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# INVESTIGATION OF FLEXURAL BEHAVIOR OF REINFORCED CONCRETE BEAMS PRODUCED WITH SELF COMPACTING AND NORMAL CONCRETE

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**Keywords**
*Reinforced Concrete Beams, Self-Compacting Concrete, Experimental Study, Damage Mechanics.*

**Abstract**

In the construction industry, which is constantly evolving and open to new technologies, concrete has been used to build constructions and has great importance, but unless enough vibration application during casting process, occur gaps between the concrete components, therefore the physical and mechanical properties of concrete cannot be forecasted accurately. Self-compacting concrete does not require vibration or compaction, it saves workmanship and time, and has high performance. Because of less workmanship and shorter production time, the self-compacting concretes offer the possibility of making the construction more economical. In this study, the flexural behavior of the reinforced concrete beams produced with self-compacting and normal concrete were investigated in terms of damage mechanics. Flexural behavior, shear capacity, energy absorption capacity and fracture type of both concrete types was investigated and results were compared. Variables of the samples are the ratio of the stirrup, and the concrete type. Totally 8 pieces of 1/2 scale beams used in this study. The specimens tested with 4-point bending test. When all the results were examined, it was observed that the beams produced with self-compacting concrete consumed more energy.

# KENDİLİĞİNDEN YERLEŞEN VE NORMAL BETON İLE ÜRETİLMİŞ BETONARME KİRİŞLERİN EĞİLME DAVRANIŞININ İNCELENMESİ

**Anahtar Kelimeler**
*Betonarme Kiriş, Kendiliğinden Yerleşen Beton, Deneysel Çalışma, Hasar Mekaniği.*

**Öz**

Sürekli gelişen ve yeni teknolojilere açık olan inşaat endüstrisinde beton, inşaatlar için kullanılmıştır ve büyük önem taşımaktadır, fakat döküm işlemi sırasında yeterli titreşim uygulaması yapılmazsa, beton bileşenler arasında boşluklar oluşur, bu nedenle betonun fiziksel ve mekanik özellikleri doğru bir şekilde tahmin edilemez. Kendiliğinden yerleşen beton, titreşim veya sıkıştırma işlemi gerektirmez, işçilik ve zaman tasarrufu sağlar ve yüksek performansa sahiptir. Daha az işçilik ve daha kısa döküm süresi nedeniyle, kendiliğinden yerleşen betonlar inşaatı daha ekonomik hale getirme imkanı sunar. Bu çalışmada, kendiliğinden yerleşen ve normal beton ile üretilmiş betonarme kirişlerin eğilme davranışları hasar mekaniği açısından incelenmiştir. Her iki beton türünde eğilme davranışı, kayma kapasitesi, enerji yutma kapasitesi ve kırılma tipi araştırılmış ve sonuçlar karşılaştırılmıştır. Numunelerin değişkenleri etriye aralığı ve beton tipidir. Bu çalışmada toplam 8 adet 1/2 ölçekli kiriş kullanılmıştır. Numuneler 4 noktalı eğilme düzeneği ile test edilmiştir. Tüm sonuçlar incelendiğinde, kendiliğinden yerleşen betonla üretilen kirişlerin daha fazla enerji tükettiği gözlenmiştir.

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## 1. Introduction

Self-compacting concretes (SCC) are defined as concrete which has the ability to move into the mold with its own weight without the need for any external effect (vibration etc.) and to pass through between steel rebars without decomposition. The SCC were first developed in Japan in the late 1980s to produce underwater concrete applications. The first presentation on SCC was made by Ozawa in 1989 at the East Asia and Pacific Conference on Structural Engineering. The same presentation was held in 1992 at the CANMET & ACI International Conference in Istanbul. This has accelerated the expansion of SCC into the world. After the ACI workshop in Bangkok in 1994, SCC attracted the attention of engineers and researchers, and became widespread in USA and Canada with the ACI Autumn Congress held in New Orleans in 1996. As a result, in the last years of the 20th century it became widespread all over the world and the researches on SCC intensified (Okamura ve Ouchi, 1999; Topçu vd., 2008).

There are many experimental and theoretical researches in the literature about self-compacting concrete. However, the researchers used only concrete samples instead of a reinforced concrete system. Therefore, the effect of the physical and mechanical differences of the self-compacting concrete on the reinforced concrete systems used in buildings cannot be fully understood. In this study, the differences between self-compacting concrete and normal concrete in reinforced concrete beams were investigate (Kumar ve Roy, 2018; Altın vd., 2006).

Beams, being an important part of structure support system, transfer loads from structural elements like floor and loads directly coming upon them to columns. Fracture mechanism that may occur on beams against loads affecting structures is quite important in terms of building behaviour. That’s why, beam elements should be tested under various loads. Many studies have been made about beams in literature. Beam behavior under various loads has been tried to be identified (Kamanlı, 1999; Kamanlı and Ünal, 2016; Ünal and Kamanlı, 2016; Spadea et al., 2015; Queshta et al., 2015, Ünal et al., 2018; Ahmad et al., 2017; Jindal et al., 2019; Kamal et al., 2018; Mahmod et al., 2018; Niewiadomski et al., 2018; Pajak, 2016; Pajak and Ponikiewski, 2017; Avcar and Mohammed, 2017; Avcar, 2010)

4 pieces of 1/2 scale specimens were tested to be able to identify real beam behavior within the scope of this study. Test elements were tested on 4-point loading mechanism. Under the experimental studies, one test element without stirrup, one with ϕ6/200 mm stirrup, one with ϕ6/100 mm stirrup, and one with ϕ6/50 mm stirrup were tested to research about the stirrup effect on beams. Load-displacement graphs about test elements tested were drawn and interpreted. Interpretations were made about beam behavior by examining fractures occurring during tests.

## 2. Material and Method

Within the scope of this study, four 1/2 scale beam specimens were tested on 4-point loading mechanism. Experimental studies were conducted in Konya Technical University Earthquake Laboratory. The loading mechanism designed is shown in Fig. 1. Loading is done with the help of hydraulic cylinder fixed to the steel profiles. A load cell was put at the end of hydraulic cylinder in order to identify loads given to the beam. Load cell was fixed to a loading beam made of steel profiles. Loading points were identified by putting miller on specific points of the beam. The length of the loading point/effective depth ratio was considered as (a/d)=3 while identifying loading points.

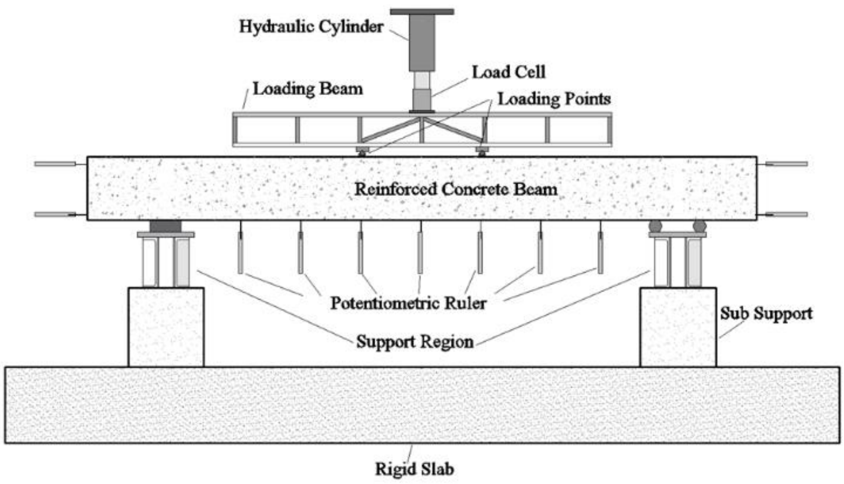



**Figure 1.** Test Setup

Test elements were produced in the same size and properties. The differences between them are the stirrup ratio and concrete type. Test elements were produced 2500 mm in length. The distance between beam support points was 2000 mm. Beam cross-section was designed as 125-250 mm. 3ϕ8 mm longitudinal reinforcement was used on beams.

The concretes class was chosen as C60 and reinforcement class as S420. Compressive strength of concretes and properties of beam samples are shown in Table 1 and Table 2.

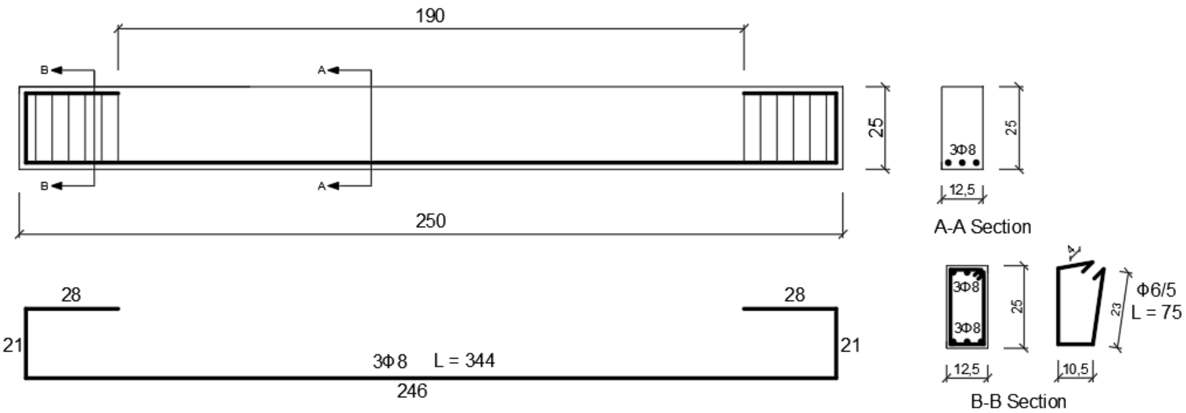
**Table 1.** Compressive strength of concretes

| Concrete Samples | | | | |
|---|---|---|---|---|
| No | Normal | | Self Compacting | |
| | Cube Strength (Mpa) | Average Cube Strength (MPa) | Cube Strength (MPa) | Average Cube Strength (MPa) |
| 1 | 77.40 | 73.11 (C60/75) | 74.40 | 73.41 (C60/75) |
| 2 | 75.06 | | 74.92 | |
| 3 | 66.87 | | 70.90 | |

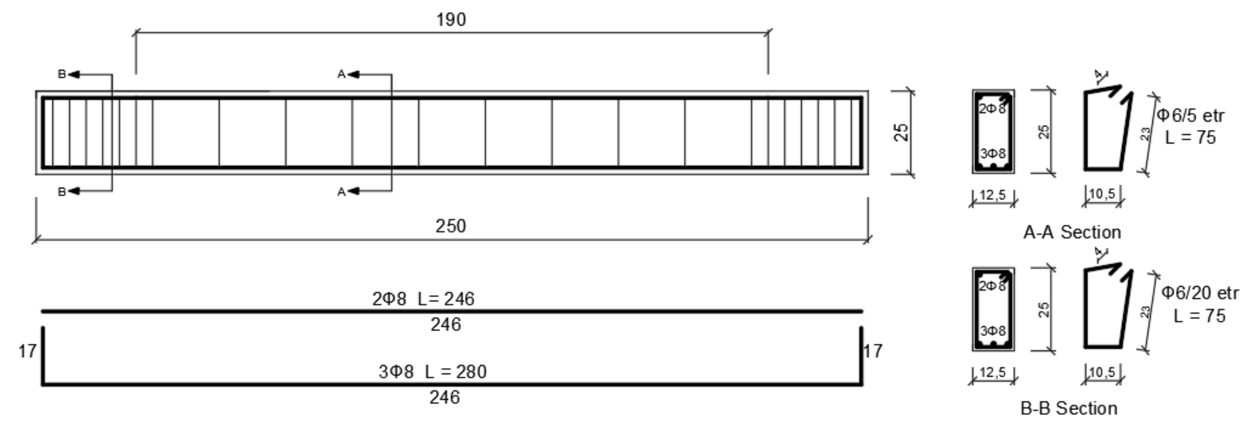
**Table 2.** Properties of beam samples

| Beam No | Concrete Type | Stirrup Spacing |
|---|---|---|
| B-1 | Normal | - |
| B-2 | Normal | 200 mm |
| B-3 | Normal | 100 mm |
| B-4 | Normal | 50 mm |
| B-5 | Self Compacting | - |
| B-6 | Self Compacting | 200 mm |
| B-7 | Self Compacting | 100 mm |
| B-8 | Self Compacting | 50 mm |

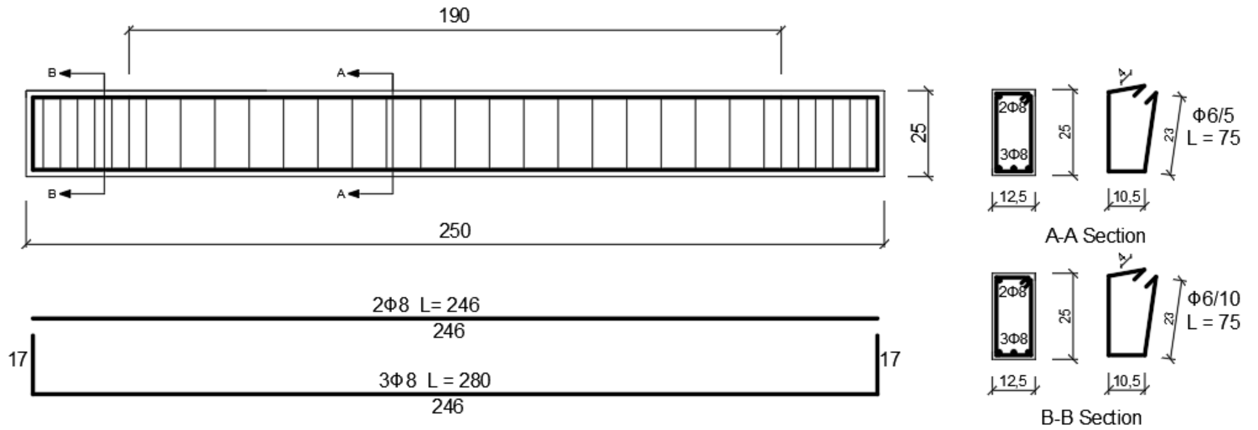
Size and reinforcement properties of test elements are shown in Fig. 2.



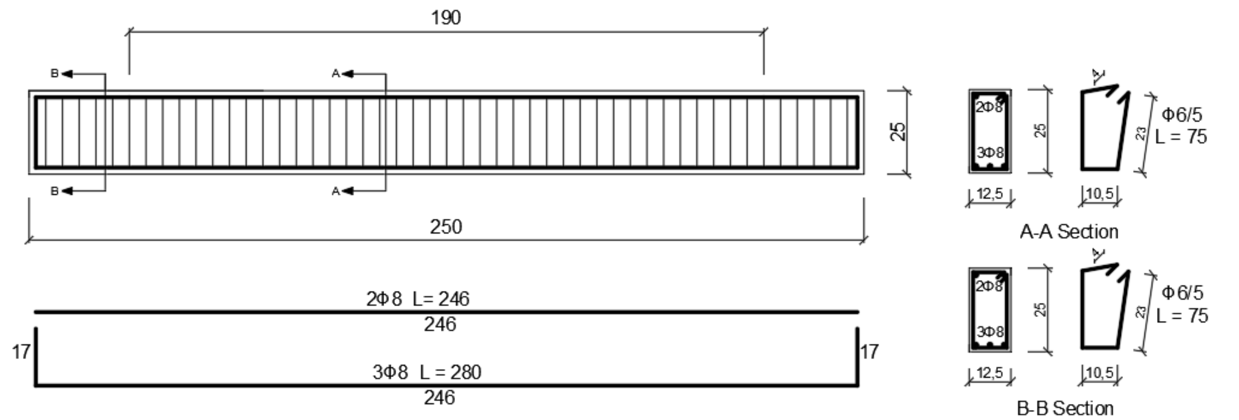

(a)




(b)




(c)




(d)

**Figure 2.** Reinforcement rebar detailing (all lengths are cm)
(a): without stirrup, (b): 200 mm spacing, (c): 100 mm spacing, (d): 50 mm spacing

## 3. Results

Experimental studies within the scope of this study were made in Konya Technical University Earthquake Laboratory. Tests were subjected to 4 point bending test. Tests started with load control and continued with displacement control after nominal current value. 5 kN load increments and 5 mm displacement increments were experimented in the tests.

The first crack in the B-1 test element occurred at about 25 kN load value and in the B-5 test element occurred at about 17 kN load. While yield in the B-1 test element occurred at 45 kN load value and 10.00 mm displacement value, in the B-5 test element occurred at 42 kN load and 13.76 mm. Maximum load was measured as 50 kN for B-1 test element and 45.8 kN for B-5. Mid-point displacement at maximum load was measured as 45.37 mm in the B-1, 81.39 mm in the B-5. Shear fracture occurred after maximum load and the amount of load was decreased suddenly. Load-displacement graph of the test element is shown in Fig. 3. Fractures on the test elements that occurred at the end of the test are shown in Fig. 4 and Fig. 5.

The first crack in the B-2 test element occurred at about 20 kN load value and in the B-6 occurred at about 16 kN. While yield in the B-2 test element occurred at 42 kN load value and 10.28 mm displacement value, in the B-6 occurred at 40 kN load and 13.14mm. Maximum load was measured as 51.5 kN for B-2 test element and 50.0 kN for B-6. Mid-point displacement at maximum load was measured as 85.65 mm in the B-2 and 120.0 in the B-6. The test was ended after reaching the maximum load because of reaching the maximum capacity of the loading mechanism. Load-displacement graph of the test element is shown in Fig. 6. Fractures on the test element that occurred at the end of the test are shown in Fig. 7 and Fig. 8.

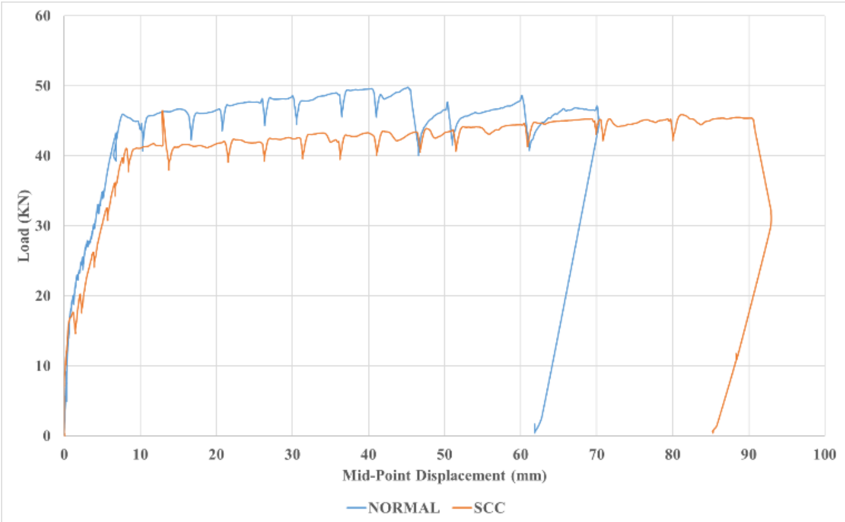



**Figure 3.** Load-Displacement Curve (B-1 and B-5)

**Figure 4.** Fractures in specimen (B-1)

**Figure 5.** Fractures in specimen (B-5)

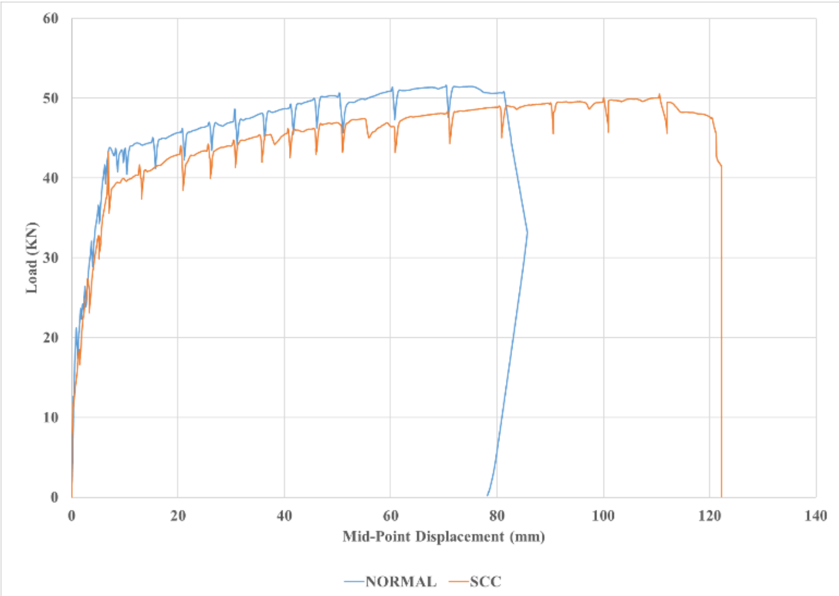



**Figure 6.** Load- Displacement Curve (B-2 and B-6)

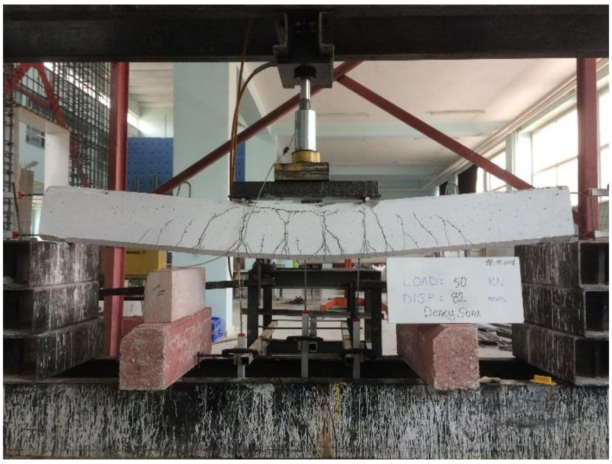


**Figure 7.** Fractures in specimen (B-2)

**Figure 8.** Fractures in specimen (B-6)

The first crack in the B-3 test element occurred at about 25 kN load value and in the B-7 occurred at about 17 kN. While yield in the B-4 test element occurred at 46 kN load value and 12.00 mm displacement value, it occurred in the B-6 at 42 kN load and 13.00 mm. Maximum load was measured as 53.17 kN for B-3 test element, and 46.82 for the B-7. Mid-point displacement at maximum load was measured as 121.8 mm in the B-3 and 102.58 in the B-8. The test was ended after reaching the maximum load because of reaching the maximum capacity of the loading mechanism. Load-displacement graph of the test element is shown in Fig. 9. Fractures on the test element that occurred at the end of the test are shown in Fig. 10 and Fig. 11.

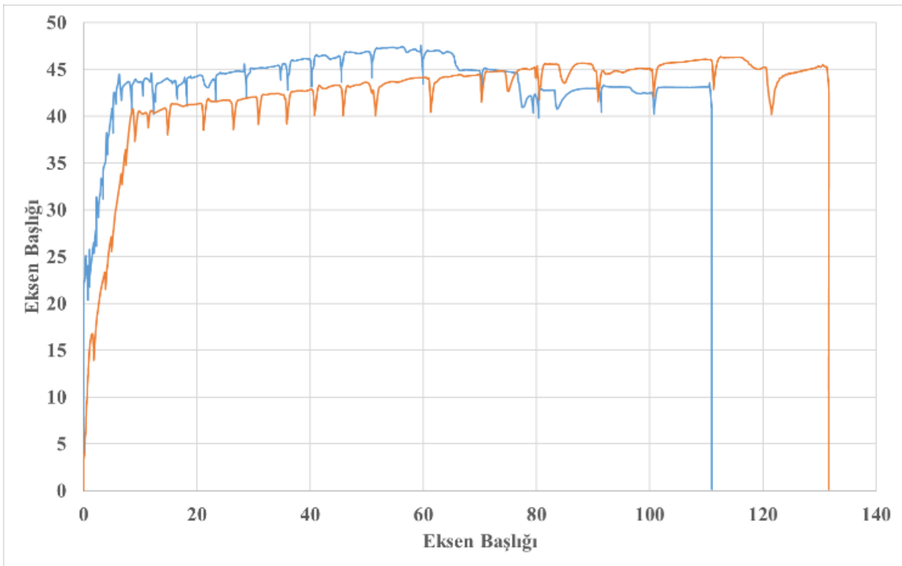



**Figure 9.** Load- Displacement Curve (B-3 and B-7)

**Figure 10.** Fractures in specimen (B-3)

**Figure 11.** Fractures in specimen (B-7)

The first crack in the B-4 test element occurred at about 25 kN load value and in the B-6 occurred at about 17 kN. While yield in the B-4 test element occurred at 46 kN load value and 12.00 mm displacement value, it occurred in the B-6 at 42 kN load and 13.00 mm. Maximum load was measured as 53.17 kN for B-4 test element, and 46.82 for the B-6. Mid-point displacement at maximum load was measured as 121.8 mm in the B-4 and 102.58 in the B-8. The test was ended after reaching the maximum load because of reaching the maximum capacity of the loading mechanism. Load-displacement graph of the test element is shown in Fig. 12. Fractures on the test element that occurred at the end of the test are shown in Fig. 13 and Fig. 14.

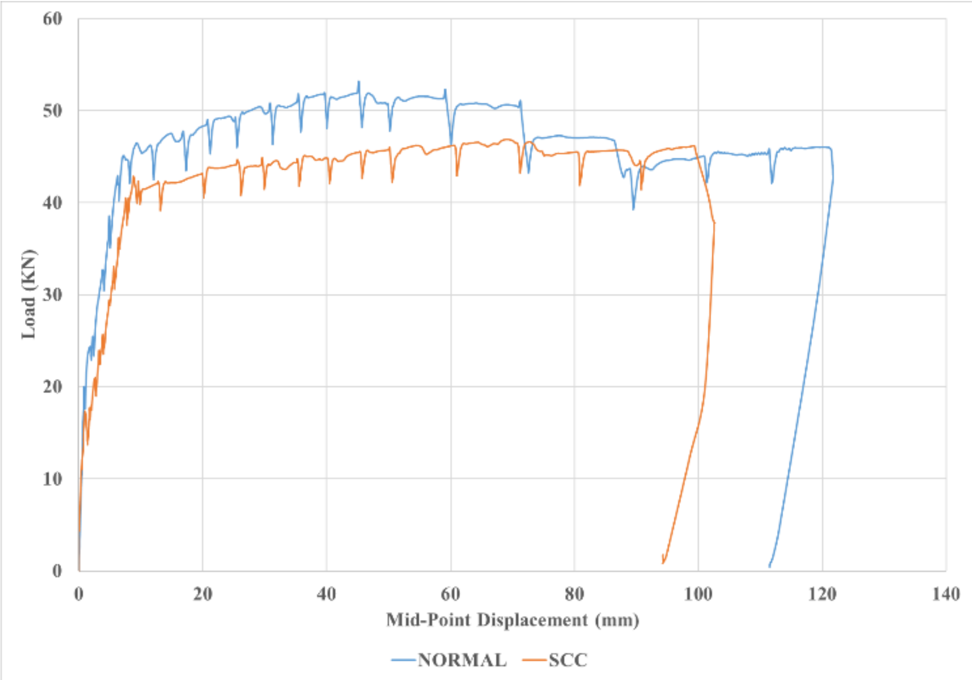



**Figure 12.** Load- Displacement Curve (B-4 and B-8)


**Figure 13.** Fractures in specimen (B-4)

**Figure 14.** Fractures in specimen (B-8)

## 4. Discussion

The purpose of this study was to examine the concrete type effect on 1/2 scale reinforced concrete beams. For this purpose, four test elements produced and tested on 4 point beam flexural mechanism.

The first crack value in normal concretes was occurred at higher loads than SCC (Fig. 3-6-9-12). These loads in B-1 is %47 higher than B-5, in B-2 is %33 higher than B-6, in B-3 is %56 higher than B-7 and in B-4 is %41 higher than B-8 test element. These results show that the SCC's tension strength is lower than normal concrete.

Although the yield point load in all normal concretes is higher than SCC, the mid-point displacement values are lower at this time. These results show that the SCC is less rigid than normal concrete.

The energy absorption capacity of all the SCC beams except for B-8 beam is higher than the normal concrete (Fig. 3-6-9-12). These results show that the SCC is more ductile than normal concrete.

## 5. Conclusion

According to the results of this study, self compacting concretes can be used in earthquake resistant building design due to their properties. Because the enough level ductile structural elements more dampers the earthquake force. SCC is more useful than normal concrete due to their easy placement and technical advantages.

The load values in the first crack formed in the beams produced with SCC were lower than those produced with NC.

Tension reinforcement in all samples reached yield point at an average load of 42 kN. Displacement values at the same point gave similar results.

The maximum load value of NC beams is higher than that of SCC. It is concluded that this situation occurs because the amount of coarse aggregate in NC-produced beams is considerably higher than the amount of coarse aggregate in SCC-produced beams.

The beams produced with SCC consumed much more energy than those produced with NC. The ability to consume energy, which is an important feature in earthquake resistant structure design, is greater in SCC.

In general, as the stirrup spacing decreases, the beams make more displacement and consequently the energy consumed increases. Therefore, it is very important for the behavior of the beams to have a suitable range of stirrups.

In this study, the behavioral properties of SCC reinforced concrete beams generated similar results with NC produced concrete beams. Furthermore, SCC is more advantageous than NC structures due to its advantages such as fast production, easy placement, no gaps, smooth surface structure etc.

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## Conflict of Interest

No conflict of interest was declared by the authors.

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