Impact effect on different sized reinforced concrete specimens

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Behavior of structural members under various loads has been a major interest. However, impact loading type is the least known one among them. Researchers have investigated the behavior of structural members under impact effect recently. For this reason, a well-instrumented experimental program is used to understand the impact behavior of six different sized reinforced concrete specimens. All specimens both have longitudinal and transverse reinforcements. A testing apparatus is developed to perform tests under impact loading. Accelerometers, optic photocells, dynamic force sensor, a data logger and connecting cables are used as well as testing apparatus. Free falling height and mass of steel hammer are taken constant in the study. Test program has been successful to provide several data to understand the impact behavior. Drop numbers and rebound movements of the hammer are determined according to damage situations. Acceleration values are measured from four different points of the specimens. The change of velocity and displacement values is determined for all specimens. Impact force is also measured for each free falling movement and absorbed energy values are calculated according to the area under the curve of impact force-displacement graphs. Test results give substantial information about impact resistances of reinforced concrete members.

Keywords: Absorbed energy, Impact loading, Reinforced concrete specimens, Testing apparatus

Impact loading is an important sudden dynamic loading and its intensity may be bigger than static and other dynamic loads. Analysis and design of structures under impact loading are very complex. However, investigations about this loading type shall be deepened and taken into consideration in design phase. Typical examples of impact incidents are structures subjected to vehicle crash impact, marine and offshore structures exposed to ice impact, crane accidents while carrying members and structures sustaining shock and impact forces during explosions.

Concrete is a composite construction material composed of three main components as cement, aggregate and water. Concrete is frequently used in buildings, water structures, bridges and highways. Behaviors and deformations of materials under various loading types are important. Several studies have been performed to determine the behavior under tensile, compression, torsion loads. Besides, behavior of concrete under the effect of impact loading has become significant recently.

As reinforced concrete structures are widely used in civil engineering field, these structures shall be designed with a certain safety margin under dynamic effects. Due to increasing terrorism threat, demand of impact resistant structures has increased all around the world. It is usually difficult to create correct material models and perform time taking analytical analyses by computer software. In this way, several tests have been completed in laboratory conditions to understand the behavior of reinforce concrete structural members by researchers.

Impact tests on structural members are based on several test devices. Crack patterns and damage situations are determined by using these devices. Free falling testing apparatus is the most common one among them. Many researchers investigate the impact behavior by using drop weight testing apparatuses. While significant development about limits and test devices of impact tests in ASTM E 23, there is no standard available yet.

In this paper, impact behavior of reinforced concrete specimens is investigated after a well-instrumented experimental program. For this purpose, six different reinforced concrete specimens having different section sizes are produced in the laboratory. These specimens are tested under the effect of impact loading by using a testing apparatus.

Damage situations are determined according to drop numbers. Optic photocells are used to measure time in milliseconds. After impact force and acceleration values are measured by dynamic force sensor and

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accelerometers, velocity and displacement values are obtained by integration operations. Furthermore, energy absorption values of the specimens are calculated according to damage situations. Finally, the results are compared and suggestions are proposed.

**Experimental Procedure**

**Test specimens and materials**

In this study, twelve reinforced concrete specimens which have different section sizes are produced in the first place. Six of them are used to determine the optimum drop height and mass of the steel hammer. The rest six specimens are used in tests. While length of the all specimens are 710 mm, section sizes are 100×100 mm, 100×150 mm, 100×200 mm, 150×150 mm, 150×200 mm and 200×200 mm. Reinforcement steel material is taken as 420 MPa for the yield strength of both longitudinal and transverse reinforcements. While diameters of longitudinal reinforcements differ from 6-10 mm, transverse ones are 6 mm. Concrete covers are taken as 20 mm. Reinforcement configuration and section of RS6 specimen are seen in Fig. 1. Both names and sizes of the specimens with diameters and numbers of reinforcements are given in Table 1.

Concrete compression strength is targeted as 30 MPa and material ratios given in Table 2 are determined for 1 m$^3$ concrete production. 2-day strength of selected cement type is minimum 20 MPa. While initial setting time is minimum 60 min, completion of setting is about 10 h of the selected cement. The mixture is prepared in the concrete mixing machine and poured into the moulds and six cubic specimens. All specimens are located into the curing pool for 28 days. Average compression strength is determined as 30.64 MPa after testing the compression strength of cubic specimens in the test press$^{17}$.

Afterwards, all surfaces of the specimens are painted to white by ceiling paint as seen in Fig. 2. By this way, cracks and damage failures are observed better. Four holes have been symmetrically made on the top surfaces. Steel dowels are driven in these holes to measure acceleration values from four points...
of the specimens. Finally, brass devices transferring all kinds of effects are placed in the holes.

**Test equipments**

The necessary equipments for experimental study are free falling testing apparatus, accelerations, dynamic force sensor, data logger, connecting cables, optic photocells and a computer. The testing apparatus is used to apply weight falling on specimens. Different masses can be tested up to 2.5 m in this apparatus. The base platform weighing almost 500 kg with 1000×1000×70 mm sizes is made of steel plates and placed on a smooth surface. Working mechanism of the testing apparatus is seen in Fig. 3.

Steel hammer which weighs 8 kg is fallen from 1 m height in tests. Castermid material is used to minimize the friction surfaces of the hammer. Dynamic ring force sensor is placed in the edge point of the hammer and impact force values are measured by this way. Ring force sensor having right rigidity is produced for dynamic pressure measurements. This sensor has the capacity to measure big force signals with even small waves for very short time spans. It also has high linearity and repeatability properties.

There are four piezoelectric accelerometers symmetrically placed into the brass devices to obtain acceleration values without any loss. Accelerometers perceive the movement in accordance with gravity. Shock accelerometers which are used to determine the impact behavior of several materials are utilized in tests. These accelerometers can measure any vibrations on test specimens. In addition, they do not lose the signal quality in spite of in negative environmental conditions.

Support conditions of the reinforced concrete test specimens are provided by strong connection devices. These devices have 50×50×500 mm size values and they are produced from steel plates to restrain the movement of the specimens during tests.

Optic photocells which take place on the apparatus measure the drop time for each movement and the results can be seen on the electronic screen. Moreover, total drop numbers are also given on this screen.

Special connection cables are used to connect measurement devices to the data logger. By this way, acceleration and impact force values are transferred to the software in the computer. This special software is also used to calibrate accelerometers and dynamic force sensor before starting tests. Data logger used in tests can digitize data collected from measurement devices and transfer it to computer very fast. It can also collect data at high speed.

Point loading is applied by the hammer in impact tests. However, inner reaction along the specimen is distributed. Because of this reason, a neoprene rubber with 5 mm thickness and a steel plate with 10 mm thickness are placed on the specimens and fixed by plastic clips to distribute the impact force and prevent local crashing on the contact surface during tests. RS2 test specimen with necessary equipments is given in Fig. 4 as an example.
Results and Discussion

Tests are performed after placing the specimens with necessary equipments in the apparatus. Reinforced concrete specimens having different section sizes are tested under impact effect. While drop height is 1 m, mass of the steel hammer is taken as 8 kg in tests. Support conditions are strictly provided for each specimen. The results are obtained for the first drop, first damage and collapse damage situations. While first cracks on the surfaces of specimens are observed in the first damage situation, accelerometers and force sensor measure the minimum values again and again for the collapse damage situation. In addition, some concrete pieces separate from the specimens when they reach collapse damage situations. First damage situation of RS1 test specimen is given in Fig. 5.

Acceleration values are symmetrically obtained from 150 and 250 mm of the impact point. Maximum accelerations at these points are determined for each specimen. While velocities are obtained by integrating acceleration values, displacements are calculated by integrating velocity values. Impact force-displacement graphs are the combination of calculated displacement and measured impact force values for the same time intervals.

Acceleration, velocity, displacement and impact force values of test specimens are obtained for the first drop, first damage and collapse damage situations. Moreover, energy absorption capacities are calculated according to force-displacement graphs.

Acceleration-time graphs for 150 mm and 250 mm distances from the impact point according to first drop movement are given in Figs 6 and 7 for RS4 test specimen that has 150×150×710 mm sizes.

Maximum velocity-time and displacement-time graphs are presented in Figs 8 and 9. The values are obtained after integration operations. Finally, the graphs for impact force-time and impact force-displacement are seen in Figs 10 and 11.

Minimum and maximum acceleration values are measured by symmetrically placed accelerometers for
each drop movement of the steel hammer. These values are obtained for all test specimens according to first drop, first damage and collapse damage situations as given in Table 3. Bigger values are measured from the accelerometers that are closer to impact point as expected.

Calculated velocity and displacement values after integration operations for 150 mm and 250 mm distances from the impact point are given in Tables 4 and 5. It shall not be forgotten that these velocity and displacement values belong where accelerations are connected. As it can be seen from the tables, velocity and displacement values increase as the specimens approach to collapse damage situations. Bigger

Table 3—Measured acceleration values for test specimens

<table>
<thead>
<tr>
<th>Specimen</th>
<th>First drop</th>
<th></th>
<th>First damage</th>
<th></th>
<th>Collapse damage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acceleration (m/s²)</td>
<td></td>
<td>Acceleration (m/s²)</td>
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<td>Acceleration (m/s²)</td>
</tr>
<tr>
<td></td>
<td>at 250 mm</td>
<td>at 150 mm</td>
<td>at 250 mm</td>
<td>at 150 mm</td>
<td>at 250 mm</td>
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<tr>
<td>RS1</td>
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<td>-3224</td>
<td>-2214</td>
<td>-3132</td>
<td>-1965</td>
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<tr>
<td>RS2</td>
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<td>-2759</td>
<td>-3226</td>
<td>-2044</td>
</tr>
<tr>
<td>RS3</td>
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<td>-3377</td>
<td>-2359</td>
<td>-3304</td>
<td>-2593</td>
</tr>
<tr>
<td>RS4</td>
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<td>3733</td>
<td>-2759</td>
<td>-3226</td>
<td>-3503</td>
</tr>
<tr>
<td>RS5</td>
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<td>-4354</td>
<td>-2604</td>
<td>-3608</td>
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</tr>
<tr>
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<td>-4518</td>
<td>-2949</td>
<td>-4351</td>
<td>-3251</td>
</tr>
</tbody>
</table>

Table 4—Velocity values for test specimens

<table>
<thead>
<tr>
<th>Specimen</th>
<th>First drop</th>
<th></th>
<th>First damage</th>
<th></th>
<th>Collapse damage</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Velocity (m/s)</td>
<td></td>
<td>Velocity (m/s)</td>
<td></td>
<td>Velocity (m/s)</td>
</tr>
<tr>
<td></td>
<td>at 250 mm</td>
<td>at 150 mm</td>
<td>at 250 mm</td>
<td>at 150 mm</td>
<td>at 250 mm</td>
</tr>
<tr>
<td>RS1</td>
<td>-0.80</td>
<td>-0.88</td>
<td>-0.95</td>
<td>-1.02</td>
<td>-1.12</td>
</tr>
<tr>
<td>RS2</td>
<td>-0.62</td>
<td>-0.68</td>
<td>-0.72</td>
<td>-0.81</td>
<td>-0.94</td>
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<tr>
<td>RS3</td>
<td>-0.51</td>
<td>-0.61</td>
<td>-0.57</td>
<td>-0.70</td>
<td>-0.83</td>
</tr>
<tr>
<td>RS4</td>
<td>-0.44</td>
<td>-0.55</td>
<td>-0.49</td>
<td>-0.57</td>
<td>-0.64</td>
</tr>
<tr>
<td>RS5</td>
<td>-0.34</td>
<td>-0.44</td>
<td>-0.39</td>
<td>-0.46</td>
<td>-0.56</td>
</tr>
<tr>
<td>RS6</td>
<td>-0.19</td>
<td>-0.25</td>
<td>-0.27</td>
<td>-0.34</td>
<td>-0.36</td>
</tr>
</tbody>
</table>
displacements are observed for RS1 test specimen having the lowest rigidity.

Impact force values are measured by dynamic force sensor which is placed in the edge point of the hammer. The obtained results according to first drop, first damage and collapse damage situations are given in Table 6. The values decrease from the first drop to collapse damage situation.

Energy absorption capacities of the test specimens are determined by calculating the area under the curve of impact force-displacement graphs. The values for each test specimen according to first drop, first damage and collapse damage situations are presented in Table 7. The values increase due to the rigidity of the specimens.

Drop numbers causing first damage and collapse damage situations and total drop numbers for each specimen is given in Table 8. Five drops have been made after collapse damage situation to see the change in measured values. Minimum drop numbers are observed for RS1 specimen whose section sizes are the smallest.

Rebound movements occur after the steel hammer hits the specimen. Rebound numbers of the test specimens according to first drop and damage situations are presented in Fig. 12. Biggest rebound numbers are observed for RS6 test specimen which has the biggest section size values.

**Conclusions**

In this study, six reinforced concrete specimens having different section sizes are tested under the effect of impact force by using a testing apparatus and necessary equipments. Drop height and mass of the hammer are taken constant. Four accelerometers are symmetrically placed on the specimens. Distances of the accelerometers from the impact point are 150 and 250 mm. While acceleration values are measured by
 accelerometers, impact force values are obtained by dynamic force sensor. Velocity and displacement values are calculated after integration operations. Afterwards, energy absorption values of test specimens are determined according to impact force-displacement graphs.

Acceleration values measured at 150 mm distance from the impact point are bigger than the measured values at 250 mm for all specimens. Moreover, acceleration values get bigger with the increase of specimen due to rigidity. On the other hand, acceleration values change according to damage situations. Minimum accelerations are measured for collapse damage situation for each specimen due to crack development.

Velocity and displacement values are calculated after integration operations. Acceleration form directly effects the calculations. While velocity values are obtained by integrating accelerations, displacement values are obtained by taking the integral of velocities for the same time intervals. These time intervals are taken for the first hit of the hammer where the biggest accelerations are obtained free from noise effects.

Velocity and displacements values at 150 mm distance are also bigger than the values at 250 mm. Bigger velocity and displacement values are calculated for the collapse damage situation similarly with the behavior of specimens. On the other hand, velocity and displacement values change due to section sizes. While the biggest values are obtained for RS1 specimen, the lowest values are calculated for RS6 specimen.

Absorbed energy capacities of the test specimens are determined by calculating the area under the curve of impact force-displacement graphs. The values change due to section sizes and damage situations. The biggest energy capacity is calculated for the first drop movement of each specimen. However, the capacities decrease with the damage development. According to calculations, the biggest energy is absorbed by RS6 test specimen. Maximum drop numbers are observed for RS6 specimen having the biggest section sizes. This specimen has reached collapse damage situation at the latest among all. On the other hand, total rebound numbers of the hammer decrease from first drop to collapse situation for each member. Finally, this study can be improved by testing various specimens under different hammer masses and drop heights.

References