonal compressive strut and hence prevent compressive strut failure of the concrete.

In BS8110 the maximum allowable shear is dependent on the strut angle and concrete strength, and since the angle of inclination of the strut has a constant value, the maximum shear is dependent only on the concrete strength [7].

$$v_{max} = 0.8\sqrt{fc} \quad \leq 5N/mm^2 [BS8110]. \qquad (5)$$

where fc is the Compression stress of concrete

In Eurocode2 the angle $\theta°$ has a value within the range of 22° to 45°, and hence the maximum shear is a function of the angle $\theta°$ and the concrete strength [7].

$$v_{Rd,max} = \frac{0.36(1-{fck}/{250})\times fck}{\cot\theta - \tan\theta} [7] \qquad (6)$$

A comparison of the maximum shear stress permitted within BS8110 and Eurocode2 is shown in Table 3.

Table 3: *Maximum Shear Stress Limitation in BS8110 and Eurocode2 [5].*

Cube strength (N/mm^2)	Eurocode2 $\theta°$		BS8110
	27°	35°	
25	2.91	3.38	4
30	3.38	3.92	4.38
40	4.19	4.87	5
50	4.85	5.64	5
60	5.36	6.22	5

2.1.4 Enhanced Shear Near Supports

BS8110 and Eurocode2 allow greater shears to be resisted by a concrete section which is close to the supports of a beam. The enhancement is a function of the av/d ratio where d is the effective depth of the section and av is the distance from the section considered to the face of the beam support. In BS8110, the design concrete shear stress vc, can be enhanced by $2d/av$ where $2d$ is greater than av. In Eurocode2 the shear which can be resisted by the concrete without shear links, can be enhanced by $2.5d/av$ where $2.5d$ is greater than av[5, 6]. Eurocode2 allows a slightly higher enhancement of the shear capacity than BS8110 , so benefits are less in the case of BS8110 compared to Eurocode2 [8]

2.1.5 Spacing Of Links

BS8110

"The spacing of links in the direction of the span should not exceed 0.75d. At right-angles to the span, the horizontal spacing should be such that no longitudinal tension reinforcing bar is more than 150 mm from a vertical leg; this spacing should in any case not exceed d"[9]

Eurocode2

In Eurocode2 the spacing is a function of the applied shear. The rules are shown in Table 4.

Table 4: *Spacing between Links [5, 6]*

Applied Shear	Spacing (mm)	
	Lateral Spacing	Longitudinal Spacing
$v < v_{max} \times 1/5$	$d \leq 800$	$0.8d \leq 300$
$v_{max} \times 1/5 < v < v_{max} \times 2/3$	$0.6d \leq 300$	$0.6d \leq 300$
$v > v_{max} \times 2/3$	$0.3d \leq 200$	$0.3d \leq 200$

2.1.6 Additional Tensile Forces

In Eurocode2 the tensile force in the bottom tension member is given by:

$$Fs = M/Z + 1/2 \times V_{Ed} \times \cos\theta \quad (7)$$

where Fs is the Tensile stress of reinforcement, M is the Design ultimate moment, and Z is the Lever arm.

The second term in this equation is related to the shear forces in the links, so Eurocode2 takes into account the tensile forces which are caused by the bending and shear force in the links. BS8110 takes into account only the first term in this equation (the bending term) and ignores the tensile force which is caused by shear force (second term in this equation).

2.2 Deflection

1- The assumptions which are required to define the behavior of a section under any loading condition are as follows:

BS8110

In an un-cracked section the reinforcement and the concrete in tension and compression are assumed to behave elastically. The modulus of elasticity of the reinforcement may be taken as 200 $kN/mm^2$and for the concrete may be taken from BS8110-2:1985, Section 3.5

In a cracked section the reinforcement in tension and compression is assumed to behave elastically and the concrete in compression is also assumed to behave elastically but in the tension region the concrete is assumed to behave linearly from zero stress at the neutral axis to a limiting stress of $1\ N/mm^2$ at the centroid of the tensile reinforcement for short term loading and $0.5\ N/mm^2$ for long term loading. [9].

Eurocode2

In an un-cracked section the reinforcement and concrete in tension and compression are assumed to behave elastically [5]. The modulus of elasticity for the reinforcement can assumed to be $200kN/mm^2$.

In a cracked section the reinforcement in tension and compression is assumed to behave elastically and the concrete in compression is assumed to behave elastically but in tension the concrete stress is ignored. [7].

Where BS8110 assumes that the tensile strength of concrete is approximately 1 $N/mm^2$and Eurocode2 uses a significantly higher value than BS8110 [5].

2- Curvature

According to Narayanan [18], see Figure 1 (a parameterized moment-curvature diagram), when M/bd^2 is in between 0.3 and 0.6, BS8110 gives higher curvature values than Eurocode2. This is because BS8110 uses a value for the tensile strength of concrete of approximately 1 N/mm^2 and Eurocode2 uses a much higher value. In general terms BS8110 and Eurocode2 are more or less equivalent.

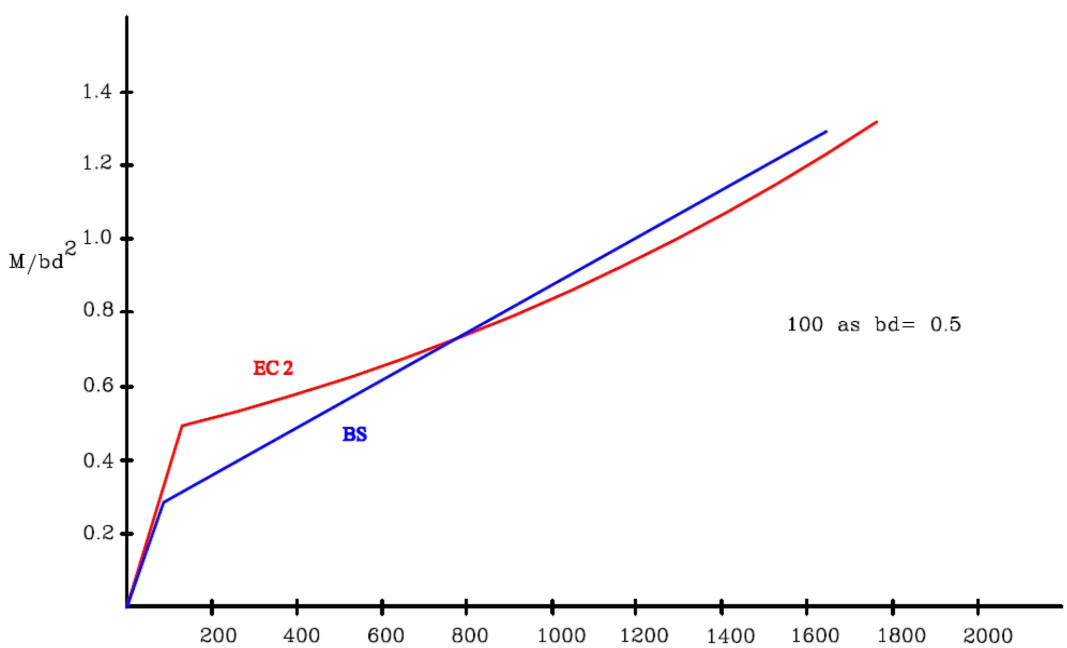

Figure 1: *Comparison of Curvatures Predicted by BS8110 and Eurocode2 [18]*

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2.3 Economic Study

The Table 5 shows that the traditionally designed beams, which have been designed using BS8110 and Eurocode2, the weights of the reinforcement are 38.48 kg and 39.78 kg respectively.

Table 5: *Weight and Cost of Reinforcing Bars in Beam*

	Size of bar	No. Of bars	Length of bar (m)	Total length of bars (m)	Density of bar	Weight of bar (kg/m)	Total weight of bars (kg)	Weight of beam (kg)
Beam (1) BS8110	6	23	1.178	27.094	7.8	0.220	5.97	38.48
	10	2	3.45	6.9	7.8	0.612	4.225	
	20	3	3.85	11.55	7.8	2.45	28.297	
Beam (2) Eurocode2	6	28	1.178	32.984	7.8	0.220	7.27	39.78
	10	2	3.45	6.9	7.8	0.612	4.225	
	20	3	3.85	11.55	7.8	2.45	28.297	

3 Details of Materials and Test Procedure

3.1 Description of Beams and Loading Arrangement

Two beams were prepared for the laboratory based test programme with a rectangular cross-section of $200mm \times 300mm$, an overall length of 3500 mm, an effective span of 3000 mm and a minimum cover of 25 mm.

The two beams were tested using a four point loading arrangement the loading points were located at distance equal to 662.5 mm from the centerline of each support, see Figure 2, the spacing was based on Kani's Valley.

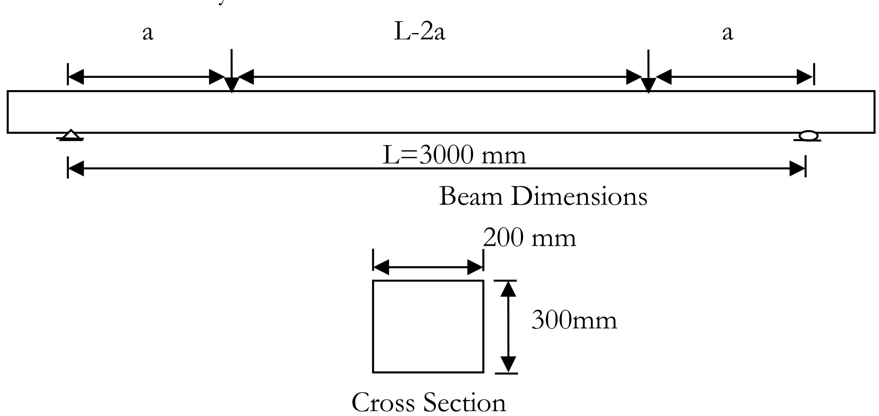

Figure 2: *Details of Beam and Loading Arrangement*

3.2 Design Of Test Beams

The beams were designed using two design approaches i.e. BS8110 Part 1 [1] and Eurocode2 [7]. The first beam was designed using the approach described in BS8110 and the secondbeam was designed using the approach in Eurocode2. Table 6 provides details of the three beams.

Table 6: *Beam Specifications*

Beam	Cross-section (mm^2)	Tensile bars (mm^2)	Spacing of links (mm)
BS8110	(200×300)	$3T20$	$T6\ at\ 150$
Eurocode2	(200×300)	$3T20$	$T6\ at\ 100$

3.3 Details of Reinforcement

Three sizes of reinforcing bars were used and they are as follows:

- 6mm diameter reinforcing bars were used as shear reinforcement in all three beams.
- 10mm diameter reinforcing bars were used as hanger bars for the links in all three beams.
- 20mm diameter reinforcing bars were used as tensile reinforcement in all three beams.

The three barsizes were tested to obtain the mechanical properties using of the steel. Tables 7, 8 and 9 show the tensile test results. All reinforcing bars were high yield steel.

Table 7: *Tensile Test Results for 6mm Diameter Reinforcing Bars*

Test	Maximum load (kN)	Tensile strength (N/mm^2)	Young's modulus (N/mm^2)
Test 1	16.61	588	196
Test 2	16.51	584.1	194
average	16.015	567	195

Table 8: *Tensile Test Results for 10mm Diameter Reinforcing Bars*

Test	Maximum load (kN)	Tensile strength (N/mm^2)	Young's modulus (N/mm^2)
Test 1	49	624	197
Test 2	47.98	611	202
average	48.49	617.5	199.5

Table 9: *Tensile Test Results for 20mm Diameter Reinforcing Bars*

Test	Maximum load (kN)	Tensile strength (N/mm^2)	Young's modulus (N/mm^2)
Test 1	203.2	647	211
Test 2	199.47	635.25	205
average	201.33	641.13	208

3.4 Details Of The Concrete

Six cubes and six cylinders were taken from the concrete mix in order to obtain the concrete crushing strengths at the time the beams were tested. These results were used to obtain the best estimate of the flexural/shear capacities of the beams and also the deflection values for the beams i.e. two sets of calculation were prepared one set assuming the concrete strength to be 30 N/mm^2 and the second set using actual concrete strength obtained from the cubes and cylinders. The material and load safety factors were moved from all the calculations used to predict the flexural and shear carrying capacities and the deflections of the beams. Tables 10 and 11 show the results obtained from the cube and cylinder tests carried out at the time the beams were tested.

Table 7:*Concrete Cube Crushing Test Results*

Ten day strength	Weight of cube (g)	H_1 (mm)	H_2 (mm)	H_3 (mm)	Applied loading (kN)	f_{cu} (N/mm^2)
Cube 1	2417	100	100	100	182	18.2
Cube 2	2518	100	100	100	200.4	20.04
Cube 3	2442	100	100	100	195.3	19.53
Cube 4	2421	100	100	100	211	21.1
Cube 5	2420	100	100	100	180.7	18.07
Cube 6	2400	100	100	100	203.4	20.34

Table 8: *Concrete Cylinder Crushing Test Results*

Ten day strength	Weight of cube (kg)	Diameter (mm)	high (mm)	Applied loading (kN)	f_{cK} (N/mm^2)
Cylinder 1		150	300	214.5	12.4

Average cube strength = $19.54 \quad N/mm^2$

Average cylinder strength = $12.4 \quad N/mm^2$

4 Results From Laboratory Based Test Programme

4.1 BS8110 Beam

According to the results from the laboratory based test, the maximum failure load was 80kN and the maximum deflection at mid span was 11.64 mm. Figure 3 shows the relationship between the applied load and central deflection of the beam.

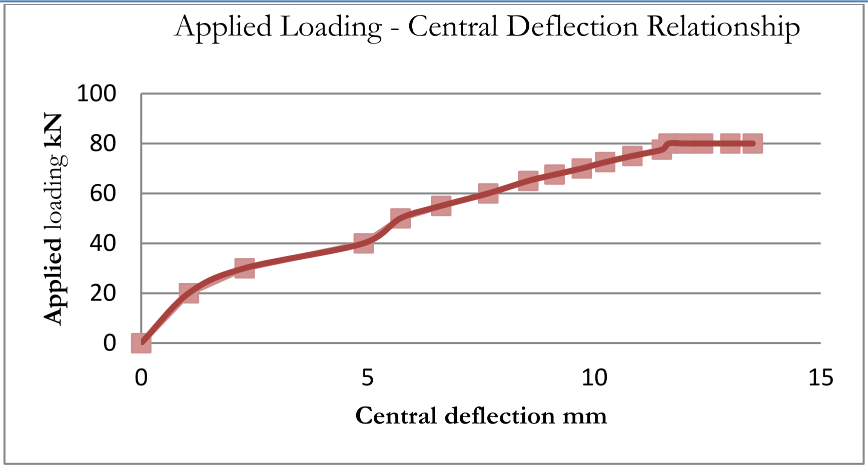

Figure 3: *Applied Load- Central Deflection Relationship*

4.2 Eurocode2 Beam

The maximum applied load at failure for the Eurocode2 Beam was 95kN and the maximum deflection at mid span at failure was 24 mm. Figure 4 shows the corresponding applied load - deflection relationship.

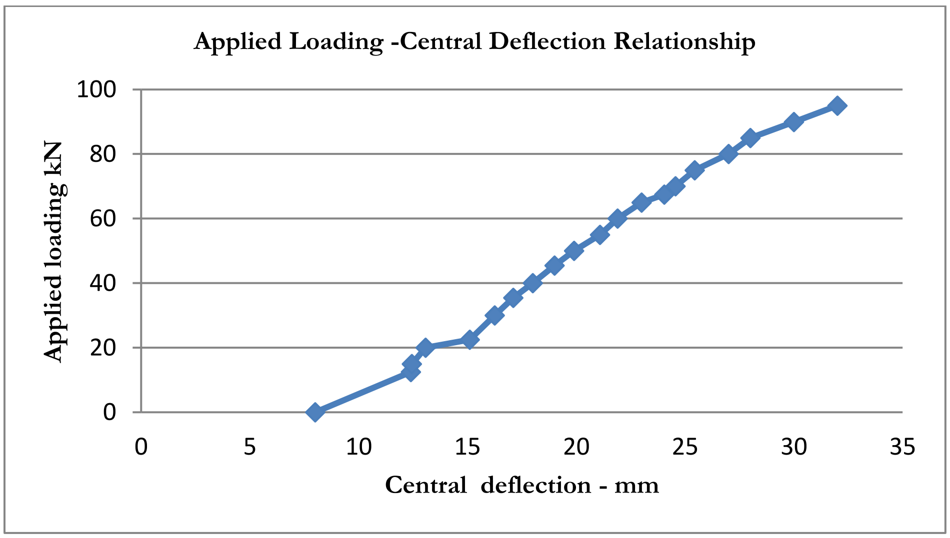

Figure 4: *Applied Loading-Central Deflection Relationship*

5 Conclusion

1. The BS8110 and Eurocode2 beams failed in shear before reaching their ultimate flexural capacity.
2. The Eurocode2 specification is much easier to follow than the specification detailed in BS8110
3. The Eurocode2 specification requires less shear reinforcement than the BS8110 specification
4. BS8110 and Eurocode2 are similar in that

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- The shear stress depends on the effective depth and tensile reinforcement ratio and the concrete strength
- There is a shear stress below which only minimum shear reinforcement need be provided

5. BS8110 and Eurocde2 are different in that
    - In BS8110 the shear reinforcement does not resist all the applied shear but resists only the shear in excess of that which can be resisted by the concrete ($v - vc$) [18], where v is the design shear stress and vc is the design concrete shear stress. In Eurocode2 the shear must be carried by the shear links, when the shear links are required
    - The BS8110 specification gives a higher value of v_c than is obtained from Eurocode2 for C30 concrete
    - Eurocode2 permits significantly higher shears to be resisted by a section than does BS8110
    - The scope of the approach in Eurocode2 is more extensive than the specification used in BS8110 for instance in Eurocode2 there is no limit placed on the concrete strength and designer is free to chosen any angle of inclination of the compression strut between 22° and 45° [8].
    - In Eurocode2 the designer can seek out economies in the provision of shear reinforcement.
6. The results from the laboratory tests have shown that the Eurocode2 beam carried a higher load (95kN) and gave a higher central deflection (24mm) compared to BS8110 beam which failed under a load of 80 $kN$and a maximum central deflection of 13.5mm.

References

[1] MacGinley T J, Choo B S, Reinforced concrete, design theory and examples. Second edition, 1990.

[2] Royal Society of Chemistry, The Concrete conundrum. Available on: http://www.rec.org/chemistryworld/restricted/2008/Msrch/TheConcreteConundrum. asp.

[3] Gambhir M L, Concrete Technology, 2004.

[4] Kuttab, A S and Haldane, Detailing for shear with the compressive force path concept. Proceeding of the IABSE Colloquium. Structural Concrete, Vol 69 No: 6, pp74-150, 1991.

[5] Narayanan R S, Concrete structures: Eurocode EC2 & BS8110 Compared, 1994.

[6] Hulse R, Monypenny P C, An instruction to EC2 and comparison with BS8110, 1993.

[7] Mosley W, Bungey J, and Hulse R, Reinforced concrete design to Eurocode2. Sixth Edition, 2007.

[8] Moss, R. EN1992-Eurocode and BS8110 Compared. Proceedings of the Institution of Civil Engineers - Civil Engineering, Volume: 156 Issue: 3, Aug 2003.

[9] British Standard BS8110, Structural use of concrete of concrete – Part 1: Code of practice for design and construction, 1997.