

Behaviour of Self-Consolidating Concrete Two Way Slabs Under Uniform Loading

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Abstract

An experimental investigation was conducted to study the strength, behaviour and deflection characteristics of two way slabs made with both self-consolidating concrete (SCC) and conventional concrete (CC). Six concrete slabs were tested to failure under simply supported uniform by distributed loading conditions. The variables were concrete type and macro synthetic fibres ratio (0%, 0.07% and 0.14%). The performance was evaluated based on crack pattern, ultimate load, load-deflection response and failure mode. The results showed that the ultimate strength of SCC slabs was larger than that of their CC counterparts. The results also showed an improvement of the behaviour and strength of slabs by adding the synthetic fibres.

Key Words: Self consolidating concrete, two way slab, uniform distributed loading, synthetic fibres.

تصرف البلاطات الخرسانة ذاتية الرص الشائبة الاتجاه تحت التحميل المنتظم
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الخلاصة

تتمحور البحث حول التجارب المختبرية لدراسة المقاومة، التصرف و الهطول الخاصة بالبلاطات الشائبة الاتجاه و المصنعة من الخرسانة ذاتية الرص (SCC) و الخرسانة التقليدية (CC). تمت الفحوصات لستة بلاطات بسيطة الاسناد لحد الفشل تحت حمل منتشر و موزع بانتظام. كانت المتغيرات هي نوع الخرسانة ونسبة الالياف الصناعية المضافة (0%، 0.07% و 0.14%). تم التقييم اعتمادا على شكل التشققات، الحمل الاقصى، علاقة الهطول بالاحمال المسلطة وشكل الفشل. بينت النتائج ان المقاومة القصوى للبلاطات المصنعة من SCC اكبر من تلك المصنعة من CC. كما بينت النتائج تحسن بالسلوك و المقاومة عند اضافة الالياف الصناعية الى البلاطات الخرسانة.

1. Introduction

Conventional reinforced concrete (CC) which is one of the most widely used construction materials worldwide is a composite material of steel bars embedded in a hardened concrete matrix. To enhance the properties of this material, many suggestions may be taken according to the problems that need to be improved. One of these suggestions is using self-consolidating concrete to enhance the fresh properties of concrete. Self-consolidating concrete (SCC) is the latest innovation in concrete technology. It is a highly flowable mixture that spreads readily under its own weight, without the use of vibrators for consolidation, and it achieves good compaction without segregation,

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even in members with congested reinforcement. SCC is produced by increasing the fine aggregate content through the incorporation of mineral admixtures and/ or viscosity modifying admixtures (Khayat et al., 1997; Sonebi and Khayat, 1999; EFNARC, 2000; Lachmi et al., 2004). The coarse aggregate content in SCC is usually lower than in CC, and the minimum slump flow value is limited to 550mm to enhance the workability and flowability. Lack of information regarding in situ properties and structural performance of SCC is one of the main barriers to its acceptance in the construction industry (Lachmi et al., 2005). There is some concern among researchers and designers that SCC may not be strong enough in shear because of some uncertainties in mechanisms resisting shear notably the aggregate interlock mechanism. Because of the presence of comparatively smaller amount of coarse aggregates in SCC, the fracture planes are relatively smooth as compared with CC that may reduce the shear resistance of concrete by reducing the aggregate interlock between the fracture surfaces (Hassan et al., 2010). However, only few studies have been conducted on the strength and behaviour of structural elements made by using fibre reinforced SCC (Pereira et al., 2004).

Many studies explain the effect of synthetic fibres on the serviceability of concrete and to control on the bleeding and plastic shrinkage cracking (Wang and Belarbi, 2005). The increasing use of macrosynthetic fibres for structural applications necessitates the understanding and the evaluation of the effect of fibre addition on the behaviour of concrete members. Unlike steel fibres, there are only few studies reporting results on member strength with synthetic fibres (Wang and Belarbi, 2005; Altoubat et al., 2009). The results revealed that simple material tests do not always successfully predict the contribution of fibres in cases where structural geometry and boundary considerations control redistribution of load (Roesler, 2004).

This study is focused on the behaviour of two way slabs made with both SCC and CC with macro-synthetic fibres. Results obtained from testing six two-way concrete slabs under uniform loading are presented. The slabs were reinforced with longitudinal flexural reinforcement in two directions and were designed to fail in shear under uniform loading while being simply supported on all four sides.

2. Experimental Programme

Six simply supported rectangular reinforced concrete slabs were tested to failure in an experimental program conducted at Al-Mustansiriya University. They consisted of two series CC, and SCC. The primary variable was the concrete materials; SCC or CC. Each group consists of three specimens with different percentages of synthetic fibres (polypropylene); 0%, 0.07%, and 0.14% by volume. Each slab was loaded directly on the top compression face with uniform distributed load (sand bags) and concentrated load at mid-span over sand bag (from universal machine) and supported at four edges at the bottom, see Plate 1. The specimens were rectangular of 900×450×80 mm and reinforced with one layer mesh of #6@150 mm on the tension side of the slab as shown in [Figure 1](#).

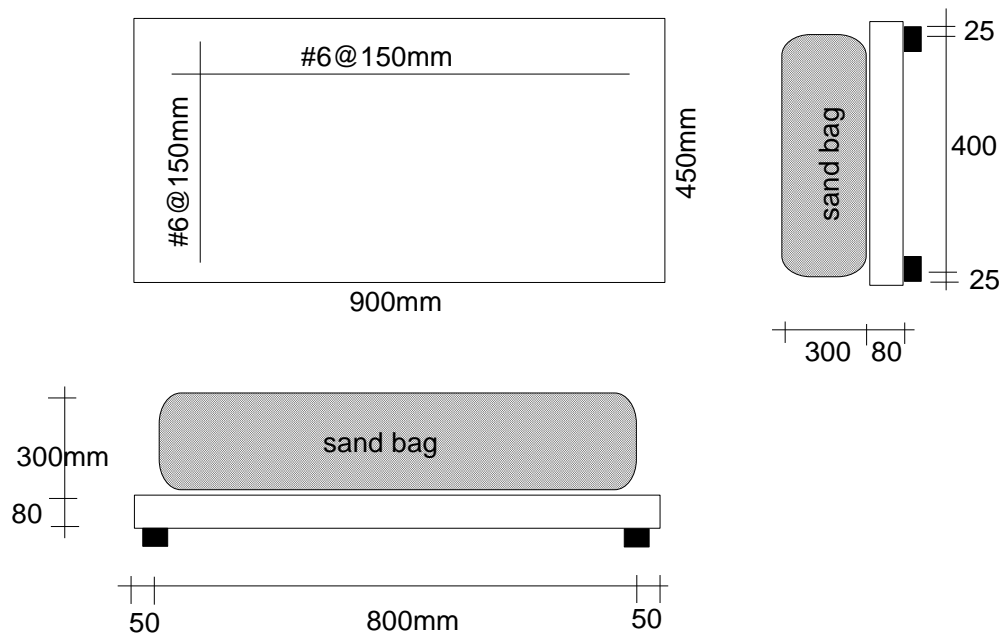


Figure 1. Dimensions and details of two way slabs



Plate 1. Slab loading method

2.1. Materials Properties

2.1.1. Cement

The cement used in this study was Ordinary Portland cement (Type I). This Cement conformed with the requirements of the ASTM C150 standards.

2.1.2. Aggregate

Natural siliceous desert sand was used as fine aggregate and crushed river gravel with maximum size of 14 mm was used as coarse aggregate. Both types of aggregate conformed to ASTM C33 requirements.

2.1.3. Superplasticizer

For the production of SCC as well as high strength CC a superplasticizer is needed. In this work Gelnum 51 superplasticizer was used. Its composition is based on polycarboxylic ether. This superplasticizer conformed to the requirements of types A and F of the ASTM C494 standard.

2.1.4. Limestone Powder

The filler powder used was crushed limestone with a fineness of 3100 cm²/gm (100% passing sieve 0.075mm). The particle size of the filler powder according to Ref's (EFNARC, 2000; Esping, 2008) must be less than 0.125mm to be most beneficial. The chemical composition of the limestone powder is shown in Table 1.

2.1.5. Steel Reinforcement

In this study the reinforcement in concrete slab used is deformed bar #6mm. The material properties are obtained from the tests for steel reinforcements. The reinforcing steel bars had an average yield strength of 433MPa and average ultimate strength of 471MPa.

2.1.6. Synthetic Fibres

High performance micro polypropylene fibre (Grace Cemfiber) was used. Table 2 shows fibre specification according to manufacture label.

Table 1. Chemical analysis of the limestone powder.

Oxide	Content %
CaO	56.10
SiO ₂	1.38
Fe ₂ O ₃	0.12
Al ₂ O ₃	0.72
MgO	0.13
SO ₃	0.21
L.O.I (loss On Ignition)	40.56

Table 2. Specification of polypropylene fibres.

Fibre Length	Diameter	Specific Gravity	Surface Area	Constituents
12 mm	18micron	910kg/m ³	244m ² /kg	C ₃ H ₆

2.2. Mix Proportioning Concrete

Mix proportioning of SCC must satisfy the criteria on filling ability, flowability, passability and segregation resistance. The mix design method used in the present study is according to EFNARC, 2002. Numerous trial mixes were prepared to obtain both the fresh concrete properties as well as the target concrete compressive strength. On the other hand, corresponding CC mixes were designed according to British mix proportioning method given in BS 5328. The details of the SCC and CC mixes are shown in Table 3. The main purpose of choosing these mixes is to give the same concrete grade.

Table 3. Details of concrete mixes.

Mix	W/C* ratio	Water kg/m ³	Cement kg/m ³	Limestone kg/m ³	Sand kg/m ³	Gravel kg/m ³	SP** kg/m ³
SCC	0.74	185	250	250	739	870	2
CC	0.70	222	317	-	720	1136	-

W/C*: Water / Cement ratio. SP**: Superplasticizer.

2.3. Testing of Fresh SCC

Fresh concrete testing is of serious importance for the production of SCC. The main characteristics of SCC are the properties in the fresh state. Production of SCC is focused on its ability to flow under its own weight without vibration and the ability to obtain the homogeneity without segregation of aggregate. The slump flow, V-funnel and L-box are used for assessment of fresh properties of SCC in this study. The tests results of the fresh properties of the SCC mix are shown in Table 4.

Table 4. Fresh properties of SCC mixes.

Mix	Slump Flow (mm)	T _{500mm} (sec)	V-Funnel		L-Box		
			T _v (sec)	T _{v5} (sec)	Blocking Ratio	T20 (sec)	T40 (sec)
SCC	742	1.50	5.97	7.28	0.90	1.18	2.01
Criteria	500-800	< 2	< 6	< T _v +3	≥ 0.80	1±0.5	2±0.5

2.4. Testing of Mechanical Properties of Concrete

2.4.1. Compressive Strength Test

Two types of specimen shapes were tested to determine the concrete compressive strength. The concrete compressive strength was determined in accordance to ASTM C39 and BS1881. These types of specimens investigated were:

1. 150x300mm. cylinders.
2. 150x150x150mm. cubes.

The concrete compressive strength of each concrete mix, represents the average of three specimens, are tabulated in Table 5. The concrete specimens were tested at age 28 days of water curing.

2.4.2. Splitting Tensile Strength Test

Splitting tensile strength tests were conducted in accordance to ASTM C496 on cylinder of 150x300mm size. The splitting tensile strength of each mix is shown in Table 5 which represents the average of three specimens at the age of 28 days of water curing.

2.4.3. Static Modulus of Elasticity

The modulus of elasticity was determined according to ASTM C469-02. The modulus of elasticity of each mix was the average of three (150x300mm) cylinder specimens, tested at age 28 days of water curing and tabulated in Table 5.

Table 5. Mechanical properties of concrete.

Mix	Fibre %	f _{cu} (MPa)	f _c (MPa)	f _t (MPa)	E _c (GPa)
	0	28.6	24.4	2.41	25
CC	0.07	29.3	25	2.45	25.4
	0.14	28.8	24.6	2.45	25.7

	0	29.5	25.5	2.71	21
SCC	0.07	29.7	25.7	2.76	22.3
	0.14	30.2	26.1	2.79	22.5

3. Slab Test Setup and Loading Procedure

The slabs were simply supported for all sides and tested under uniform load condition. A hydraulic jack was used to gradually apply the concentrated load at mid of the sand bag (the sand bag putting over the slab and cover all surface area of slab) until slab failure. The sand bag has a suitable thickness to distribute the concentrated load as uniform load. Three dial gauges were installed directly under the mid and quarters span to measure the deflection.

4. Experimental Load Deflection Response and Strength Characteristics

The main experimental results for tested slabs are reported in Table 6. Ultimate capacity of two way reinforced concrete slabs was determined using the design approach proposed by ACI318M-08. The Figure 2 shows the experimental load-deflection curves for the CC slabs that have different values of fibres. It is possible to evidence the relevant difference between curves corresponding to the fibre percentage. The deflections of the 0.07% V_f is higher than that of slab without fibres, while the deflection of the slab having 0.14% V_f is the lowest. Also the Figure 3 explains the effect of fibres on SCC which is similar to CC behaviour. Figures 4 to 6, explain the difference between SCC and CC slabs with the same percentage of fibres.

Table 6. Experimental ultimate load and mode failure

Slabs	Ultimate Load P_u (kN)	Failure Mode
CC	72	Shear
CC 0.07% V_f	78	Shear
CC 0.14% V_f	82	Shear
SCC	95	Concrete Crushing
SCC 0.07% V_f	99	Concrete Crushing
SCC 0.14% V_f	102	Yielding Steel
ACI318M-08	71	Shear failure
ACI318M-08	90	Flexural failure



Plate 2. Top failure surface of SCC slab without fibres.



Plate 3. Top failure surface of SCC slab with 0.07% fibres.



Plate 4. Bottom failure surface of SCC slab with 0.14% fibres.



Plate 5. Bottom failure surface of CC slab without fibres.

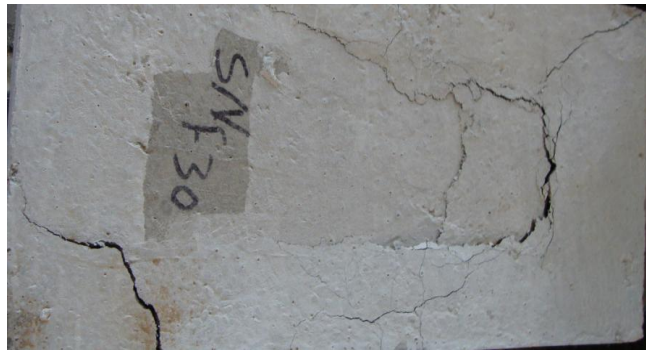


Plate 6. Top failure surface of CC slab with 0.07% fibres.



Plate 7. Bottom failure surface of CC slab with 0.14% fibres.

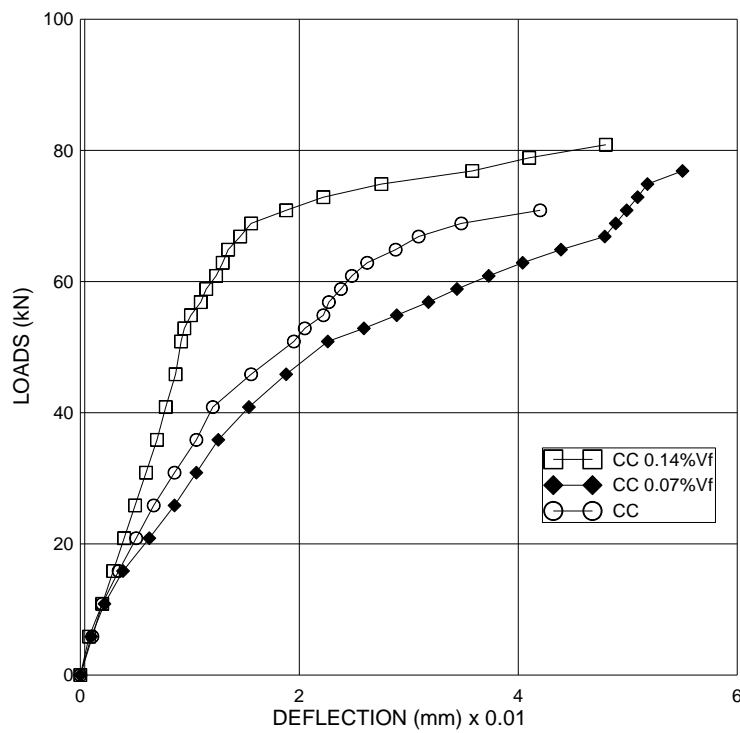


Figure 2. Experimental load midspan deflection response for the CC.

5. Modes of Failure

For a two way slab simply supported on all four sides and subjected to a uniform load, failures are generally due to combination of the two failure modes with the least ultimate load governing the failure of the slab. Usually bending failure cracks are the first to develop underneath the slabs as applied loading is gradually increased and the concrete tensile strength is exceeded. This is because concrete is weak in tension. Typical crack patterns observed underneath the slabs are illustrated in Plates 2 to 7. Collapse may therefore occur either through flexural failure resulting from the crushing of concrete and/ or fracture of the tension steel bars, or shear. The final failure mode however depends on the concrete type (SCC or CC) and the amount of synthetic fibres. It was observed from the tests that SCC gives good resistance to the shear than CC and the addition of synthetic fibres also increase the strength of two way slab for both flexural and shear failure.

6. Discussion of Test Results

The compressive, splitting tensile strength and the modulus of elasticity of CC and SCC was found to be stay without any improvement by the addition of synthetic fibres as listed in Table 5. From the load-deflection curves, it has been noted that when synthetic fibres are added, energy absorption capacity increases for both CC and SCC as shown in Figures 2 and 3. In the case of CC the ultimate strength is enhanced by about 14% and 8% for 0.14% and 0.07% of volume fraction of fibres respectively as listed in Table 6. In SCC the ultimate strength is enhanced by about 7% and 4% for 0.14% and 0.07% of volume fraction of fibres respectively as listed in Table 6. For the same percentage of fibres the ultimate strength of SCC is larger than of CC by about 32%, 28% and 24% for 0%, 0.07% and 0.14% of volume fraction of fibres respectively.

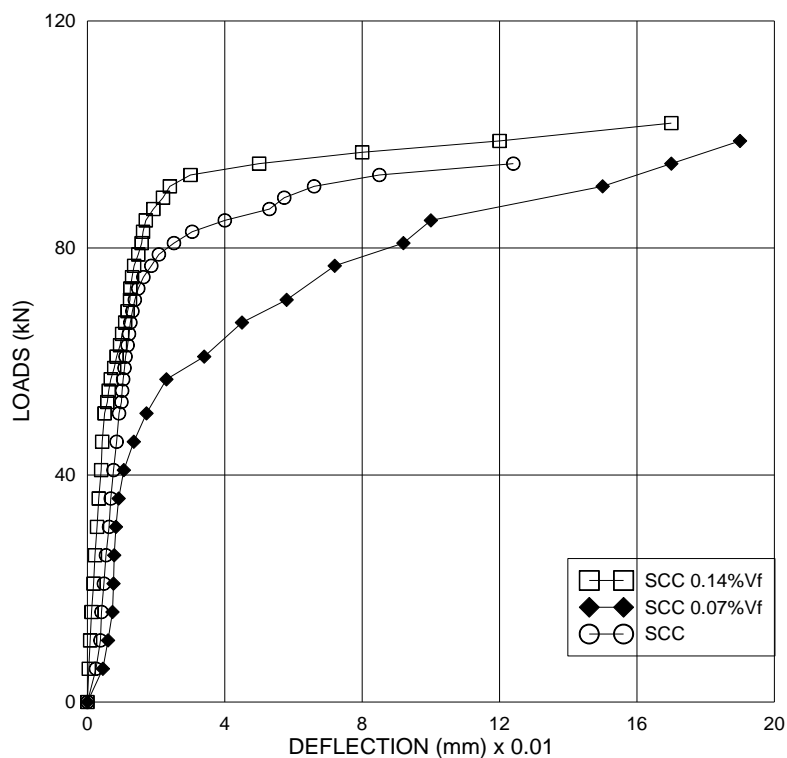


Figure 3. Experimental load midspan deflection response for the SCC.

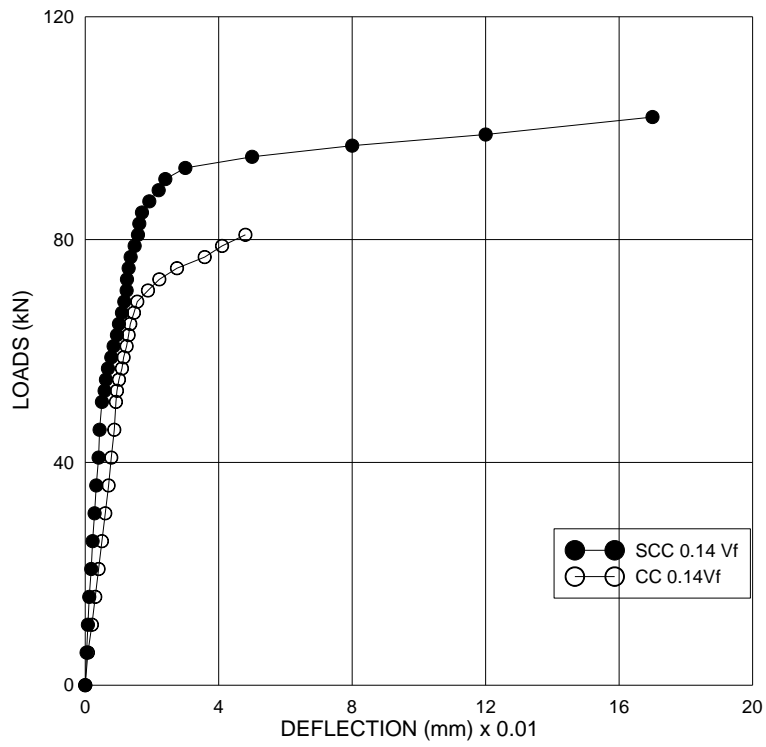


Figure 4. Experimental load midspan deflection response for slabs with 0.14% Vf fibres.

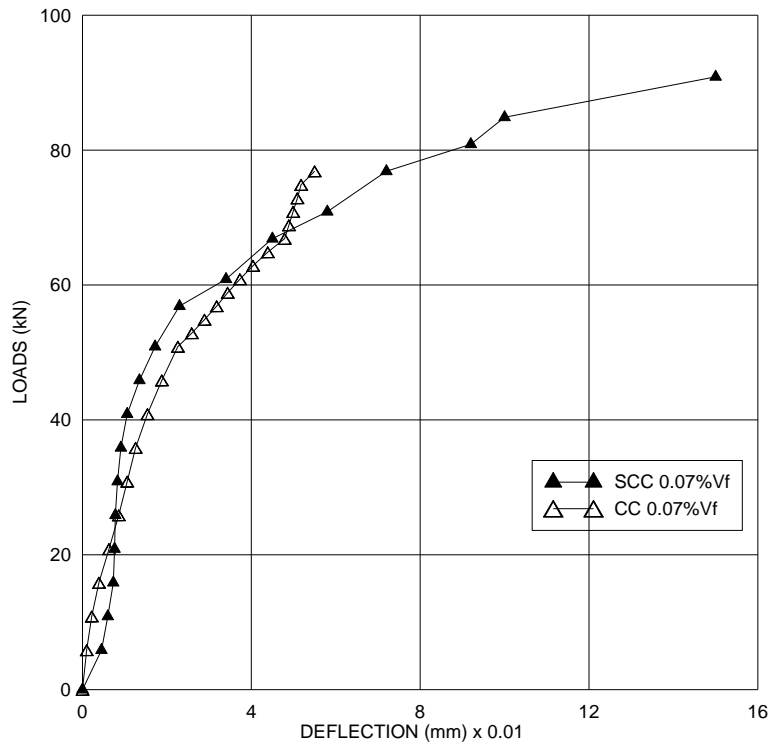


Figure 5. Experimental load midspan deflection response for slab with 0.07% Vf fibres.

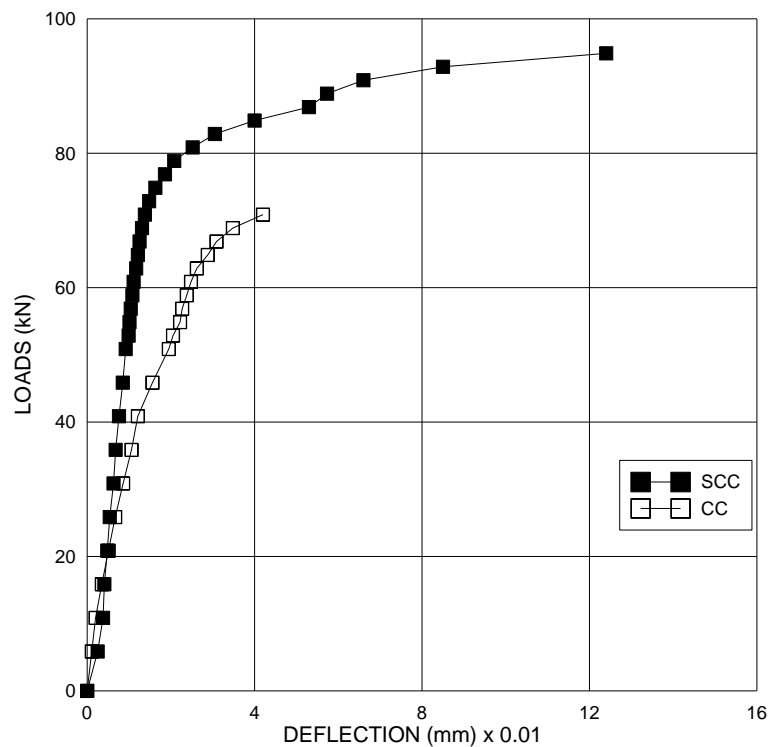


Figure 6. Experimental load midspan deflection response without fibres.

7. Conclusion

A two-dimensional Euler-Bernoulli flexible beam undergoing rigid-body motions is modelled. The equations of motion are obtained using the extended Hamilton principle. An exact solution for the natural frequencies is obtained. The model can be extended to a three-dimensional beam with variable cross section.

Based on the results of this experimental investigation, the following conclusions are drawn:

For the same concrete grade and the same size aggregate, self-compacting concrete with limestone filling gives shear strength larger than conventional concrete. The ultimate load carrying capacity of the two way slabs, for both conventional and self-compacting concrete, increased by adding synthetic fibres. The stiffness has also increased gradually both in conventional as well as in self-compacting concrete due to the addition of fibres.

References

- ACI Committee 318, 2008, "Building code requirements for structural concrete (ACI 318M-08) and commentary (ACI 318RM-08)," *American Concrete Institute*, Farmington Hills, MI, 473.
- Altoubat, S., Yazdanbakhsh, A., and Rieder K. A., 2009, "Shear behavior of macro synthetic fibre reinforced concrete beams without stirrups," *ACI Materials Journal* **106**(4), 381-389.
- EFNARC, 2002, "Specification and Guidelines for Self Compacting Concrete," *European federation for specialist construction chemicals and concrete systems*, Norfolk, UK.
- Esping, O., 2008, "Effect of limestone filler BET(H₂O) area on the fresh and hardened properties of self-compacting concrete," *Cement and Concrete Research* **38**, 938-944.
- Hassan, A. A. A., Hossain, K. M. A., and Lachmi, M., 2010, "Strength, cracking and deflection performance of large scale self-consolidating concrete beams subjected to shear failure," *Engineering Structures* **32**, 1262-1271.
- Khayat, K. H., Manai, K., and Trudel A., 1997, "In situ mechanical properties of wall elements casting using self-consolidating concrete," *ACI Materials Journal* **94**(6), 492-500.
- Lachmi, M., Hossain, K. M. A., Lambros, V., Nkinamubanzi, P. C., and Bouzoubaa, N., 2004, "Self compacting concrete incorporating new viscosity modifying admixtures," *Cement Concrete Research* **24**(6), 917-926.
- Lachmi, M., Hossain, K. M. A., and Lambros, V., 2005, "Shear resistance of self-consolidating concrete beams- experimental investigations," *Canadian Journal of Civil Engineering* **32**(6), 1103-1113.
- Pereira, E. B., Barros, J. A. O., Ribeiro, A. F., and Camões, A. F. F. L., 2004, "Post-cracking behavior of self-compacting steel fibre

- reinforced concrete," *6th International RILEM Symposium on fibre reinforced concrete - BEFIB 2*, 1371-1380.
- Roesler, J. R., Lange, D. A., Altoubat, S. A., Rieder K. A., and Ulreich, G.R., 2004, "Fracture of plain fibre reinforced concrete slabs under monotonic loading," *ASCE Journal of Materials in Civil Engineering* **16**(5), 452-460.
- Sonebi, M. and Khayat K. H., 1999, "Effect of water velocity on performance of underwater self-consolidating concrete," *ACI Materials Journal* **96**(5), 519-528.
- Wang, H. and Belarbi A., 2005, "Flexural behavior of fibre reinforced concrete beams reinforced with FRP rebars," *7th International Symposium on Fibre-Reinforced (FRP) Polymer Reinforcement for Concrete Structures, ACI Symposium Publication*, SP230-51, 895-914.