Structural Behavior of Reinforced Concrete Hollow Beams under Partial Uniformly Distributed Load

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ABSTRACT

A Longitudinal opening is used to construct hollow core beam is a cast in site or precast or pre stressed concrete member with continuous voids provided to reduce weight, cost and, as a side benefit, to use for concealed electrical or mechanical runs. Primarily is used as floor beams or roof deck systems. This study investigate the behavior of six beams (solid or with opening) of dimension (length 1000 x height 180 x width120mm) simply support under partial uniformly distributed load, four of these beam contain long opening of varied section (40x40mm) or (80x40mm). The effect of vertical steel reinforcing, opening size and orientations are investigated to evaluate the response of beams. The experimental behavior based on load-deflection measured at central and quarter of tension zones. The experimental test result shows the presence of Hollow decrease the load carrying capacity by about (37.14% to 58.33%) and increased the deflections by about (71.6% for (Hollow ratio 7.4%) to 75.5% for (Hollow ratio 14.8%)) for same applied load compared with solid beams with the same properties. The increase shear steel reinforcing will decrease all the deformations at all stages of loading, but particularly after initial cracking and give enhancement in ultimate load capacity of beams by about 31.5% with increasing the amount of shear steel reinforcing by about 50%. Finally, ductility is increased in all cases under partial uniformly distributed load when hollow ratio decreased by about 50% or increased in shear steel reinforcing by about 50%.

Key words: longitudinal opening, shear reinforcing, first crack, deflection, hollow ratio.

السلوك الإنشائي للعتبات الخرسانية المسلحة المجوفة تحت حمل موزع بانتظام جزئياً

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الخلاصة

الفتحات الطولية تستعمل لتكوين عتبة مجوفة مصبوبة موقعيا" أو مسبقة الصب أو مسبقة الإجهاد ومستمرة الفراغات مع العضو الخرساني وذلك لتخفيف الوزن وكذلك الكلفة والفائدة الرئيسية هو لتمرير الخدمات الكهربائية والميكانيكية . الاستعمال الرئيسي هو كعتبات الطوابق او أنظمة السقوف. هذه الدراسة تحرت سلوك ست عتبات خرسانية مسلحة (صلدة او مجوفة) وبأبعاد (الطول 1000 ملم والارتفاع 180ملم وعرض 120 ملم) بسيطة الإسناد تحت تأثير الحمل الجزئي الموزع بانتظام، أربعة من النماذج مجوفة وبأبعاد تجويف مختلفة (40*40 ملم او 80*40 ملم). تم دراسة تأثير نسبة التسليح العمودي ونسبة الفتحة واتجاهها لتقييم استجابة العتبات من الناحية العملية بالاعتماد على علاقة الهطول - الحمل المقاس في مركز وربع الطول تحت منطقة الشد. نتائج الفحص العملي بينت ان وجود التجاويف (الفتحات الطولية) في العتبات

الخرسانية تقلل قابلية التحمل لها بمقدار حوالي (37.14% إلى 58.33%) وتزيد في الهطول بمقدار (71.6% الى 75.5% لنسبة تجويف مقدارها 7.4% و 14.8%على التوالي) لنفس الحمل المسلط وبالمقارنة مع العتبات الصلدة ولنفس الخصائص الأخرى, كذلك زيادة حديد القص يقلل كل التشوهات في كل مراحل التحميل ولكن عملياً بعد التشقق الأولي وتعطي تحسين في قابلية التحمل للعتبات بمقدار 31.5% مع زيادة حديد القص بمقدار 50%. أخيرا" المطاوعة تزداد في كل الحالات تحت تأثير الحمل الموزع بانتظام عند نقصان نسبة التجويف بمقدار 50% أو زيادة حديد القص بمقدار 50 %.

1. INTRODUCTION

Many parameters may influence the overall hollow girder response such as: the shape of the section, the amount of the longitudinal and transverse reinforcement, the cross section thickness, load ratio and finally the material strength of concrete and reinforcement, **Alnuaimi, 2003** and **Mander, 1984**. This study focuses on rectangular hollow cross sections and investigates the beams behavior under a state of uniformly distributed loading

2. ADVANTAGE OF HOLLOW CROSS SECTION

The advantages of hollow cross section , **Nimnim, 1993**.

1. Reduced the weight, which affects especially the cost of transport, handling and erection for pre-cast cross sections.
2. Substantial reduction of material quantities, the materials required are usually much less than those needed for other conventional systems and they are little more than those required for continuously curved shells, with the advantage of utilizing relatively simple formwork.

3. OBJECTIVE OF THE RESEARCH

The main target of this research is studying the effect of different amount of shear reinforcement (stirrup) and hollow ratio of cross section on the strength and behavior of hollow cross section beams subject to partial distributed load and also studying load deflection behavior which occurs at the center and quarter of span length of beams.

The variables which taken in this research are: stirrups (shear reinforcement, hollow and solid section with thickness of walls for hollow section.

It's expected in this research to state the influence of distributed load on the strength and behavior of hollow cross section beam and comparison between experimental tests result of specimens and confirm the best specimens with hollow section which result the nearest value to the solid section result.

Finally studying the factors that affect the behavior of reinforced concrete beams under partial uniformly distributed load which have directly relation with the (stirrup reinforcement and dimension of sections).

4. EXPERIMENTAL WORK

4.1 Scope of Work

In order to study the structural behavior and ultimate strength of reinforced concrete beam under partial uniformly distributed load, which can be used as rectangular hollow cross section. A total of six specimens in four groups, detailed as shown in **Table 1**, were cast in plywood forms. All the beams were made from a single mix proportion (Cement: Sand: Gravel) of 1:1.5:3 by weight with a water/cement ratio 0.45 and also all beams were designed to have the same longitudinal and varied stirrup reinforcing. Each of the mixtures was thoroughly mixed prior to casting. The beams details, mix proportion, materials properties and formwork given in **Tables 1,**

2, 3 and 4, and **Figs. 1,2** and **3** respectively.

4.2 Considered Parameters

In the present investigation, four group parameters were adopted to study the behavior and ultimate load of beams and to investigate the influence of hollow ratio, shear reinforcing in concrete beams when subjected to uniformly distributed load. All beam details are shown in Table 1.

Group 1: Consists of one solid specimen with dimension (120, 180) mm, length (1000 mm), longitudinal bars (3-Ø12mm) with stirrups of (Ø10mm @ 100 mm c/c).

Group 2: Consists of one solid specimen with dimension (120, 180) mm, length (1000 mm), longitudinal bars (3Ø10 mm) with stirrups of (Ø10 mm @ 50 mm c/c).

Group 3: Consists of two hollow specimens, all properties as same in group 1, but with different hollow section (40x40 mm and 40x80 mm). Group 4: Consists of two hollow specimens, all properties as same in group 2, but with different hollow section (40x40 mm and 40x80 mm).

5. TEST RESULTS OF REINFORCED CONCRETE BEAMS

A partial uniformly distributed load (i.e. loaded length 120mm which equal to 13.34% of span length) was provided using universal testing machine of capacity (3000 kN) applied at the center of the beam gradually at increments of (5 kN) up to failure. Test results for each case, including deflections and cracking are highlighted. Load versus deflection was recorded at point of (central and quarter of span length) at distances about (500 and 250 mm) from the edges of the beam. Arrangement specimens of partial uniformly distributed loading and instrumentation as shown in **Figs. 4 and 5**. Crack patterns, first crack load and propagation of cracks are also studied. Ultimate load capacity and failure modes are recorded as shown in **Table 5**. A study of the effect of vertical shear reinforcement and section type (solid or hollow), was carried out. Deflections, crack patterns at all stages of loading of the reinforced concrete beam were also discussed.

6. CRACK PATTERNS

The first crack was found to develop around the sides of the loading area of ($120mm^2$) on the tension fiber of the beam center. These cracks were formed at about (8.0 – 11.5%) of the ultimate failure load, as shown in **Table 5**. In the case of beams with hollow section cracks appear in the tension zone of the beam near one or more of the corners as shown in Table 5. The ultimate load, maximum central deflection were recorded and given in **Table 5**. As the load is increased after formation of the first crack, more cracks begin to appear and, propagated diagonally towards the corners of applied load (i.e. under position of applied load). At high loads, these cracks extended with the formation of new cracks at different orientations. Meanwhile, cracks start to appear around the edge of the applied load at tension zone.

Failure was distinguished by the successive deflections at the center of the beam at higher load levels through shear and wide flexural cracks at the tension zone, then, yielding of the tensile reinforcing steel. All beams were tested up to failure. The crack pattern zone of each reinforced concrete beam was painted with concrete color this allows the cracks to be visible and the failure can be pointed as shown in **Figs. 6 to 11**.

7. DEFLECTION MEASUREMENT

For all tested beams, deflections were measured at a distance of (500mm and 250 mm) from the ends of beams at the bottom surface. The deflections occur at these locations were measured to compare response.

Deflection measures may give a reasonable interpretation of the load carrying capacity of the beams. The load-deflection curves for six tested beams under applied loads are shown in **Figs. 12 to 16**, While the comparison of deflection for all beams at quarter and central location as show in **Figs. 17 and 18** for the cases of beam solid or hollow section. While, these curves demonstrate a certain tendency in which, at early stages of loading (elastic stage), the deflection-load relation is linear up to the first cracking load. After this, new cracking start and continuous up to the first yielding; these are flexural cracking. Beyond first yielding plastic deformations continuous and yielding up to failure at a stress near the ultimate flexural strength, as calculated by the yield line theory. In this stage, yielding of the tension reinforcement spreads from the loaded area towards the beam edges. Finally (stage of failure) a plastic stage of rapidly increasing deflection at no additional load application.

Tests of all beams demonstrated that the ultimate load becomes smaller as the beam varied from solid to Hollow by about (37.14% to 58.33%). Also ultimate load increases as shear reinforcement ratio increases. The deflections of the beams at both points (A and B) increase when the beam varied from solid to hollow section (71.6% (hollow ratio of 7.4%) to 75.5% (hollow ratio of 14.8%)) for the same applied load compared with solid beams with the same properties and noticed smaller values when increased shear reinforcing as shown in Table 5. In general R.C. beams those are solid or hollow with more shear reinforcing show higher load carrying capacity with reduction in deflection values. Finally the deflection varied along of all tested specimens at loading stages are shown in **Figs. 19 to 24**.

8. CONCLUSION

In this study it has become to study the behavior and strength of hollow concrete beams under partial uniformly distributed load was investigated. From an experimental program the following conclusion were drawn:

1- It has been observed from the tests carried out that the slope of main cracks under partial uniformly distributed load for reinforced concrete beam is about 45^o.

2- As per the result of tested, some of concrete beams fails under flexural failure and other compound failure (i.e. shear and flexural failures) when the crack constructed at flexural zone or flexural and near support under load.

3- The presence of hollow recess in reinforced concrete beams was found to decrease the load carrying capacity by about (37.14% to 58.33%) and increase the deflections by about (71.6% (hollow ratio 7.4%) to 75.5% hollow ratio (14.8%)) for same applied load compared with solid beams for same properties.

4- When increasing the hollow ratio from (7.4% to 14.8%) the load carrying capacity is decreased and deflection is increased by about (28.5% and 14%) respectively for same other properties.

5- Shear steel reinforcement decreased all the deformations at all stages of loading, particularly after initial cracking.

6- Ductility is increased in all cases for partial uniformly distributed load when decreased Hollow ratio by about 50% or increased in steel reinforcing.

7- The phenomenon of crushing concrete cover (Spalling down) was avoided when increased the shear steel reinforcing by about 50% in the reinforced concrete beam under partial uniformly distributed load.

9. REFERENCES

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Table 1. Details of reinforced concrete beams specimens.

Specimen Symbol	Bottom Reinforcing	Top Reinforcing	Stirrups Reinforcing	Hollow Ratio	Section Property
B1	3 Ø 12 mm	2 Ø 12 mm	Ø10@100 mm	---	Solid
B2	3 Ø 12 mm	2 Ø 12 mm	Ø10@ 50 mm	---	Solid
B3	3 Ø 12 mm	2 Ø 12 mm	Ø10@100 mm	7.4%	Hollow
B4	3 Ø 12 mm	2 Ø 12 mm	Ø10@ 50 mm	7.4%	Hollow
B5	3 Ø 12 mm	2 Ø 12 mm	Ø10@ 50 mm	14.8%	Hollow
B6	3 Ø 12 mm	2 Ø 12 mm	Ø10@100 mm	14.8%	Hollow

Table 2. Mix proportions for (1 m^3) of concrete (1: 1.5: 3) by weight.

Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water/Cement Ratio	Water (kg/m^3)
400	590	1180	0.45	180

Table 3. Properties of steel reinforcement.

Nominal Diameter (mm)	Measured Diameter (mm)	A_s (mm^2)	Yield Stress f_y (MPa)	Tensile Strength f_u (MPa)
10	9.88	76.67	421	520
12	12.2	116.89	480	570

Table 4. Compressive strength of concrete cylinder (150 x 300 mm) (28 days).

Sample No.	Strength (MPa)	Average Strength (MPa)
1	29.43	
2	28.41	
3	27.73	28.52

Figure 1. Moulds of reinforced concrete solid and hollow reinforced concrete beams.

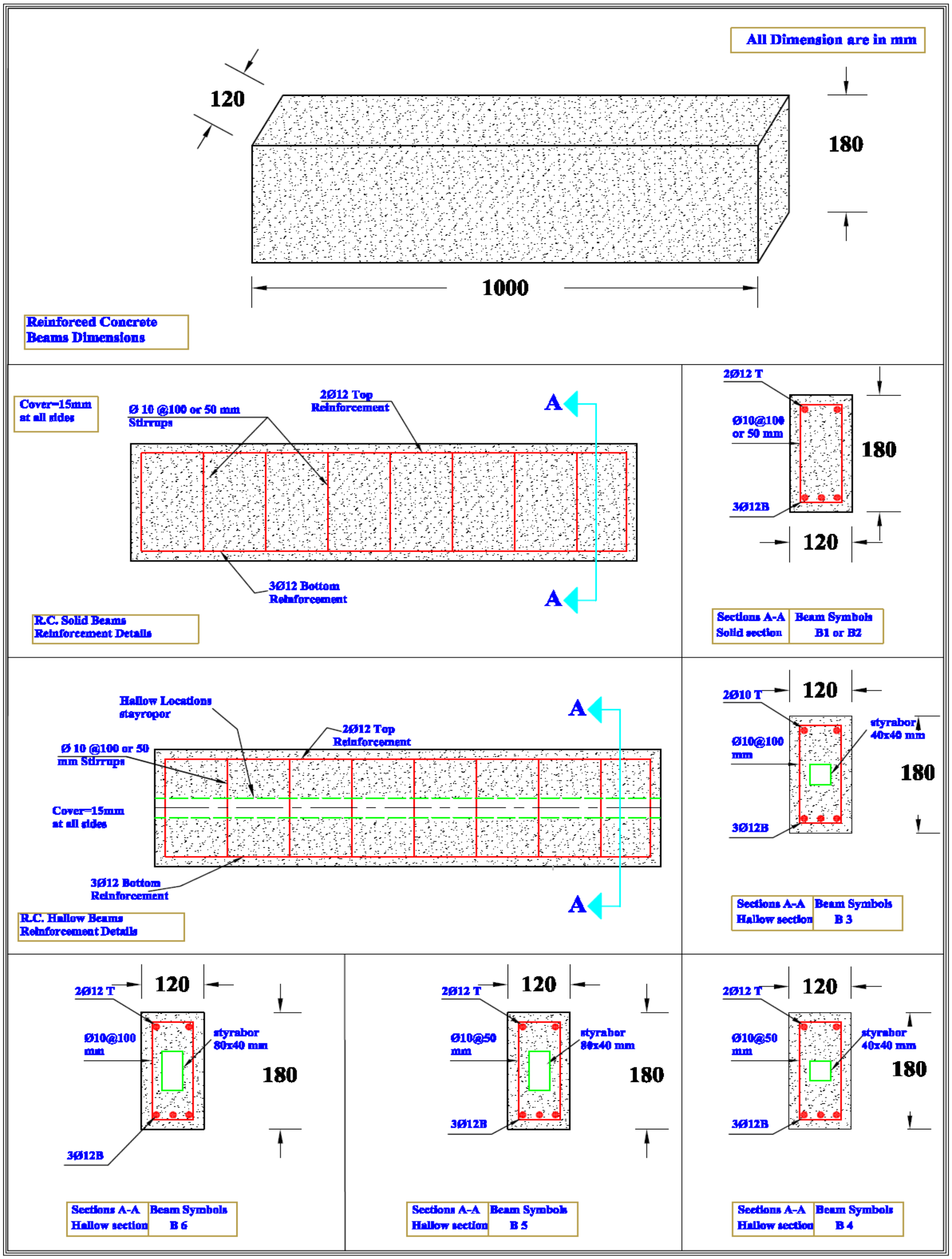

Figure 2. Cross-section & longitudinal shape of the beam.

Figure 3. Recess through section of hollow beams.

Figure 4. Beams under partial uniformly distributed loading.

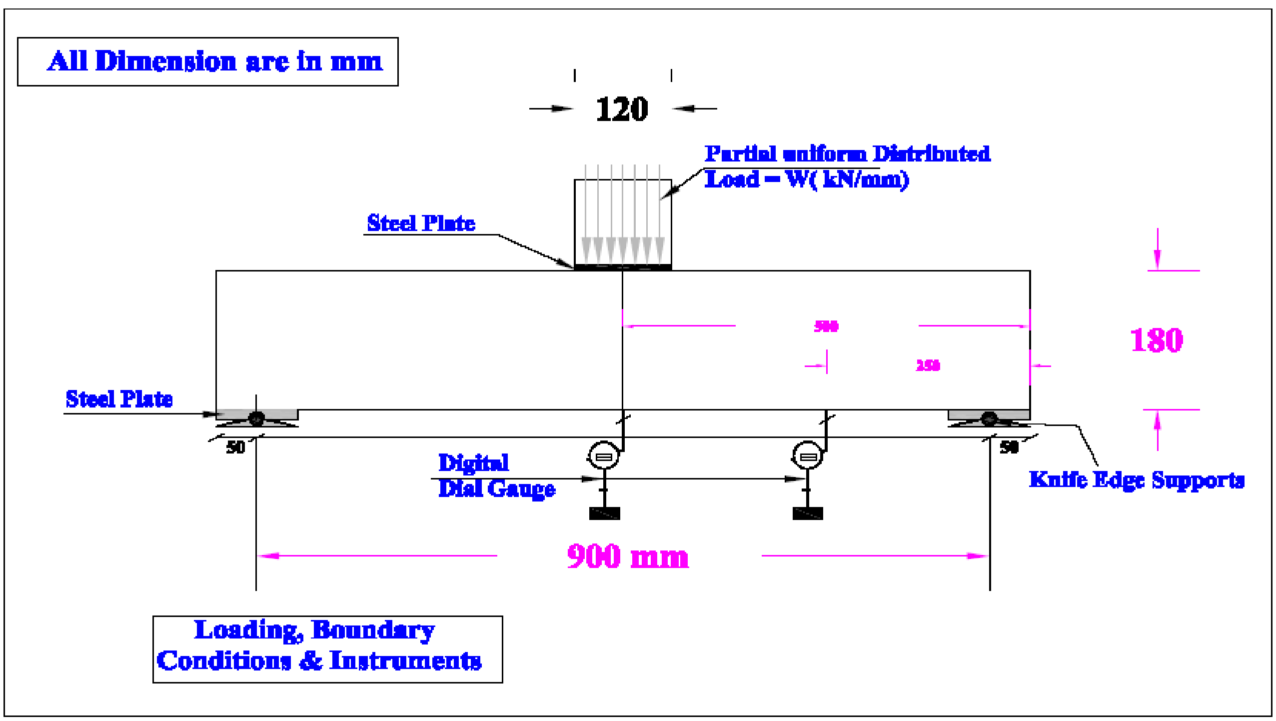

Figure 5. Arrangement specimens of partial uniformly distributed loading and instrumentation.

Table 5. First crack, ultimate load and deflections.

Beam No.	Beam Section	Shear Reinforcing	Hollow Ratio %	First Crack Load (Wcr) (kN/m)	Ultimate Load (Wu) kN/m	Central Deflection (mm)	Wcr / Wu %
B1	Solid	Ø10@100 mm	---	5.0	60.0	3.32	8.3
B2	Solid	Ø10@50 mm	---	10.0	87.5	3.72	11.5
B3	Hollow	Ø10@100 mm	7.4	4.0	40.0	5.70	10.0
B4	Hollow	Ø10@50 mm	7.4	5.0	55.0	8.08	9.0
B5	Hollow	Ø10@50 mm	14.8	3.0	35.0	5.69	8.5
B6	Hollow	Ø10@100 mm	14.8	2.5	27.0	4.3	9.2

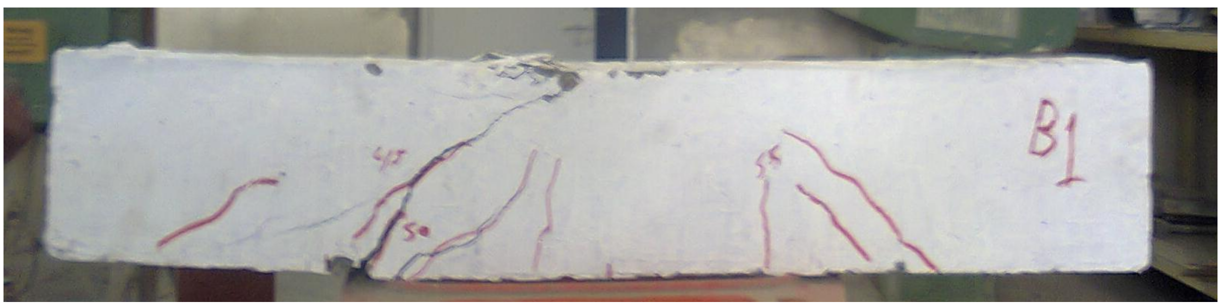

Figure 6. Crack patterns of beam (Solid) B1.

Figure 7. Crack patterns of beam (Solid) B2.

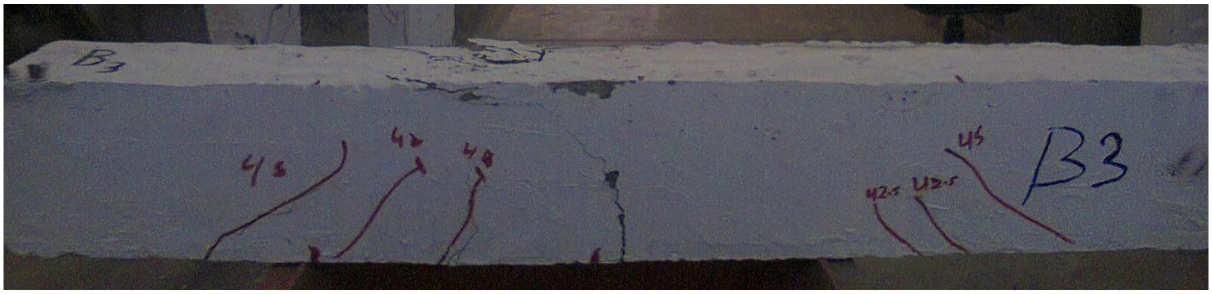

Figure 8. Crack patterns of beam (Hollow) B3.

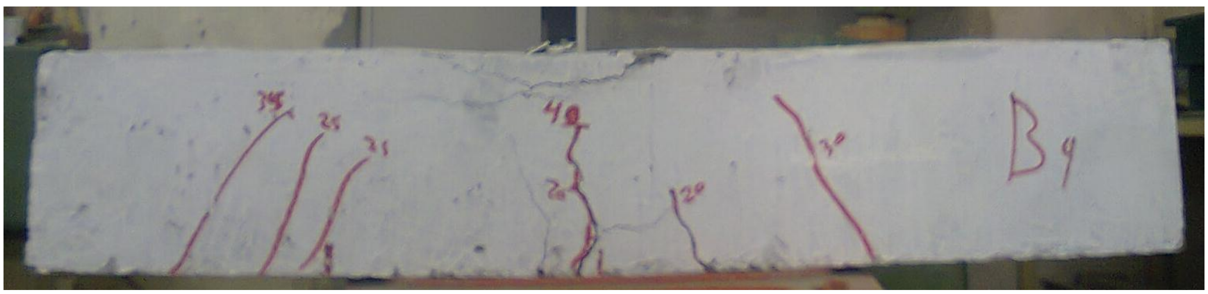

Figure 9. Crack patterns of beam (Hollow) B4.

Figure 10. Crack patterns of beam (Hollow) B5.

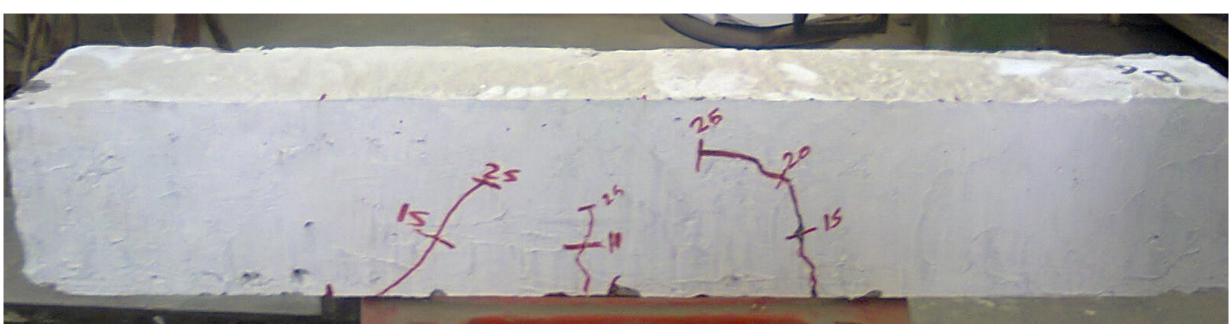

Figure 11. Crack patterns of beam (Hollow) B6.

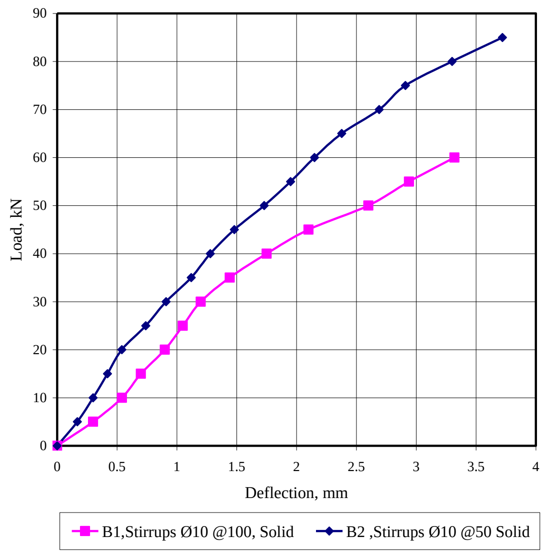

Figure 12. Comparison of central deflection of beams B1 & B2.

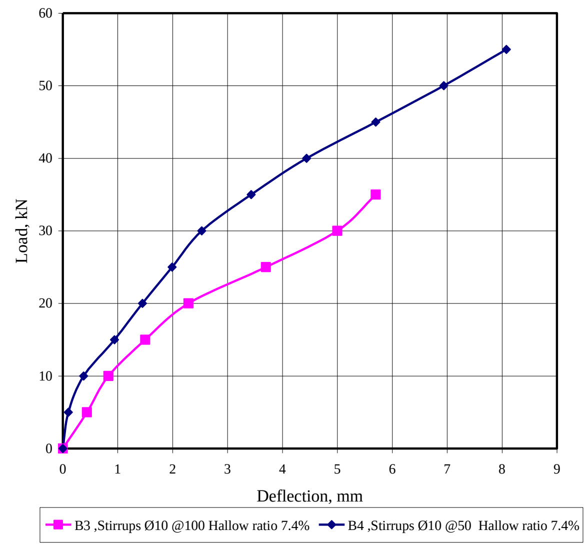

Figure 13. Comparison of central deflection of beams B3 & B4.

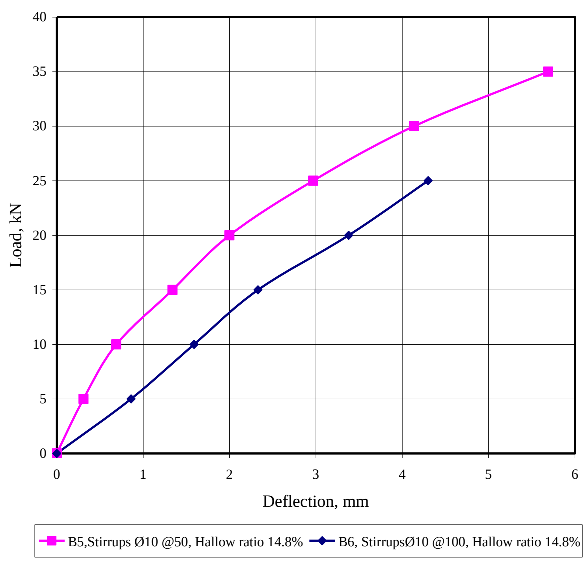

Figure 14. Comparison of central deflection of beams B5 & B6.

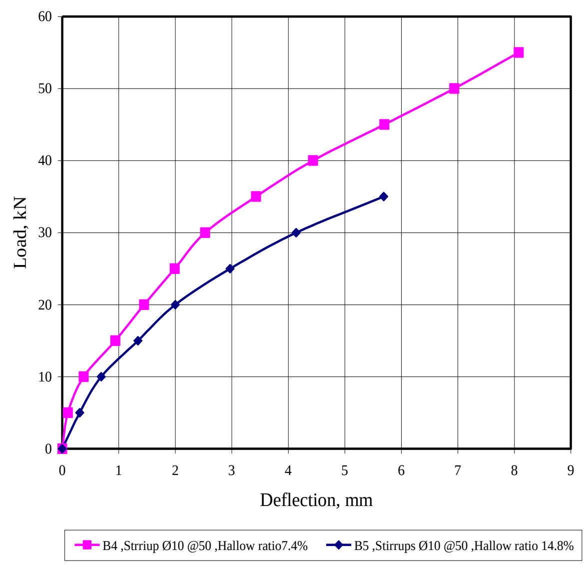

Figure 15. Comparison of Central Deflection of Beams B4 & B5.

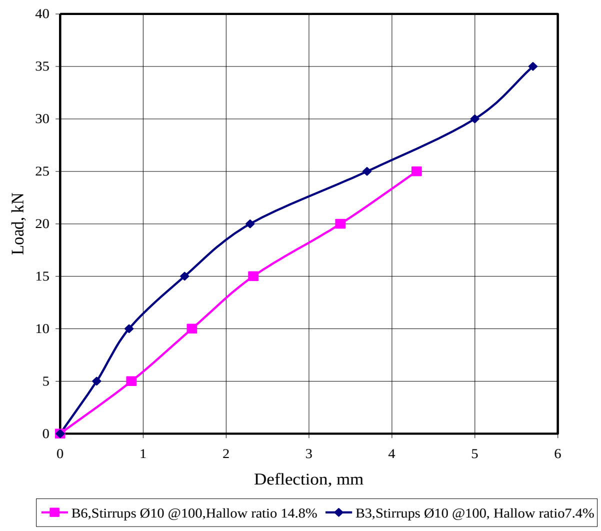

Figure 16. Comparison of central deflection of beams B6 & B3.

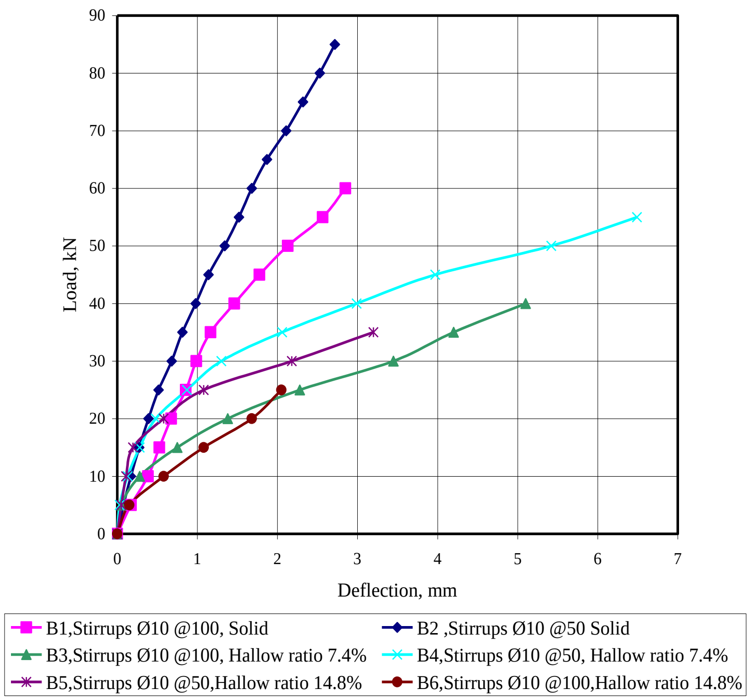

Figure 17. Comparison of quarter deflection of all beams.

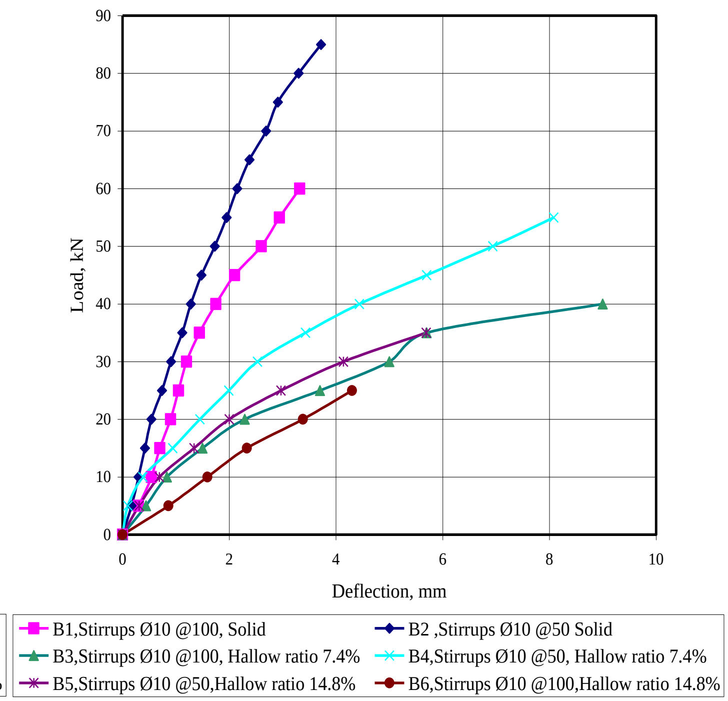

Figure 18. Comparison of central deflection of all beams.

Note: The deflection of all beams at left quarter side are assumed to be the same values on right quarter side as shown in Figs. 19 to 24.

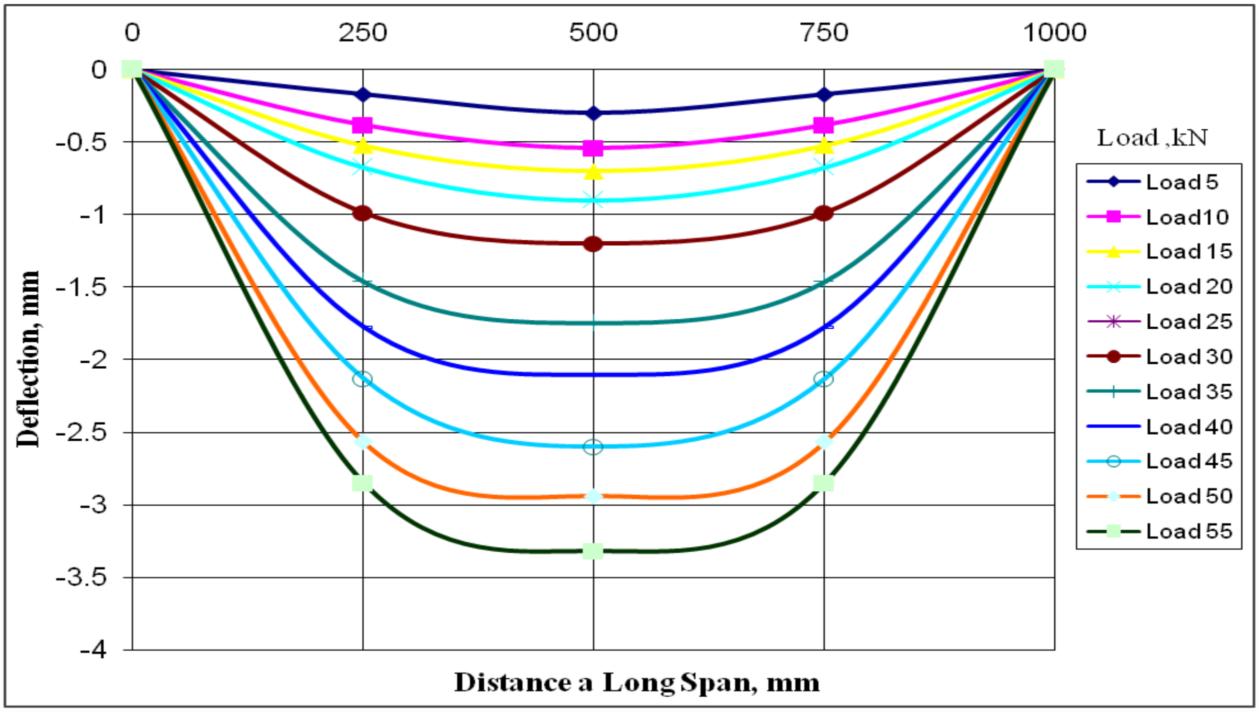

Figure 19. Deflection through a long of reinforced concrete beam, B1.

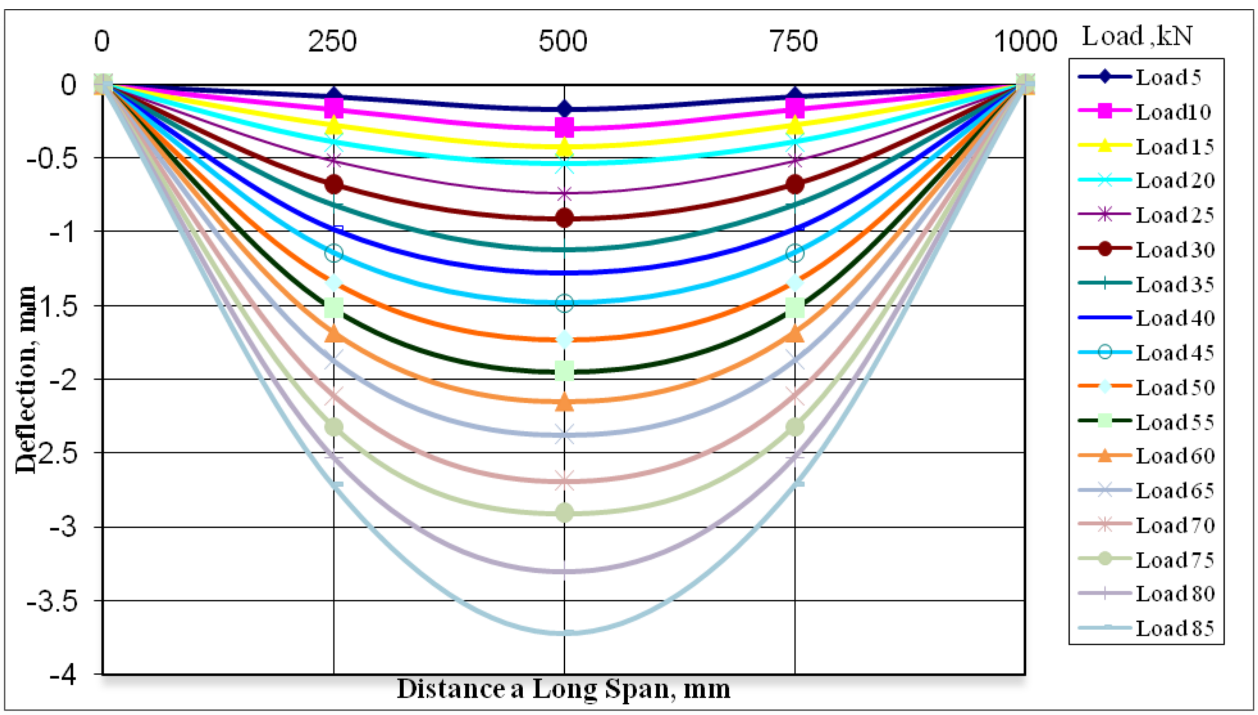

Figure 20. Deflection through a long of reinforced concrete beam, B2.

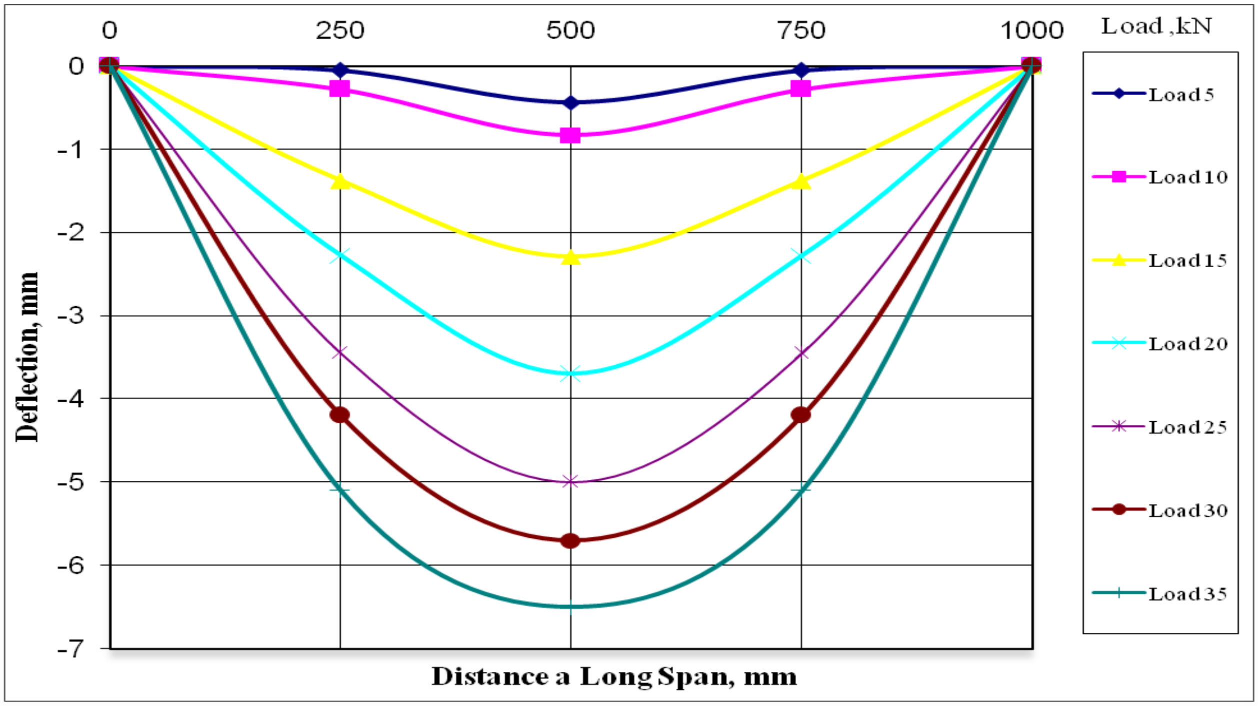

Figure 21. Deflection through a long of reinforced concrete beam, B3.

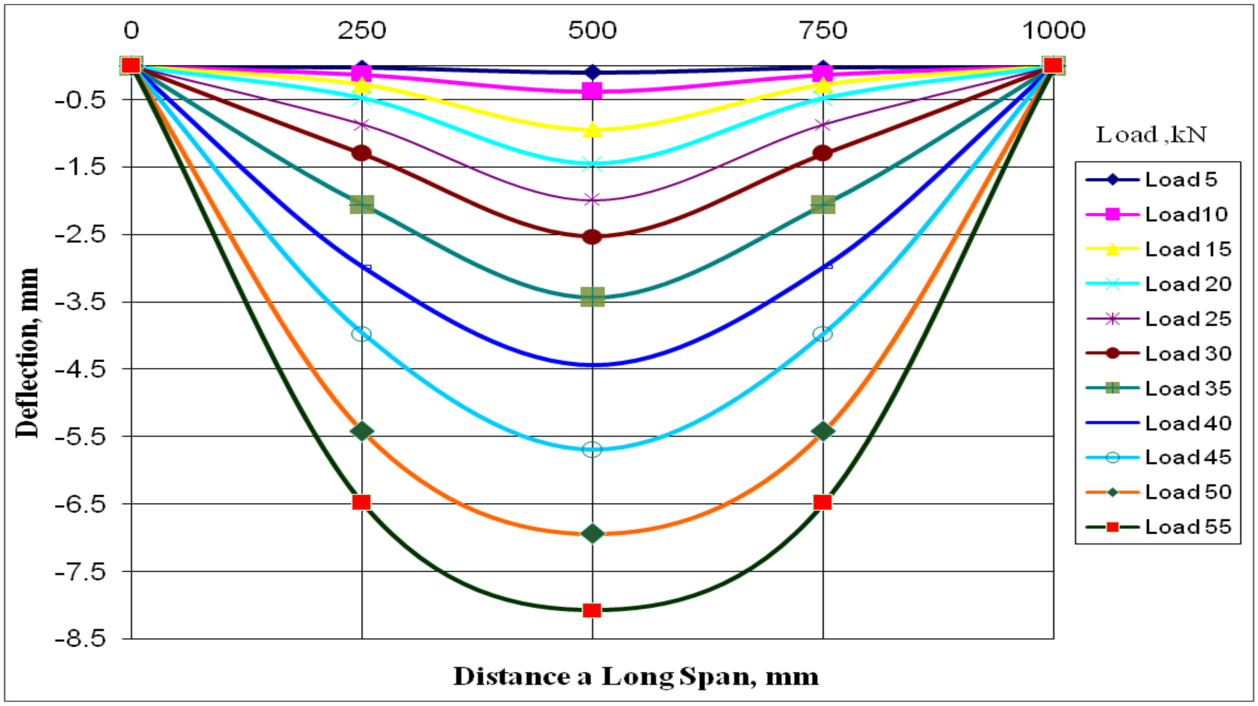

Figure 22. Deflection through a long of reinforced concrete beam, B4.

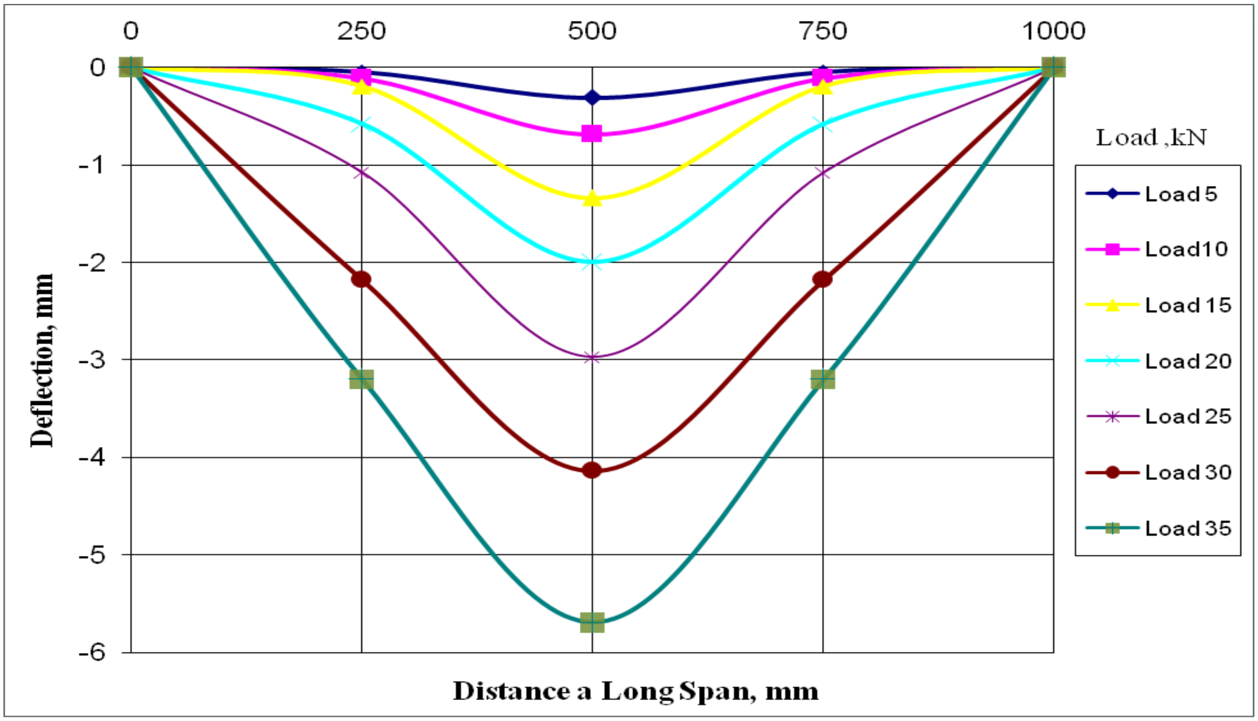

Figure 23. Deflection through a long of reinforced concrete beam, B5.

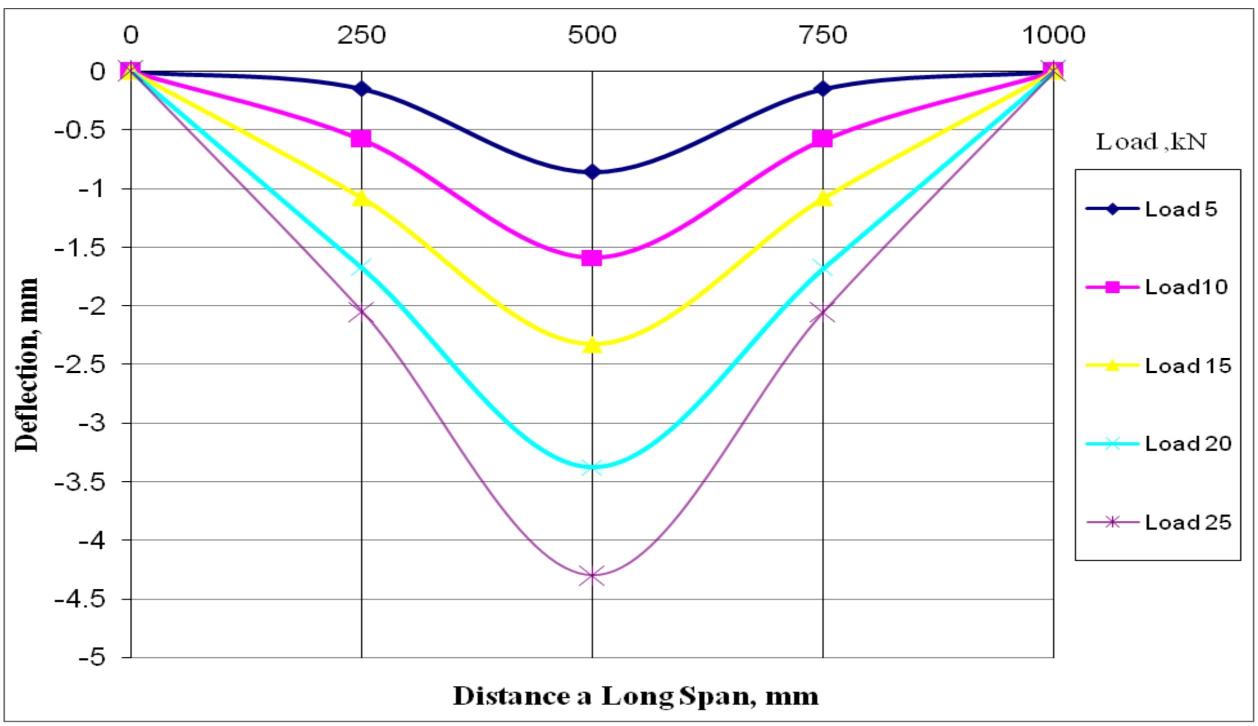

Figure 24. Deflection through a long of reinforced concrete beam, B6.