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# The 6th Civil Engineering Conference in The Asian Region and Annual HAKI Conference 2013

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## PRESIDENTIAL

**1A. Performance Based Design**

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# THE BEHAVIOUR OF RC-BEAM AND RC-SLAB USING COARSE AND FINE RECYCLED CONCRETE AGGREGATES

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## ABSTRACT

The reinforced concrete beam and slab which was made from recycles concrete aggregates with different percentage of recycled and natural aggregates was investigated. The nine reinforced concrete beam specimens was made from coarse recycles concrete aggregates with $f_c$' 25 MPa and nine reinforced concrete slab specimens was made from coarse and fine recycles concrete aggregates with $f_c$' 20 MPa was tested. The flexural strength, ductility, crack pattern and its behaviour was observed. The material of concrete using recycled concrete aggregates was also tested for compression, bending, splitting and shear strength. The analytical prediction of RC-beam and RC-slab based on the material test of concrete using recycled concrete aggregates was compared to the test result. The result showed that the flexural strength and ductility of RC-beam and RC-slab specimens made from recycles concrete aggregates was satisfied.

**Keywords:** *Coarse Recycle Concrete Aggregates, Fine Recycle Concrete Aggregates, Flexural Strength, Ductility.*

## INTRODUCTION

It has been estimated before year 2000 approximately more than 100 million tons of concrete are currently demolished each year in the world. It is estimated now, may be three times more demolished concrete will be generated each year today. The used of recycling of demolished concrete will solve and also contribute to the solution of an environment waste disposal problem. It will also reduce and conserve natural resources of sand and gravel for building and road construction, Hansen, 1992.
Much concrete material research has been done using recycled concrete aggregates. In these research six different mixed designs was done. The concrete using coarse and fine recycled concrete aggregates was tested for compression, bending, splitting and shear strength. The application of these concrete using coarse and fine recycled concrete aggregates on the RC-beam and RC-slab was done.

## MATERIALS AND METHODS

The source of coarse and fine recycled aggregates is the waste concrete materials from specimens tested in the laboratory. The mass concrete was breaking manually by hammer into 19 mm and smaller diameter. The coarse recycled aggregates have more rough and sharp surface rather than natural coarse aggregate, as in Fig.1.

Fig. 1: Coarse aggregates, natural (left), recycled (right)

Fig. 2: fine aggregates, natural/sand (left), recycled (right)

The fine recycled aggregates visually more grey than the color of natural sand because content a lot of cement, Fig. 2. In mixed design the target of concrete characteristic strength was 25 MPa and 20 MPa for RC-beam and RC-slab, respectively. The weight proportion of six different mixed designs per $m^3$ was tabulated as in Tab. 1 and in Fig.3.

Tab.1: Weight proportion at various mixed design (per $m^3$)

| Weight Proportion (kg) | Beam, $f_c$' 25 MPa | | | Slab, $f_c$' 20 MPa | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| | 0-RCA 100-NCA | 50-RCA 50-NCA | 100-RCA 0-NCA | 100-RCA 0-RFA | 80-RCA 20-RFA | 60-RCA 40-RFA |
| Water | 188 | 196 | 180 | 190 | 244 | 245 |
| Cement | 418 | 418 | 418 | 356 | 356 | 356 |
| Natural coarse aggregates (NCA) | 972 | 463 | 0 | 0 | 190 | 400 |
| Recycled coarse aggregates (RCA) | 0 | 463 | 870 | 987 | 756 | 601 |
| Natural fine aggregates/sand (NFA) | 767 | 805 | 877 | 847 | 667 | 467 |
| Recycled fine aggregates (RFA) | 0 | 0 | 0 | 0 | 167 | 312 |

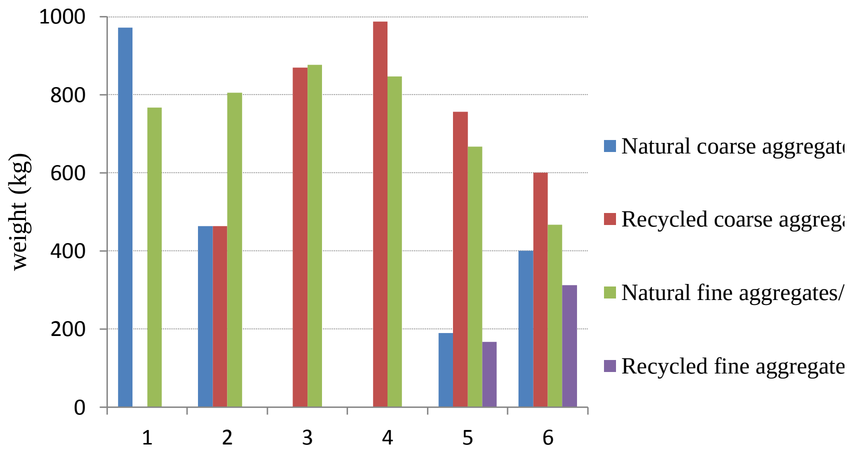


Fig. 3: Comparison of the weight of natural and recycled concrete aggregates for various mixed design

The yield strength of longitudinal steel reinforcement for RC-beam (D-11) based on tensile test was 370 MPa and the overstrength factor was 1.43. The yield strength of longitudinal steel reinforcement for RC-slab (D-10) was 430 MPa and the overstrength factor was 1.53.

## EXPERIMENTAL TEST

The test mainly was based on the ASTM method for RC-beam and RC-slab materials. The target concrete characteristic strength was 25 MPa and 20 MPa for beam and slab, respectively. Each mixed design has 12 cylinder specimens for compression tested at various age of concrete. The specimens for splitting, bending and shear test; each has three specimens and was tested at 28 days as was shown in Fig. 4 and Fig.5.

The dimension of RC-beam was 200 mm x 200 mm x 1200 mm and 120 mm x 500 mm x 1200 mm for RC-slab, each mixed design has three specimens, the test setup as was shown in Fig. 6 and Fig.7. The longitudinal reinforcement for RC-beam was 2-D11 on top and 3- D11 at bottom and 3-D10 on top and 4 D-10 at bottom for RC-slab. The shear strength of the beam was designed twice of the probable failure load, to make sure that the failure was in bending. The shear reinforcement was 2Ø10@80 mm spacing. The theoretical bending strength of the RC-beam and RC-slab was 15.0 kNm and 12.6 kNm, respectively.

Fig. 4: Material test: Compression (left), Splitting (right)


Fig. 5: Material test: Flexural (left), Shear (right)

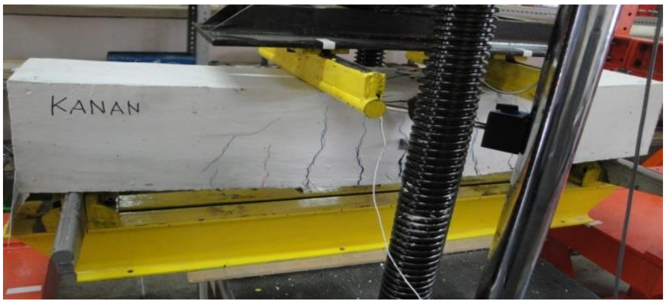


Fig. 6: RC-Beam under third point loading bending test

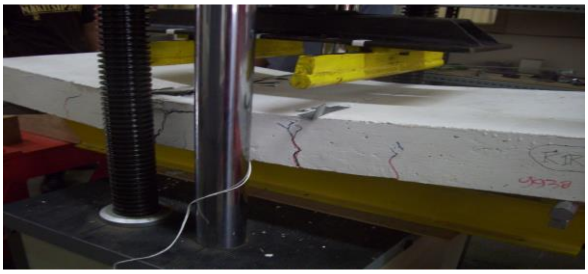

Fig. 7: RC-Slab under third point loading bending test

## RESULTS AND DISCUSSIONS

The target of concrete characteristic strength was achieved and was tabulated as in Tab.2. with deviation standard of 4– 5 MPa and CoV between 10% to 17%. The test result for splitting, bending and shear strength was divided by $\sqrt{f_c'}$ and then compared to the limit value commonly used for design, it was shown in Tab.3. The moment-displacement curve was plotted as in Fig.8 to Fig.13.

Tab.2: Concrete material strength test results

| Concrete strength, MPa (28 days) | Beam $f_c'$ 25 MPa | | | Slab $f_c'$ 20 MPa | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| | 0-RCA 100-NCA | 50-RCA 50-NCA | 100-RCA 0-NCA | 100-RCA 0-RFA | 80-RCA 20-RFA | 60-RCA 40-RFA |
| Avr. compression strength | 26.90 | 34.59 | 34.91 | 29.91 | 29.63 | 24.66 |
| Deviation standard | 4.04 | 3.59 | 3.98 | 3.82 | 4.95 | 3.19 |
| Characteristic strength, $f_c'$ | 20.29 | 28.70 | 28.37 | 23.64 | 21.51 | 19.43 |
| Avr. shear strength, $f_v$ | 5.55 | 4.28 | 3.86 | 3.66 | 3.78 | 2.81 |
| Avr. splitting tensile strength, $f_{st}$ | 2.73 | 2.97 | 3.14 | 3.04 | 2.78 | 2.59 |
| Avr. flexural strength, $f_{bt}$ | 3.80 | 3.07 | 2.78 | 2.82 | 2.59 | 2.28 |

NCA: Natural Coarse Aggr., RCA: Recycled Coarse Aggr., NFA: Natural Fine Aggr., RFA: Recycled Fine Aggr.

Tab.3: Strength ratio to $\sqrt{f_c'}$ (square root of compression characteristic strength)

| strength ratio to √fc' | shear strength | splitting tensile strength | flexural tensile strength |
|---|---|---|---|
| normal concrete | 0.166 | 0.620 | 0.620 |
| mixed design 1 | 1.232 | 0.606 | 0.843 |
| 2 | 0.798 | 0.554 | 0.574 |
| 3 | 0.725 | 0.589 | 0.522 |
| 4 | 0.753 | 0.598 | 0.580 |
| 5 | 0.814 | 0.613 | 0.558 |
| 6 | 0.638 | 0.581 | 0.589 |

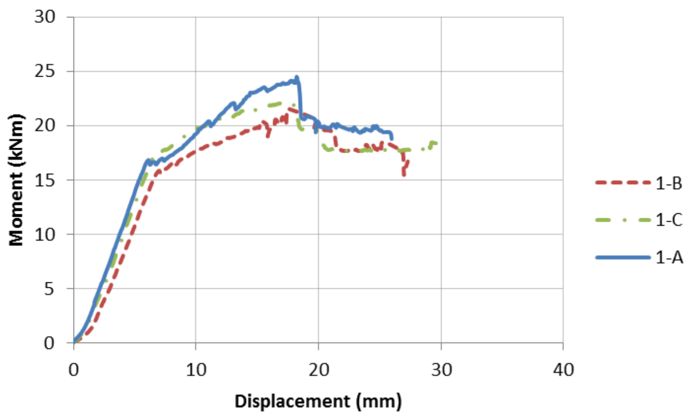


Fig. 8: RC-Beam moment and deflection curve, mixed design 1 (0-RCA; 100-NCA)

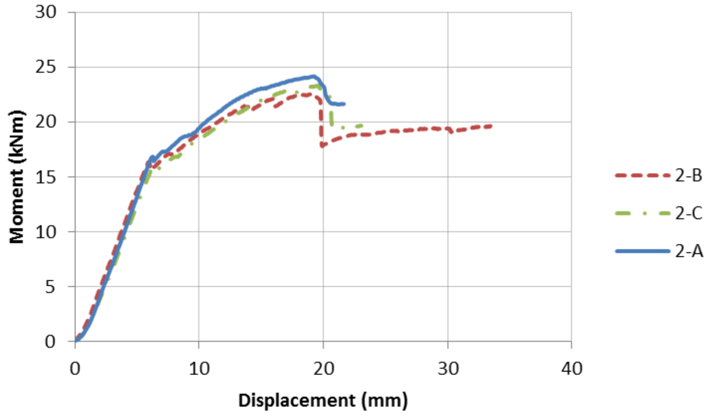


Fig. 9: RC-Beam moment and deflection curve, mixed design 2 (50-RCA; 50-NCA)

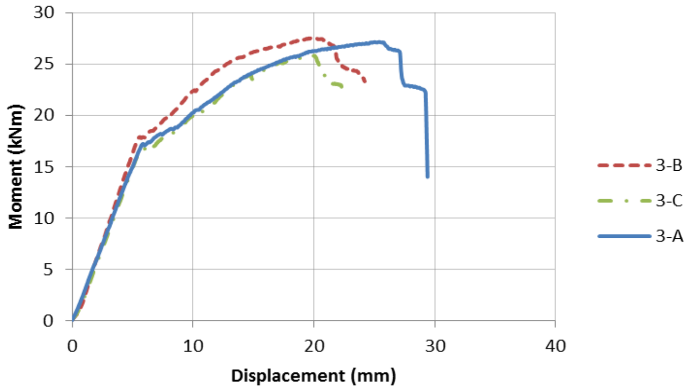


Fig. 10: RC-Beam moment and deflection curve, mixed design 3 (100-RCA; 0-NCA)

Tab.4: RC-Beam test results

| Specimen | $M_y$ (kNm) | $\Delta_y$ (mm) | $M_u$ (kNm) | $\Delta_u$ (mm) | $\Delta_r$ (mm) | $\mu_u$ | $\mu_r$ | overstrength |
|---|---|---|---|---|---|---|---|---|
| 1-A | 15.98 | 7.48 | 21.55 | 17.52 | 27.28 | 2.34 | 3.65 | 1.35 |
| 1-B | 17.70 | 7.28 | 22.12 | 17.48 | 30.60 | 2.40 | 4.20 | 1.25 |
| 1-C | 16.98 | 7.64 | 24.49 | 18.20 | 25.96 | 2.38 | 3.40 | 1.44 |
| 2-A | 16.18 | 6.64 | 22.55 | 19.08 | 33.44 | 2.87 | 5.04 | 1.39 |
| 2-B | 15.77 | 6.76 | 23.30 | 17.44 | 23.04 | 2.58 | 3.41 | 1.48 |
| 2-C | 16.94 | 6.72 | 24.16 | 19.20 | 21.64 | 2.86 | 3.22 | 1.43 |
| 3-A | 18.07 | 6.16 | 27.60 | 20.04 | 24.20 | 3.25 | 3.93 | 1.53 |
| 3-B | 17.02 | 6.20 | 25.82 | 20.04 | 22.88 | 3.23 | 3.69 | 1.52 |
| 3-C | 17.36 | 6.24 | 27.16 | 25.40 | 29.40 | 4.07 | 4.71 | 1.56 |

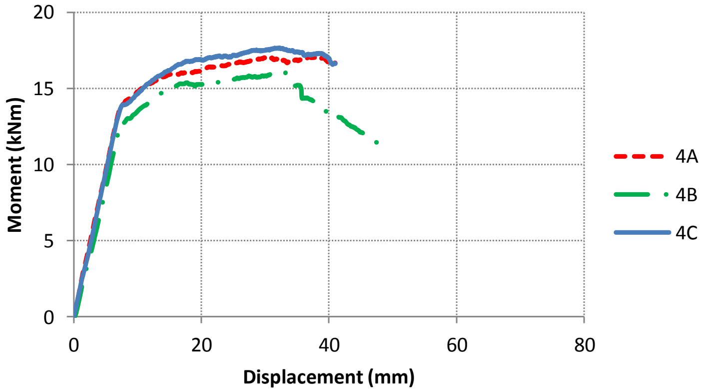


Fig. 11: RC-Slab moment and deflection curve, mixed design 4 (100-RCA; 0-RFA)

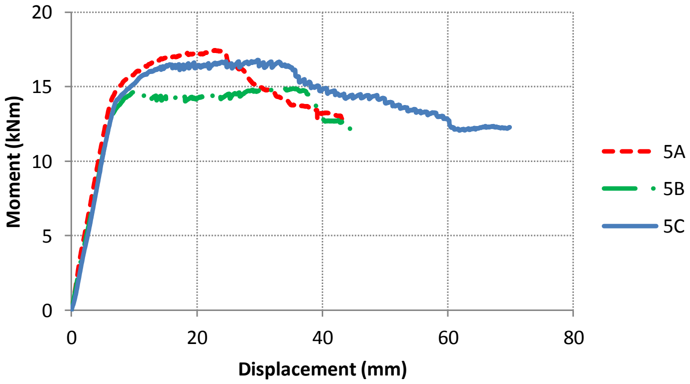


Fig. 12: RC-Slab moment and deflection curve, mixed design 5 (80-RCA; 20-RFA)

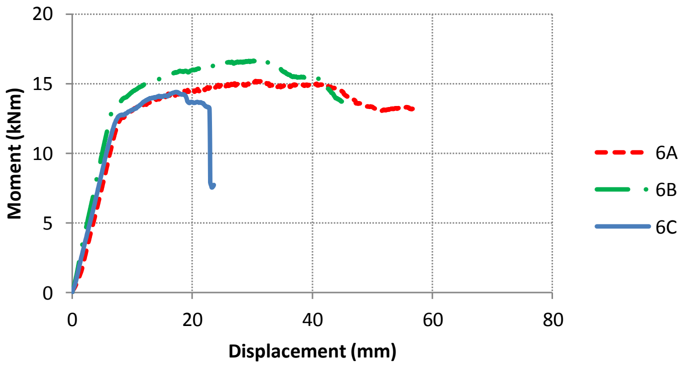


Fig. 13: RC-Slab moment and deflection curve, mixed design 6 (60-RCA; 40-RFA)

Tab.5: RC-Slab test results

| Specimen | $M_y$ (kNm) | $\Delta_y$ (mm) | $M_u$ (kNm) | $\Delta_u$ (mm) | $\Delta_r$ (mm) | $\mu_u$ | $\mu_r$ | overstrength |
|---|---|---|---|---|---|---|---|---|
| 4-A | 14.07 | 7.28 | 17.39 | 36.76 | 48.56 | 5.05 | 6.67 | 1.24 |
| 4-B | 14.37 | 8.60 | 18.02 | 32.24 | 49.56 | 3.75 | 5.76 | 1.25 |
| 4-C | 13.11 | 8.08 | 16.37 | 33.28 | 54.52 | 4.12 | 6.75 | 1.25 |
| 5-A | 14.54 | 6.48 | 17.79 | 22.76 | 43.92 | 3.51 | 6.78 | 1.22 |
| 5-B | 13.71 | 6.92 | 15.22 | 32.40 | 44.56 | 4.68 | 6.44 | 1.11 |
| 5-C | 14.60 | 7.68 | 17.13 | 29.64 | 69.88 | 3.86 | 9.10 | 1.17 |
| 6-A | 12.86 | 8.68 | 15.49 | 30.52 | 57.48 | 3.52 | 6.62 | 1.20 |
| 6-B | 13.50 | 7.04 | 16.99 | 31.08 | 44.92 | 4.41 | 6.38 | 1.26 |
| 6-C* | 12.87 | 7.60 | 14.68 | 17.20 | 23.60 | 2.26 | 3.11 | 1.14 |

*defect

Since the bending strength of the RC-beam and RC-slab mainly depend on the tension steel reinforcement rather than concrete strength, the used of recycles concrete aggregates with different percentage of recycled and natural aggregates give a good performance. The yield bending strength very closed to the theoretical bending strength of RC-beam and RC-slab of 15.0 kNm and 12.6 kNm, respectively, see Tab.4 and Tab.5. Moment overstrength in the RC-beam closed to the yield bending moment times the overstrength factor, but for RC-slab seems the reinforcement was not achieved the overstrength. More cracks were happened in the RC-beam or RC-slab with more proportion of coarse or fine aggregates.
Ductility at failure in between 3.22-5.04 for RC-beam and 5.76-9.10 for RC-slab.

## SUMMARY

Replacing 100% of coarse natural aggregate and combination of replacing 60% of coarse and 40% of fine recycle concrete aggregate showed a good result in bending strength and ductility. The design shear strength of concrete can still use limit value of $1/6 \cdot \sqrt{fc'}$ and the limit for tensile strength must be reduced from $0.62\sqrt{fc'}$ to $0.52\sqrt{fc'}$.

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