Evaluation of stress block parameters for self compacting rubberised concrete composites

Discussion by M.C Nataraja

Reply by N. Ganesan, Bharati Raj. J. and A.P. Shashikala

Dear Sir,

This has reference to the paper titled 'Evaluation of stress block parameters for self compacting rubberised concrete composites', by N. Ganesan, Bharati Raj. J. and A.P. Shashikala, published in ICJ February 2015 issue (Vol 89, No. 2, pp. 24-38).

The paper mainly deals with the evaluation of stress-block parameters for self compacting concrete (SCC), self compacting rubberized concrete (SCRC) and steel fiber reinforced self compacting rubberized concrete (SFRSCRC). Authors have thoroughly investigated stress-strain characteristics of these concrete partially replacing 5, 10 and 15% of fine aggregate in SCC with shredded rubber for varying grades of concrete namely M20, M30, M40 and M50. The effect of adding different volume fractions of steel fibers (0.25, 0.5 and 0.75%) on the stress-strain behavior of SCRC has also been explored. Testing sufficient number of cylinders, stress-strain model for SCC, SCRC and SFRSCRC is developed. Based on these models, the stress-block parameters are evaluated. The authors claim that these models can be used to determine the flexural strength of members made using the above composites.

The authors have executed the research work meticulously and based on the thorough evaluation of the generated results, stress block parameters are proposed. The sincere effort of authors should be appreciated and the discusser congratulates the authors for suggesting the stress block parameters which will facilitate in evaluating the MOR of SCC reinforced beams.

The discusser seeks some clarification from the authors for better understanding of the behavior of SCC and the effect of fibers on SCC.

1. Due to the addition of shredded rubber, the strength of concrete has decreased due to obvious reasons reported and the strain corresponding to peak stress should increase due to softening effect of the matrix. This is observed to some extent for higher percent of replacement (15%) of rubber. For 5% replacement, the increase in strain should be slightly more compared to control concrete without rubber. However, in this case, the strain corresponding to peak is slightly less compared to control concrete. What is it due to? The discusser is of the opinion that this strain should have been still higher as the matrix is softer. Is this trend observed due to the type of strain measuring principle adopted in this work?

2. In case of high strength normal concrete, the strain corresponding to peak increases marginally as reported in literature. Here as the strength increase from M20-M50, for SCC (SCC20 to SCC50, R0), the peak strain has decreased continuously. What is it due to?

3. Due to addition of 5 to 15 % of rubber the peak strain has changed from 0.002 to 0.00208. It is about 4%. This again appears to be slightly less considering the amount of fine aggregates being replaced by rubber. Please give your opinion.

4. For combined fiber and rubber case, though the compressive strength is more or less comparable to that of control concrete, the peak strain should have been substantially higher due to softness of matrix due to rubber and due to continuous straining of fibers at the peak load. However the authors have observed only 5-8% increase in peak strain. The discusser is of the opinion that this increase should have been much higher due to combined effect (say 0.0025 to 0.003 as noticed by many other researchers).

5. If the authors had reported the modulus of elasticity of SCC and other concretes considered, it would have thrown some more light on the behavior of these concretes from the point of their serviceability requirements. Authors have mentioned that moment of resistance of beam can be determined by using the stress block parameters derived. This is ok from the point of view of limit state of collapse. However from the point of view of limit state of serviceability, especially for deflection check, information about modulus of elasticity, creep and shrinkage strain of SCC and the other concretes discussed is also necessary. If authors provide or generate this information in due course of time, then complete analysis and design of beam for these concrete can be taken up. According to the discusser and based on the literature, E for SCC is rather less and the creep and shrinkage strains are higher. The limiting values of these strains for analysis are must.

6. Let us analyse a simply supported singly reinforced RC beam for the following data:

Example 1

b=200mm, d=400mm, A_{st}= 2 - #20 = (2x314) = 628 mm^2, f_{ck}= 20 N/mm^2, f_y= 415 N/mm^2

For conventional concrete:

$$x_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} b} = \frac{0.87\ x\ 415\ x\ 628}{0.36\ x\ 20x\ 200} = 156\ mm$$

$$\frac{x_u}{d} = \frac{156}{400} = 0.39\ < 0.48, \qquad URS$$

$$M_u = 0.87 f_y A_{st}[d - \frac{f_y A_{st}}{b\ f_{ck}}]$$

$= 76 \times 10^6$ N mm = 76 kN m

$$M_{u,lim} = 0.36 f_{ck} b x_{u,lim}(d - 0.42 x_{u,lim})$$

$= 0.138 f_{ck} b d^2$ =87 kN m

SCC :

$$x_u = \frac{0.87 f_y A_{st}}{\mathbf{0.33} f_{ck} b} = \frac{0.87\ x\ 415\ x\ 628}{0.33\ x\ 20x\ 200} = 171.8\ mm$$

$$\frac{x_u}{d} = \frac{171.8}{400} = 0.43\ > \mathbf{0.37}, \qquad ORS$$

The moment of resistance is limited to

$$M_{u,lim} = \mathbf{0.33} f_{ck} b x_{u,lim}(d - 0.42 x_{u,lim})$$

$$M_{u,lim} = \mathbf{0.33} f_{ck} b * \mathbf{0.37} d(d - 0.42 * \mathbf{0.37} d)$$

$$M_{u,lim} = \mathbf{0.103} f_{ck} b d^2 = 65.92\ kNm$$

Discussion: The MOR of SCC beam is 65.92 kNm which is the limiting MOR of the section. As a result the SCC beam will take lesser load. On the other hand MOR of conventional concrete beam is 76 kNm and the beam is still URS. Switching over form conventional concrete to SCC, the beam loses its strength. Even the limiting moment of resistance of SCC beam is less than that of conventional concrete beam by about 24%, which is a significant reduction.

Example 2

b =200mm, d=400mm, A_{st}= 2 - #16 = (2x201) = 402 mm^2, f_{ck}= 20 N/mm^2, f_y= 415 N/mm^2

For conventional concrete:

100.79 mm

$$x_u = \frac{0.87 f_y A_{st}}{\mathbf{0.33} f_{ck} b} = \frac{0.87\ x\ 415\ x200\ 2}{0.33\ x\ 20x\ 400} = 109.96\ mm$$

$$\frac{x_u}{d} = \frac{100.79}{400} = 0.252 < 0.48, URS$$

$$M_u = 0.87 f_y A_{st}[d - 0.42\, x_u]$$

$$M_u = 0.87 * 415 * 402[400 - 0.42 * 100.79]$$

= 51.91 kN m < $M_{u,\,lim}$

For SCC:

$$x_u = \frac{0.87 f_y A_{st}}{\mathbf{0.33} f_{ck} b} = \frac{0.87\ x\ 415\ x\ 402}{0.33\ x\ 20x\ 200} = 109.96\ mm$$

$$\frac{x_u}{d} = \frac{109.96}{400} = 0.275 \quad < \mathbf{0.37}, URS$$

The moment of resistance is given by

$$M_u = 0.87 f_y A_{st}[d - \ 0.42\, x_u]$$

$$M_u = 0.87 * 415 * 402[400 - \mathbf{0.42} * 109.96] = \ 51.35\ kNm$$

$$< M_{u,lim} = \mathbf{0.103} f_{ck} b d^2 = 65.92\ kNm$$

Discussion: The MOR of both beams is more or less comparable, even thought the stress block parameters are different. Hence the SCC beams can be designed as if it is a conventional concrete beam using IS:456-2000 as long as the beam is more under reinforced. In example 1, MOR of SCC beam is (less) limited as it becomes ORS compared to conventional beam which is still a URS. Check for serviceability limit states such as deflection mainly depends on E (primary deflection) and, creep and shrinkage strains (secondary deflection) which are to be established depending on the constituents of the SCC mix which again vary significantly. These factors also should be addressed in detail.

Remarks: The discusser once again congratulates the authors for publishing these informative and useful results related to SCC to know its moment of resistance.

Dr. M.C. Nataraja, BE, MTech, PhD
Professor, Civil Engineering Department,
Sri Jayachamarajendra College of Engineering,
Mysore 570 006, Karnataka.

THE AUTHORS REPLY

Dear Sir,

The authors would like to appreciate the reader for having gone through the paper meticulously and offered critical comments on the paper. Indeed, such comments will be extremely useful for every one in understanding this topic of research. Our replies are given below for all the six comments.

Reply to comment No. 1

Referring to Figure 4 (b), it may be noted that, infact, the strain at peak stress increases as the percentage replacement of rubber increases. As pointed out by the reader, it is more prominent when the replacement was as high as 15%. However, in the case of 5% and 10% the rate of increase was less. Especially, the increase was very less in the case of 5% replacement. Still, specimen with 5% replacement registered a higher strain of 0.00192 than the specimen without rubber replacement. It may kindly be noted that marked increase may not take place at smaller % of replacement of rubber in the case of heterogeneous materials like cementitious composites.

Reply to comment No. 2

In general, as the strength of concrete increases, the material tends to become more brittle and hence the strain corresponding to peak stress decreases. The reader may kindly refer Chapter 2 of Reinforced Concrete Structures by Park, R and Paulay, T for more details.

Reply to Comment No. 3

Referring to Table No. 4, the reader may kindly note that in the case of M 20 grade concrete, the strain at peak stress varies as 0.00197, 0.002, 0.00205 and 0.00208 for rubber replacements of 0%, 5%,10%, and 15% respectively. In the case of **unconfined concrete** composites, one may not get significant increase in the values of peak strain. Even a smaller percentage increase in strain indicate how ductile the composite is.

Reply to comment No. 4

In the case of steel fibre reinforced concrete, the material softening takes place and the presence of fibres transforms the material to behave in a ductile manner and also introduces higher degree of compressibility under **confined** conditions (Ganesan, N and Ramana Murthy, J.V, ACI Materials Journal, 1990). In the present study, with percentage of rubber replacements viz; 5,10 and 15% and steel fibres having aspect ratio 66 at volume fractions viz; 0.25, 0.5 and 0.75%, the maximum value of peak strain obtained was 0.00217 only. Further studies with different values of aspect ratio and volume fractions of steel fibres may throw more light in the area of SFRSCRC.

Reply to Comment No. 5

The authors fully agree with the reader that further studies are required to generate more details considering the limit state of serviceability in the case of SCC, SCRC and SFRSCRC

Reply to Comment No. 6

In Example 1, MOR of SCC beam is less as it becomes ORS compared to conventional concrete beam which is still a URS. However, it can be noted that by reducing the value of area of reinforcement, the beam becomes URS and as pointed out by the reader, MOR of SCC can be obtained by using IS: 456-2000 and the stress block parameters of SCC. Similarly MOR of SCRC and SFRSCRC beams with different values of parameters considered in this paper need to be computed and compared with conventional concrete beams. Also further detailed studies are required for addressing the check for serviceability criteria.

The authors once again appreciate the reader for his/her interest in the area of SCC, SCRC and SFRSCRC and valuable comments on the paper.

References

1. Reinforced Concrete Structures by R. Park and T.Paulay, John Wiley & Sons, Newyork, 1975, p. 769.
2. Ganesan, N and Ramana Murthy, J.V, "Strength and Behavior of Confined Steel, Fiber Concrete Columns", ACI Materials, Vol. 87, No. 3, May-June, 1990, pp. 221-227.