EFFECT OF MAXIMUM SIZE OF AGGREGATE AND ITS GRADATION ON THE SHEAR CAPACITY OF R.C BEAMS WITHOUT WEB REINFORCEMENT

Qaisar Ali* and Akhtar Naeem Khan*

ABSTRACT

A total number of eighteen reinforced concrete beams without web reinforcement were tested primarily to know the variation of shear capacity of reinforced concrete beams by changing maximum size and gradation of coarse aggregates.

It was observed that shear strength varies much with change in gradation than change in size of aggregate i.e. surface area of aggregates. In fact shear strength increases more with improvement in gradation i.e. gradation which would produce a dense concrete than increase in size of coarse aggregates.

INTRODUCTION

In reinforced concrete beams shear dose not produce failure directly on the vertical plane on which it acts, as one might anticipate. The major effect of shear is to induce tensile stress on diagonal planes oriented at 45° to the plane on which the shear acts. Since concrete has a relatively low tensile strength compared with its compressive strength, over-stress will always be initiated by tension stresses. When these diagonal tension created by moment exceed the tensile strength of the concrete, diagonal cracking develops that can split the beam. Failure mechanism of R.C beams without web reinforcement mainly depends upon their a/d ratio, where 'a' is the shear span and 'd' is the depth of beam. The shear span is the distance from reaction to load for one point or two points load arrangements. For U.D.L a/d is taken as M/Vd. Beams with short shear spans develop inclined cracks and after a redistribution of internal forces are able to carry additional load, in part by arch action. The final failure of such beams will be caused by a bond failure, a splitting failure, or a dowel failure along the tension reinforcement or by crushing of the compression zone over the crack. The latter is referred to as a shear compression failure. In beams with slender shear-span (2.5<a/d<6), failure occurs in one of the two ways.

i) If a/d ratio is relatively high the diagonal crack would rapidly spread to the top of the compression zone, resulting in complete collapse by splitting the beam into two pieces. (ii) If a/d is relatively low, the diagonal crack tends to stop as it reaches the compression zone. With further increase in load, the diagonal crack widens and propagates along the level of the tension reinforcement. The increased load presses down the longitudinal steel and causes the destruction of the bond between the concrete and the steel, usually leading to a splitting of the concrete.

Once the diagonal crack has opened, failure will occur unless the cracked cross section can transfer the applied loads to the supports. Quantitative evidence is now available that for a typical reinforced concrete beam the applied shear force is resisted in the following approximate proportions.

\[ V_c = 20 \text{ to } 40\% \]
\[ V_d = 15 \text{ to } 25\% \]
\[ V_s = 35 \text{ to } 50\% \]

If a beam can develop sufficient additional shear resistance from the above sources, it will not fail when the diagonal crack forms. As the aggregate interlock plays an important role in resisting shear stresses, therefore an attempt to study the effect of size of coarse aggregate or its gradation on shear capacity of R.C beams without web reinforcement Viest for the first time included in his equation the effect of all the three main parameters i.e. longitudi-

* Department of Civil Engineering, NWFP University of Engineering & Technology, Peshawar
nal reinforcement \( \rho \), tensile strength as a function of \( \sqrt{t} \) and \( a/d \). In fact, the present format of ACI equation was first suggested by Viest.

Besides ACI equation, a number of other equations have also been proposed by various researchers for calculating shear capacity of R.C beams without web reinforcement. Though all of them included the effect of aggregate interlock indirectly by including \( v_c \), no one took the effect of maximum size of aggregate.

In 1987, Bazant & Kim analyzed data of various researchers and concluded that ultimate shear stress increases with decrease in \( d/da \) ratio where \( da \) is the maximum size of coarse aggregate. From their results they also concluded that shear capacity of beam increases with increase in maximum size of coarse aggregates.

As the aggregate interlock contributes 33 to 50% of the shear capacity, therefore its effect must be taken in estimating shear capacity of R.C beams without web reinforcement.

Among many equations available for shear capacity of R.C beams without web reinforcement, Bazant’s equation is the only one that considers the effect of maximum size of coarse aggregate as given below.

\[
\begin{align*}
\nu_c &= K \cdot \nu_c, \text{ psi -} \\
K &= 10^{0.125} \left( 1 + d/25da \right)^{0.125} \\
\nu_c &= \rho^{0.125} \left( \sqrt{t} + 3000 \sqrt{p} \cdot (a/d)^{-3} \right), \text{ psi}
\end{align*}
\]

Where \( \nu_c \) is the shear capacity of a R.C beam in term of stresses.

The Bazant and Kim’s equation is the only equation, which considers almost all the factors affecting shear capacity of R.C beams without web reinforcement. Nevertheless two drawbacks can be seen in their equation, which are given below.

1). They used a widely scattered data of various researchers to formulate their equation. 2) They took the effect of maximum size of coarse aggregates in their equation but ignored the effect of gradation. For a given concrete mix the coarse aggregate of maximum size may be present in any proportions like 10%, 20%, 30%, 40% etc of the total weight of coarse aggregates but according to this formula the result will be same for various set of graded concrete.

The objective of this paper is to present the effect of the maximum size of coarse aggregate and its gradation on shear capacity of R.C beams without web reinforcement.

**MATERIAL AND METHODS**

**Methodology:** Two sets of nine Beams were tested for 5/8 inch and 1 inch coarse aggregate using following proportions.

a) 25% maximum size aggregates +75% down than maximum size. b) 50% maximum size aggregates+50% down than maximum size. c) 75% maximum size aggregates + 25% down than maximum size. Three beams were tested for each of the above given proportions. Other parameters for each set of beams were as follows: Beams total depth = 12 inch; Beam width = 6 inch; Shear span to effective depth ratio (a/d) = 3.44. Flexure steel ratio = 0.025 Concrete cylinder strength = 2500psi. (Approx.) Beam length = 7 feet. The size of the beams, proportions of concrete, and \( \rho \), were selected such that the beams do not fail in flexure.

**Materials:** Sand & crush used were taken from the same sources.

The sand was clean and angular but wet, therefore moisture content test on sand was carried out for each batch of concrete and w/c ratio adjusted accordingly. The crush used was free from impurities like clay, organic matter & vegetation.

Sieving and mixing was carried out manually at the quarry site to collect aggregates as given in Tables 1 and 2.

Three beams and nine cylinders were cast each day. All materials were proportioned by weight in 1:2:4 ratio. Constant W/C ratio equal to 0.6 was used for all sets. The moisture content of wet sand was
### Table 1

<table>
<thead>
<tr>
<th></th>
<th>Sample A</th>
<th>Sample B</th>
<th>Sample C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passing 5/8 in,</td>
<td>52.6</td>
<td>22.22</td>
<td>77.27</td>
</tr>
<tr>
<td>retained 1/2 in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passing 3/8 in,</td>
<td>47.40</td>
<td>77.78</td>
<td>22.22</td>
</tr>
<tr>
<td></td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Sample D % weight</th>
<th>Sample E % weight</th>
<th>Sample F % weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passing 1 in,</td>
<td>24</td>
<td>49</td>
<td>65.5</td>
</tr>
<tr>
<td>retained 7/8 in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passing 6/8 in,</td>
<td>20</td>
<td>19.5</td>
<td>20</td>
</tr>
<tr>
<td>retained 1/2 in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passing 5/8 in,</td>
<td>40</td>
<td>25.5</td>
<td>14.54</td>
</tr>
<tr>
<td>retained 1/2 in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passing 3/8 in,</td>
<td>16</td>
<td>6.3</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Three beams and nine cylinders were cast each day. All materials were proportioned by weight in 1:2:4 ratio. Constant W/C ratio equal to 0.6 was used for all sets. The moisture content of wet sand was measured each day and then an effective W/C ratio was used to have same W/C ratio for all sets. Internal vibrator was used for proper compaction of concrete in beams. The average humidity in air during casting was about 50% and temperature was around 40°C. All the beams and cylinders were moist cured for seven days.

Testing and observation: The beams were tested in a 200 KN straining frame. Load was applied incrementally at mid span and cracks were observed for each increment of load and were marked on the beam (Fig 1). The first crack was too narrow to be visible and it was seen at a load higher than the calculated flexural cracking load. With further increase in load, more flexural cracks developed in the beam. These cracks propagated towards load point at an inclination less than 90°. The pattern of cracking was almost same for all the beams. It was observed that these cracks developed within the mid half of shear span before final failure of the beams.

Several flexural cracks formed before first diagonal crack. It was observed that the beams did not fail at initial diagonal cracking load and the beams supported a significant magnitude of load before their final failure occurred. With further increase in load, either one or more diagonal crack formed (Fig 2). Finally, beams collapsed when upward crack extended well into the compression zone. It was observed that the spalling of vertical cover below the longitudinal steel took place in all beams (Fig 3).
Fig. 2- Failure due to diagonal crack

Fig. 3- A close view of the diagonal crack spalling of concrete can be seen

Fig. 4- Sharing variation b/w average ultimates shear stress and all beams types

Fig. 5- Variation b/w average ultimate shear stress and beams A, B & C

The strength of each mix was also calculated by testing their corresponding cylinders. Average values of the shear capacity and compressive strength are shown in Table 3. Graphs showing relation between average

<table>
<thead>
<tr>
<th>BEAM TYPE</th>
<th>f_cv (psi)</th>
<th>V_c (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Experimental</td>
</tr>
<tr>
<td>B(25%5/8&quot;+75%down)</td>
<td>2798</td>
<td>180.2</td>
</tr>
<tr>
<td>A(50%5/8&quot;+50%down)</td>
<td>2410</td>
<td>173.9</td>
</tr>
<tr>
<td>C(75%5/8&quot;+25%down)</td>
<td>1914</td>
<td>155</td>
</tr>
<tr>
<td>D(25%1&quot;+75%down)</td>
<td>2125</td>
<td>180.9</td>
</tr>
<tr>
<td>E(50%1&quot;+50%down)</td>
<td>1900</td>
<td>154.9</td>
</tr>
<tr>
<td>F(75%1&quot;+25%down)</td>
<td>1525</td>
<td>145.4</td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

The ultimate shear strength of each of the eighteen beams was determined and average values were calculated for each beam type. The compressive ultimate shear stress and beam types have been shown in Figures 4, 5 and 6. Figure 4 shows variation between average ultimate shear stress and beams D, E, F; and A, B, C separately. Fig. 5 shows a decrease in shear strength with increase in percentage of maxi-
mum size of aggregate (Type B beams having 25% 5/8 in and 75% down have maximum shear strength whereas type C beams with 75% 5/8 in and 25% down have the least shear strength). Beams D through F having 1 in maximum size aggregates show exactly similar behavior. Moreover the effect is not only true for experimental values but also true for shear values calculated by ACI and Kim & Bazant equations. The reason is that both equations include $\sqrt{f_t}$ values for corresponding mixes. However it can be seen that as Kim & Bazant have included the effect of maximum size of coarse aggregate, their values are very close to the experimental results. The decrease in shear strength with increase in percentage of maximum size aggregate for both sets of sizes i.e. 1 in and 5/8 in is probably due to the fact that use of large quantity of one size of aggregates produce poor interlocking. Further the shear strength of type E (50% 1 in and 50% down) and type F (75% 1 in and 25% down) beams is less than that of type A (50% 5/8 in and 50% down) and type F (75% 5/8 in and 25% down) beams. (The reason seems to be the interlocking effect again but in a different way. The gaps or voids of 5/8 in down aggregates could be easily and efficiently filled by its down aggregates having a major part of 3/8 in aggregate. On the other hand big voids of 1 in aggregate could not be properly filled by 6/8 in aggregates which contained the major part of down than 1 in aggregates. Moreover the shear strength of type D beams is maximum (180.9 psi) despite its low compressive strength (2125 psi). Though the shear strength of type B beams is approximately equal to that of type D beams 180.2 psi but type B beams have compressive strength of type D beams may increase from that of type B beams for the same compressive strength.

To see more clearly the effect of maximum size and gradation of coarse aggregate on the shear strength and to diminish the effect of variation of $\sqrt{f_t}$ and $\sqrt{f_e}$ values for all sets are divided by their corresponding $\sqrt{f_t}$ values. Figures 7 through 9 show variation between $\sqrt{f_t}$ and beam type. It is clear from the figures that ACI equation gives a straight line showing no effect of maximum size and gradation on the shear strength. On the other hand Kim & Bazant equation shows the increase in shear strength with increase in size of aggregate (Fig 7) but is taking no

---

**Fig.7** Increase in shear strength with increase in size of aggregates

**Fig.8** Showing almost constant shear strength for different gradation of same size 5/8" aggregates

**Fig.9** Showing that Kim's equation is unsafe for mixes having more than 25% of maximum size aggregates
effect of gradation (Figs 8 and 9). Figure 9 shows that Kim and Bazant equation is not safe for coarse aggregates having about more than 25% of maximum size aggregates because it give shear strength values more than experimental results. The reason is most probably due to the fact that they have not considered the effect of gradation in their equation. Further it is clear from the graphs that vc ACI is almost 40% less than vc (exp). Moreover even for same aggregate size there is an increase in shear strength with good gradation. There is almost 20% increase towards good gradation for same aggregate size. However to include the effect of gradation in shear formula, more experimental work is needed to collect enough data.

The effect of aggregate size and gradation would have been more significant and pronounced if the concrete mixes had been proportioned on the basis of mix design. In the present case the w/c ratio was kept constant, which produced more lubricated and hence porous concrete for larger size of aggregates thus reducing the advantage of using larger size aggregate. In spite of this the increase in shear strength was observed which clearly shows that there will be a significant increase in shear strength with increase in aggregate size if concrete mixes are proportioned by mix design. Thus it can be finally concluded that shear strength of concrete will increase with increase in size of coarse aggregates but must be supported by good gradation which would provide a tight interlocking.

CONCLUSIONS

- Shear strength increases with increase in size of coarse aggregates but must be supported by good gradation that would provide a tight interlocking.

- The percentage amount of maximum size of coarse aggregates may not be greater than 25% of the total weight of the coarse aggregates because it will make the concrete porous.

- Kim and Bazant equation for the determination of shear capacity of R.C beams is unsafe for concrete with larger size of coarse aggregates and poor gradation. On the other hand ACI equation provides too much safety. Therefore an equation for the determination of shear capacity of R.C beams may be devised which would include the effect of coarse aggregate size as well as gradation.

RECOMMENDATIONS

1. Concrete mixes proportioned on the basis of Mix design may be studied for all these effects. Because such tests will eliminate the effect of surface area and hence better data can be obtained to study the effect of size of coarse aggregates.

2. The effect of aggregate size on torsion capacity of R.C beams may also be studied.

3. The effect of coarse aggregate size on pre stressed concrete may also be studied.

4. A statistical analysis of all the work associated with shear capacity of R.C beams may be carried out to devise a rational and economical equation for the determination of shear capacity of R.C beams.

REFERENCES


