Investigation of dowel shear in RC beams using photogrammetry

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Three beams were fabricated and tested to investigate the contribution of dowel action to the shear capacity of rectangular concrete beams with shear reinforcement. The tests involved the use of photogrammetry to measure accurately the movement of the concrete, and consequently the movement of the flexural reinforcing, as shear cracking developed. This information was used in a non-linear stiffness model to determine the percentage contribution of dowel action to the shear capacity of the beams. The results showed that dowel action significantly contributed to the shear capacity of the beams.

Notation

$h$ vertical height between hinge locations
$L$ horizontal distance between hinge locations
$M$ moment in dowel bar
$P$ axial force in a reinforcement bar
$V$ shear force

Introduction

The dowel action mechanism is one component of shear resistance in reinforced concrete (RC) beams: others include the contribution of shear reinforcement, shear transfer in the compression region and aggregate interlock. Fig. 1 shows the location of the shear transfer components within a beam.

Dowel action occurs when reinforcing bars resist forces normal to their axis. Park and Paulay\(^1\) provide three dowel resistance mechanisms, namely flexure, shear and kinking, which are differentiated by the dominant action (flexure, shear, axial force and shear respectively).

Park and Paulay\(^1\) commented that, unless large displacements occur along the shear plane, minimal resistance will be provided by dowel action and the degree of displacement required to provide significant resistance may be beyond the limits of structural usefulness.

In the present paper the dowel resistance is calculated based on the displacements measured from beam tests.

Taylor\(^2\) suggested that the dowel shear resistance may depend on either the capacity of the dowel bars or of the surrounding concrete. Where the capacity is governed by the bars, Taylor suggested that the shear capacity is given by

$$V = \frac{2M_p}{L}$$

where $V$ is the shear force, $M_p$ is the plastic moment capacity of dowel bars, and $L$ is the horizontal distance between hinge locations. This assumes that the plastic moment is reached. This is not necessarily the case at ultimate load. To enhance these predictions, the actual movements determined from the geometry of the dowel bar may be used. This enables the resistance provided by the kinking mechanisms and flexural mechanisms to be included.

From a number of model and prototype tests Taylor found that the stirrup spacing can affect the resistance...
provided by dowel action. For closely spaced stirrups the dowel strength after splitting of concrete was dependent on the strength of the stirrups. For stirrups spaced far apart the splitting strength of concrete may be higher than the capacity of the dowel bar, so that when splitting occurs there is a drop in resistance. For stirrups spaced at intermediate distances after splitting occurs, the resistance provided by the dowel bar may increase. By comparing his results to separate beam tests, Taylor concluded that dowel action can carry up to 20% of the total shear force on a beam.

Jelic et al. made a number of tests on small beams without shear reinforcement to study the contribution of dowel action. From these tests no significant contribution from dowel action was observed. This agrees with Taylor who also found that without shear reinforcement little dowel action is obtained. Jelic et al., however, tentatively concluded that dowel action may not be significant for beams with shear reinforcement. The current work further investigates dowel action in an attempt to quantify the dowel resistance and confirm whether it significantly contributes to the shear resistance of shear RC beams.

The difficulty in determining the contribution of dowel bars to the shear capacity of beams is in determining the geometry of the dowel mechanism and when it occurs. As was previously stated, there are a number of ways in which shear may be transferred in a bar. As with many investigators, Krefeld and Thurston monitored the dowel geometry using strain gauges to estimate where hinge locations occur in the main bars. Krefeld and Thurston’s results clearly indicated the longitudinal position of hinges. What is lacking, however, is an accurate record of the location of the bars in the vertical plane. The vertical movement of the bars is important as it contributes to the shear capacity by way of $P$-$\Delta$ effects, such as those obtained in the kinking mechanism.

In the current study, the contribution of dowel action to the shear resistance of a beam was determined for three beams using photogrammetry.

**Photogrammetry system**

The photogrammetry system allows the shape and change of shape of an object to be determined in a three-dimensional coordinate system. The system is based on the use of photography and highly reflective targets. The targets reflect light back to its source. By taking a series of photos with a high-resolution digital camera equipped with a flash, the locations of the targets can be obtained. In order to determine the relative position of targets on an object such as a beam, a series of photographs of the object are made at various angles. The digital images from the camera are transferred to a computer. The digital images are processed to determine the relative position of the targets on the object of interest. Atkinson describes the process in detail.

The accuracy of the system is proportional to the size of the beam being measured. Three main factors affect the accuracy of the measurements. The first factor relates to the camera’s specifications, such as focal length and resolution. The second factor is the effect of scaling: by scaling the results, their precision is scaled linearly. The last factor is the geometry of the survey, which relates to the number of photographs taken and the position from which they were taken. As the precision of the results is not constant it must be determined for each survey. The precision may be judged by the mean standard error determined for a particular set of results. For the results outlined in the present paper an accuracy of 50 $\mu$m was achieved for each target location.

On each test beam presented in this paper, over 500 targets were placed. The location of the targets on a typical beam is shown in Fig. 2. Photographs were taken at 10–15 epochs to ensure high accuracy in measurements and redundancy in results.

The movement of the beams was determined at various load increments. The pictures were taken with a scale bar in them to assess the relative distance between the targets.

By tracking the movement of the concrete surface in the region where the dowel bars were located, the position of the longitudinal reinforcement was estimated.

**Stiffness analysis model of a dowel mechanism**

From the results of the photogrammetric study an idealised failure mechanism was developed. This is a combination of flexural- and kinking-type mechanisms suggested by Park and Paulay. The imposed displacement and forces involved in the idealised failure mechanism are shown in Fig. 3.

Using stiffness analysis, line flexural elements were used to represent the dowel bars. Each end of a line of elements was restrained against rotation as in the idealised mechanism. The distance between the end restraints was defined by the length $L$. An axial load, $P$, was then applied to the elements. The magnitude of the load was determined from strain gauge readings on the bars. If any stirrups were involved in the mechanism their load, $V_s$, was applied. The stirrups’ forces were
obtained from strain gauges on the stirrups. The final step was to increment the vertical displacement of one end of the bar by a distance, \( h \), to match that observed from the photogrammetric measurements.

The geometry of the dowel bar between the hinge locations in the stiffness analysis model was then compared with that obtained from photogrammetry measurements. If the geometry compared well, the assumptions made were likely to be correct and the shear capacity of the dowel bar was determined from the shear force transferred by the dowel bar in the stiffness analysis model.

### Fabrication of concrete beams

Three rectangular beams with stirrups were cast and tested. The beams were instrumented using photogrammetry and named RB2, RB3 and RB11. A typical elevation and cross-section of the beams is shown in Fig. 4.

The main differences between the beams was the stirrup configuration, which is listed in Table 1. The yield strength of the main bars in beams RB2 and RB3 was 347 MPa. For beam RB11 the yield strength was 340 MPa. The cylinder strength of the concrete at the time of testing the beams ranged between 35 and 40 MPa.

### Test results

Figures 5 to 7 show the estimated position of the main longitudinal reinforcement for beams RB11, RB2 and RB3, respectively. The diagrams were generated using the relative displacement of the beam from initial load to within 10 kN of ultimate load. The diagrams were the basis for the stiffness analysis models. The

<table>
<thead>
<tr>
<th>Beam mark</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>RB2</td>
<td>( \phi 6.5 \text{ mm stirrups at } 225 \text{ mm spacing (} f_y = 344 \text{ MPa}) )</td>
</tr>
<tr>
<td>RB3</td>
<td>( \phi 6.5 \text{ mm stirrups at } 150 \text{ mm spacing (} f_y = 344 \text{ MPa}) )</td>
</tr>
<tr>
<td>RB11</td>
<td>( \phi 6.1 \text{ mm stirrups at } 225 \text{ mm spacing (} f_y = 643 \text{ MPa}) )</td>
</tr>
</tbody>
</table>

### Table 1. Configuration of stirrups in rectangular beams

![Fig. 4. Typical elevation and cross-section of beam](image-url)
vectors of relative displacement are drawn to a scale of 10 times that of the scale of the beam.

The results of the analysis models are given in Table 2. From the results, 18–22% of the total shear resistance of the beam is provided by the dowel bars for the beams studied.

The results from the stiffness analysis indicated that the plastic moment was obtained at one end of the dowel mechanism for beam RB2.

For beam RB11, the stiffness model showed that the measured displacement was not sufficient to achieve the plastic moment capacity of the dowel bars. The moment calculated was in between the yield moment and the plastic moment.

For beam RB3 the stiffness and the strength of the dowel bars between the hinge locations were assumed to be greater than those of the bars alone. This assumption was made so that the stiffness analysis model would replicate the geometry of the dowel bars observed in the experiment. The physical meaning of this is that the concrete surrounding the dowel bars between the two hinge locations must enhance the strength and

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*Fig. 5. Dowel mechanism at ultimate load in beam RB11*

*Fig. 6. Dowel mechanism for beam RB2*
stiffness of dowel bars. For beams RB2 and RB11 the geometry determined from the stiffness analysis compared well with the geometry observed from the experiment using the assumption that the bars acted independently.

**Discussion of results**

The percentage contribution of dowel action to the overall capacity of the beams is shown in Table 2. From the table the contribution of dowel action varies between 18 and 22% of the shear capacity of a beam at ultimate load. This confirms that dowel action can be a significant contributor to the shear capacity of a concrete beam with shear reinforcement.

From the current investigations it was observed that at below ultimate loads, the contribution of the dowel bars is less as the movements are smaller. From the strain gauge measurements on the bars, little bending occurs in the dowel bars if the concrete around them is not cracked. As loads below ultimate are not generally of interest for strength design, the behaviour of the dowel bars below ultimate loads is not mentioned further here.

The role of stirrups in shear reinforced beams enhances the shear transfer capacity of the dowel bars. Even though no direct contribution from stirrups is noted for beam RB11, the stirrups will have contributed to minimising the length of the dowel mechanism and thus increased the shear capacity of the flexural-type dowel mechanism. From beam tests without shear reinforcement the length of the dowel mechanism is only limited by the location of the base of the diagonal shear crack, the concrete capacity and the support position. For tests such as those presented by Jelic et al., no significant dowel contribution would be expected as the length of the mechanism would be large. Consequently the shear force would be small unless large displacements occurred.

The stiffness analysis models removed the need to assume fully plastic moments for the failure mechanism of the dowel bars. This was a big improvement on past investigations as it was found that the plastic moment was not always achieved at each end of the dowel bars. Consequently the dowel capacity was made.

The photogrammetry method allowed the effects to be included in the estimates of the dowel bars’ resistance to shear. This is an improvement on past attempts to quantify the behaviour of dowel bars. The photogrammetry method also highlighted the fact that the dowel bars’ capacity may be enhanced by the surrounding concrete.

Although a number of researchers have questioned whether the displacements that occur in beams are

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**Table 2. Contribution of dowel action to shear capacity of a beam**

<table>
<thead>
<tr>
<th>Beam mark</th>
<th>Dowel resistance: kN</th>
<th>Shear failure load: kN</th>
<th>Estimated shear force at flexural failure: kN</th>
<th>Dowel shear as a percentage of shear failure load: %</th>
</tr>
</thead>
<tbody>
<tr>
<td>RB2</td>
<td>22.1</td>
<td>100</td>
<td>147</td>
<td>22</td>
</tr>
<tr>
<td>RB3</td>
<td>25.7</td>
<td>143</td>
<td>147</td>
<td>18</td>
</tr>
<tr>
<td>RB11</td>
<td>16.4</td>
<td>80</td>
<td>163</td>
<td>21</td>
</tr>
</tbody>
</table>
sufficient to develop significant dowel resistance, the results have confirmed that the displacement can be sufficient in shear reinforced beams with low to high degrees of shear reinforcement.

Conclusion

Photogrammetry was used to determine the contribution of dowel action to the shear capacity of a beam. For the beams tested, 18–22% of the shear capacity was provided by the dowel bars at failure. This proves that the dowel bars in a beam can provide significant shear resistance.

The estimated dowel resistance was based on the dowel mechanism observed through experiment. By using the actual geometry of the mechanism in conjunction with a stiffness model there was no need to make the assumption that bars become fully plastic.

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References


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