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Recycled Concrete Construction Rubble as Aggregate for New Concrete

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PREFACE

BRANZ undertook this research into the use of recycled concrete construction rubble as aggregate for new concrete because there will, potentially, be a shortage of virgin aggregate supplies in New Zealand in the future.

ACKNOWLEDGMENTS

Funding for this project was through both the Foundation for Research, Science and Technology and the Building Research Levy.

Generous support was also given by the Auckland Regional Council, Waitakere City Council, Firth Industries Limited, Adams Recycling and Ward Demolition.

READERSHIP

This report is intended for engineers, ready-mixed concrete suppliers and construction waste recyclers.

RECYCLED CONCRETE CONSTRUCTION RUBBLE AS AGGREGATE FOR NEW CONCRETE

BRANZ Study Report SR 86 **Stuart G. Park**

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KEY WORDS

Aggregates; Coarse Aggregates; Concrete; Recycling; Rubble.

ABSTRACT

Good quality virgin aggregates for concrete are becoming harder to obtain easily in some areas of New Zealand, especially Auckland.

This report discusses the results of an investigation into the properties of concrete made using recycled concrete construction rubble as concrete aggregate. It also describes a field trial carried out using recycled construction rubble concrete. The aim of the work is to see if it would be possible to replace virgin aggregate with recycled rubble to reduce the drain on premium aggregate supplies.

It concludes that the use of recycled concrete construction rubble as coarse aggregate for concrete is a viable proposition.

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1. INTRODUCTION

The use of recycled construction rubble as aggregate for concrete is not a new idea. The first large scale use of demolition rubble as aggregate occurred after the second world war. At that time there was a lot of rebuilding in Germany, and large amounts of demolition rubble lying around in the form of bombed and shelled buildings, which needed to be cleaned up. This naturally led to the rubble being used as aggregate in the rebuilding process. In 1951, a German Standard, DIN 4163, 'Concrete made with broken brick. Specification for production and use', was published. This indicates that there was enough recycling of rubble into concrete to necessitate some level of control over its production.

A review of overseas literature carried out as part of this project, shows that research into using recycled concrete rubble as aggregate for new concrete began in earnest in the mid to late 1970's. Work was carried out in both North America and Europe. The main reasons generally given for carrying out the research were (Buck, 1977; Frondistou-Yannas, 1977):

- A shortage of readily available, high grade conventional aggregates.
- Environmental concerns, including lack of landfill sites for disposal of demolition rubble, and the environmental impact of transporting conventional aggregates greater and greater distances.
- Economic concerns, which parallel the environmental concerns. As aggregate supplies and rubble disposal sites become more scarce, the cost of these services increases, making recycling a cost effective option.

In some areas of New Zealand cheap, readily accessible supplies of good quality concrete aggregate are becoming a rare commodity. This is perhaps best demonstrated in Auckland where anecdotal evidence indicates aggregates have been trucked one and a half hours from the quarry to the ready-mix plant. This is a result, generally, of current supplies running out, and any possible new sites, which are relatively close to ready-mix plants, being overtaken by urban sprawl. Hence, to get a site where it is also possible to get a resource consent to quarry rock, aggregate suppliers have had to move farther out of Auckland.

This report investigates the possibility of using recycled demolition concrete as coarse aggregate for new concrete in certain situations where a high quality concrete aggregate is not necessary. Why use the same quality aggregates for structures that require a high degree of quality control, such as Auckland City's Sky Tower, as for making the concrete that will go into a residential driveway, when lower quality, recycled aggregates may do just as well? Recycled aggregate concrete is used successfully overseas to conserve virgin aggregate supplies (Buck, 1977).

This study report investigates two different phases of the research project. In the first, different properties of concrete made with two different sources of recycled concrete aggregate were investigated. These were compared with control mixes to observe their comparative behaviours.

The second phase involved carrying out a field trial using recycled aggregates supplied by a commercial operator to a ready-mixed concrete supplier. The job was a footpath placed for the Waitakere City Council. The results of this are reported here.

2. PHASE 1: LABORATORY STUDY

2.1 Experimental Method

This phase of the project was carried out in three stages. The first was making and testing a control concrete. These mixes are denoted by the letters RA. During the second stage, the crushed control concrete was used as coarse aggregate for new concrete. These mixes are denoted by the letters RC. The third and final stage used crushed concrete supplied from an Auckland demolition company as coarse aggregate for new concrete. The letters ROC denote these mixes. The RA and RC mixes incorporated greywacke aggregates, whereas the ROC mixes had basalt in the recycled aggregate.

Before each stage, the coarse aggregate properties were determined. These included determination of saturated surface-dry (SSD) density, oven-dry (OD) density and absorption to NZS 3111: 1986, Section 12 (Standards Association of New Zealand, 1986), and crushing resistance to NZS 3111: 1986, Section 14.

For the second and third stages the aggregate was graded to the same grading as the virgin aggregate used in the control mix. This was done to prevent any variation in the grading having an effect on the mix properties.

2.1.1 Stage 1: Control mix

The design for the control mix is given in Table 1, below. It was designed to have a 28-day compressive strength of 17.5 MPa. This strength was chosen as it was felt that this would give a reasonably low strength concrete to use as aggregate, representing typical recycled concrete in the strength range 17.5-28.0 MPa. This mix design was designated RA230.

Table 1. Control mix design.

Material	SSD Weight kg/m^3
19 mm crushed greywacke aggregate	545
13 mm crushed greywacke aggregate	545
River Sand	818
GP Cement	230
Water reducer	0.550
Air entrainer	0.100
Target air	5.5%
Total water	170

The concrete was weigh batched and mixed in a 100 litre pan-type mixer. Four 75 litre mixes were made, each targeting a slump (as measured to NZS 3112: Part 1: 1986 (Standards Association of New Zealand, 1986)) of 100 mm. Samples for fresh and hardened concrete testing were taken from each batch. Samples were made for compressive strength testing to NZS 3112: Part 2: 1986, flexural tensile testing to NZS 3112: Part 2: 1986, drying shrinkage to AS 1012.13 (Standards Australia, 1992), and modulus of elasticity testing to ASTM C469 (American Society for Testing and Materials, 1994). The remaining concrete was cast into slab moulds for crushing into aggregate to be used for the RC mixes.

The concrete cast as slabs was well compacted in the mould, and kept moist overnight. The next day the slabs were stripped and transferred into a fog room. The environment in the fog room was maintained at 21°C and 100% relative humidity. At an age of 28 days they were removed from the fog room and placed in the main laboratory, which did not have any environmental control. The period when this took place was December, so the ambient conditions were reasonably warm and dry.

After the slabs had dried out (they were left approximately one month), they were crushed in a laboratory jaw crusher. The resulting rubble was sieved into discrete sizes such that it could be graded the same as the virgin aggregate used for the control mix. The sizes were material retained on the 16.0 mm, 13.2 mm, 9.5 mm, 6.7 mm and 4.75 mm sieves. This new recycled aggregate appeared to mainly be pieces of virgin aggregate with some paste on the outside. There were very few large pieces which were mainly paste.

All material passing the 4.75 mm sieve was discarded. Only the coarse recycled aggregate was used. This was done because a literature study undertaken before the project indicated that while the fine material could be used, it tended to have a highly variable and large absorption making the required water demand difficult to predict (Buck, 1977; Hansen and Narud, 1983). It also decreased the workability thereby increasing the water demand. (A sample of recycled fine aggregate tested during this program had an absorption of over 8.0% compared with a normal concreting sand which will have an absorption of 1.0-1.5%).

2.1.2 Stage 2: Recycled concrete mixes

The coarse aggregate obtained from crushing the control mix concrete was used to make three different mixes. The first, RC230, had an identical mix design to RA230 given above, except that the mass of the aggregates was lighter due to the lower density of the recycled concrete aggregates. This mix was made to provide a direct comparison to the control mix.

The second mix, RC250, had 250 kg/m^3 of cement and slightly less sand. This mix was carried out to try and determine what level of cement increase would be necessary to obtain an equivalent strength to the control concrete.

RC320, the third mix, had 320 kg/m^3 of cement. The mix design used is given in Table 2 below. This is a structural mix design, the results of which are to be compared with control concretes from historical laboratory records.

Table 2. RC320 mix design.

Material	SSD Weight kg/m^3
19 mm new recycled aggregate	545
13 mm new recycled aggregate	545
River sand	818
GP cement	320
Water reducer	0.800
Target air	2.5%
Total water	165

For each of the mixes the wet concrete properties were tested to NZS 3112: 1986, Part 1, and samples were made for testing compressive strength, flexural strength, drying shrinkage and modulus of elasticity, as described in Section 2.1.1.

2.1.3 Stage 3: Recycled old concrete mixes

The concrete rubble received from the demolition company had been crushed to some extent, and was in pieces from about 150 mm down. There was some contamination with small pieces of wood and dirt, as one would expect from a demolition site. Care must be taken with any aggregate supply of this type to ensure that contamination is kept to a minimum.

A representative sample was put through the jaw crusher such that enough aggregate was obtained to carry out the required mixing. Again this aggregate was sieved out and recombined to have the same grading as the virgin aggregate. All material passing the 4.75 mm sieve was discarded. Like the new recycled aggregate described in Stage 2 above, the old recycled aggregate was mainly made up of pieces of rock with some paste attached.

The mix designs from stage two were repeated with this aggregate so that there were three mixes ROC230, ROC250 and ROC320.

Wet concrete properties were tested, and samples were again made for testing compressive strength, flexural strength, drying shrinkage and modulus of elasticity.

Some large pieces of concrete that had not been crushed were also sent with the recycled old concrete. From these, cores were taken to determine the strength of the concrete and its density before crushing. This testing was done to NZS 3112: Part 2: 1986.

2.2 Results

2.2.1 Aggregate properties

Table 3 gives the results of the testing carried out on the coarse aggregates.

Table 3. Coarse aggregate properties.

Property	Virgin Greywacke Aggregate	New Recycled Aggregate	Old Recycled Aggregate
SSD Density	2660 kg/m^3	2490 kg/m^3	2570 kg/m^3
OD Density	2650 kg/m^3	2400 kg/m^3	2450 kg/m^3
Absorption	0.5%	3.8%	4.8%
Crushing Resistance	360 kN	170 kN	110 kN

Results of the core testing from the old concrete are given in Table 4 below.

Table 4. Old concrete properties.

	Compressive Strength (MPa)	SSD Density (kg/m^3)
Old Concrete	61.5	2590

This is quite a high result for concrete. This is probably not a typical compressive strength for most concrete that would be recycled, however the crushing resistance value is still quite low.

Approximately 25% by mass of the concrete was discarded after crushing. This was the material that passed the 4.75 mm sieve. This was the case for both the new and old recycled concretes.

2.2.2 Wet concrete test results

Table 5 gives the wet concrete results for all of the mixes.

Table 5. Wet concrete properties.

Mix	Slump (mm)	Air Content (%)	Wet Density (kg/m^3)	Yield	Measured w/c*	Total Water (l)
RA230	100	7.0	2270	1.008	0.67	153
RC230	100	5.5	2220	1.006	0.71	163
ROC230	80	7.6	2210	1.012	0.66	150
RC250	100	5.5	2220	1.008	0.64	159
ROC250	90	7.0	2230	1.007	0.61	152
RA320	100	2.3	2410	1.002	0.53	170
RC320	90	2.5	2290	1.022	0.55	172
ROC320	90	3.7	2310	1.023	0.53	164

* w/c: water to cement ratio

RA: Control mixes
RC: Recycled new aggregate concrete
ROC: Recycled old aggregate concrete

2.2.3 Hardened concrete test results

Table 6 shows the results of the hardened concrete tests. The drying shrinkage results are also given graphically in Figure 1.

Table 6. Hardened concrete properties.

Mix	28 Day Strength (MPa)	Hardened Density (kg/m^3)	Flexural Tensile Strength (MPa)	56 Day Drying Shrinkage (microstrain)	Modulus of Elasticity (GPa)
RA230	28.5	2350	4.2	570	37.1
RC230	21.5	2260	3.0	780	26.0
ROC230	24.0	2270	3.4	900	28.2
RC250	27.0	2270	3.6	730	Not Tested
ROC250	28.0	2270	3.8	920	29.5
RA320	43.0	2430	Not Tested	600	Not Tested
RC320	39.0	2330	4.4	720	33.8
ROC320	43.5	2350	4.4	940	28.8

2.3 Discussion of Phase 1 Results

2.3.1 Aggregates

All of the parameters measured in the coarse aggregate testing showed differences between the virgin coarse aggregate and the recycled coarse aggregates. Firstly, the density is significantly greater for the virgin aggregate. This is not surprising given the fact that the density of the concrete crushed up to make the recycled aggregate was 2350 kg/m^3 for the virgin aggregate concrete, and 2590 kg/m^3 for the old concrete. This is less than the SSD density of 2660 kg/m^3 found for the virgin aggregate. The higher density for the old concrete was due to the fact that the aggregates used to make it were Auckland basalt, which has a higher density than greywacke.

The high absorption values in the recycled aggregates come from the air voids in the original concrete. The RA230 mix had an air content of 7.0%. This gives the resulting new recycled aggregate more pores, and hence a higher absorption. The new recycled aggregate had an absorption of 3.8%. A typical greywacke aggregate has an absorption of approximately 0.5-0.7%. In the case of the old concrete, the basalt, on observation, appeared quite vesicular. That is, the aggregate used to make the original concrete had a lot of pores already in it. This, plus any other air voids in the paste of the old concrete, gives the reasonably high absorption figure of 4.8%. A typical basalt aggregate has an absorption of approximately 3.5-4.0%.

These high figures do not make the aggregate unsuitable for concrete, but it is important that if these types of aggregates are to be used, then the aggregate stockpiles must be kept wet to keep aggregates above SSD and thereby prevent problems with mixing.

Crushing resistance is given as the force needed to break a sample of aggregate passing a 13.2 mm sieve, but retained on a 9.5 mm sieve, such that 10% will pass through a 2.36 mm sieve. The virgin aggregate quite clearly has the highest crushing resistance, with the recycled concrete second and the old recycled concrete third. This is interesting because the concrete which produced the old recycled concrete was twice as strong as the RA230 mix which produced the new recycled aggregate. What is believed to have caused this is that the old recycled aggregate may have been more prone to losing small pieces, whereas the new recycled aggregate, while it also broke down easily, may have initially broken into larger pieces, thereby requiring more force to get 10% to pass a 2.36 mm sieve. The crushing resistance test values based on 10% fines for non-homogenous aggregate (e.g. recycled aggregate with mortar and virgin aggregate) may not be relevant for describing recycled aggregate fracture within concrete.

2.3.2 Wet concrete

When used in concrete, the recycled aggregates appeared to behave very satisfactorily. This is also the observation in work carried out overseas (Frondistou-Yannas, 1977; Buck, 1977; Hansen and Narud, 1983). The only anomaly was a rather high air content in the ROC mixes. This is probably best explained by the vesicular basalt in the mix entrapping quantities of air.

The target slump was easily obtained with all of the mixes. It should be noted that all of the 230 and 250 mixes had a lower than design water content. This led to a lower w/c ratio, and hence, higher strengths. So the 17.5 MPa control mix, which should have had a strength of around 22.5 MPa, had a strength of 28.5 MPa instead. The 320 mixes were all fairly consistent.

2.3.3 Hardened concrete

In general the recycled aggregates produced weaker concrete than the virgin aggregates. From the RA230 mix to the RC230 mix there was quite a significant drop in strength of 7.0 MPa, or 25%. The drop in strength from the RA230 mix to the ROC230 mix was 4.5 MPa or 16%. Mixes RC250 and ROC250 with an extra 20 kg of cement were made to determine what level of cement increase would give a strength equivalent to the RA230 mix. The RC250 mix had a strength of 27.0 MPa and the ROC250 mix had a strength of 28.0 MPa. It can be seen therefore, that for these mixes, an increase in the cement content of the recycled aggregate mixes by 20 kg/m^3 brought the strength of the concrete back up to the level attained using virgin aggregate.

The 320 mixes all gained very similar strengths. The RC320 mix gained 39.0 MPa in 28 days compared with the 43.0 MPa gained by the RA320 mix. The ROC320 mix gained 43.5 MPa, more or less equalling the RA320 mix.

The hardened densities of the mixes made with recycled aggregates were lower than those made with virgin aggregates. This is to be expected given the lower densities of the aggregates used in the ‘recycled’ mixes.

The flexural tensile strength of the recycled aggregate concretes was significantly lower than the virgin aggregate concrete. This is as a result of the weaker aggregates. Flexural tensile strength is loosely related to the compressive strength of the concrete, so the stronger the concrete in compression, the stronger the concrete in flexure. However, the effect of the weaker aggregate seems to have a marked affect on the performance of the recycled concrete in flexure. The RC and ROC320 recycled aggregate mixes only just pass the RA230 mix for flexural strength.

The drying shrinkage of concrete made with recycled aggregate was markedly greater than that made with virgin aggregates. This correlates well with work carried out by Tavakoli and Soroushian (1996). This high level of shrinkage is again, probably due to the physical properties of the aggregate. The weaker aggregate, and in particular, the weaker mortar adhered to the aggregate, has a lesser restraining effect on shrinkage. This allows more shrinkage to take place. Care should be taken therefore, when using recycled aggregate concrete to ensure that allowance is made for any shrinkage that may occur.

The modulus of elasticity (MOE) measurements perhaps best display the difference between the virgin and recycled aggregate concretes. The virgin aggregates are just that much stronger, that much more rigid, giving the higher MOE results.

Concrete with the characteristics of the recycled aggregate concrete outlined above would be suitable for many situations, especially non-structural ones such as driveways, footpaths etc, where the higher shrinkage can be accommodated.

Overall, given the results of this test program, the use of recycled concrete as aggregate for new concrete is a practice that can be adopted as long as care is taken in handling the aggregates, ensuring that they are kept moist, and that they are not expected to perform as well as the same concrete made using virgin aggregates, and therefore not using them for extreme or critical situations.

3. PHASE 2: FIELD TRIAL

3.1 Description

The second phase of this project involved carrying out field trials, using the results from phase one, to show that recycled aggregate concrete is feasible in the field as well as the laboratory. Carrying out the field trials involved bringing together several parties in a cooperative effort. These included a recycling contractor, a ready-mixed concrete supplier and a city council.

For the purpose of the field trials, Waitakere City Council provided a footpath contract. Several sections of the footpath were to be laid; some with virgin aggregate concrete and some with recycled aggregate concrete.

3.2 Mix Properties

The recycled aggregate used for the project was an all-in 19 mm coarse aggregate, the grading of which is given in Figure 2. The mix design is given below in Table 7. This is a typical 19 mm maximum aggregate size, 20 MPa mix design.

Table 7. Ready-mixed recycled aggregate concrete mix design.

Material	SSD Weight (kg/m^3)
All-in 19 mm Recycled Concrete Aggregate	1000
PAP 7 Sand	542
EC Sand	362
GP Cement	255
Total Water	160
Air Entraining Agent	65 ml/m^3
Water Reducer	770 ml/m^3
Target Air	5.2%

3.3 Results and Discussion

The concrete was mixed and placed on 20 March, 1998. Figure 3 shows a general layout of the job. The project also included one further section of footpath, approximately 10 metres long, behind the position the photograph was taken from. More than half of the project was laid with recycled aggregate concrete. In Figure 3, the recycled aggregate concrete goes from behind the photographer, from the foreground, and most of the way to the corner in the distance. Figure 4 shows the transition point from the recycled aggregate concrete to the virgin aggregate concrete. This photograph was taken looking in the opposite direction to Figure 3, so the virgin aggregate concrete is the lighter coloured concrete in the foreground, and the recycled aggregate concrete is the darker coloured concrete in the background.

The recycled aggregate properties as measured by the ready-mixed concrete supplier are given in Table 8, below.

Table 8. Ready-mixed recycled aggregate concrete properties.

Property	Result
Target Slump	100 mm
Actual Slump	70 mm
Specified 28 Day Strength	20 MPa
Target 28 Day Strength (from NZS 3104, Table 5)	24.5 MPa
Actual 28 Day Strength	24 MPa

At the time that the site was investigated, almost seven weeks after the concrete was placed, there were only a couple of small defects noticeable in the footpath. One was a corner at a driveway that had broken away. It is thought that this was due to either early loading of the concrete or a lack of support under the concrete, or a combination of both of these factors.

The second defect, shown in Figure 5, is a crack which runs right across the footpath at the point that the two different concretes meet. It is thought that this crack is a result of drying shrinkage of the concrete, with the two different types of concrete parting at the weaker join between them.

It is noteworthy however, that these are the only cracks visible at the time the project was investigated. Figure 6 shows that the slab was relatively thin, approximately 50-60 mm, and was placed in quite long, narrow sections. This is conducive to drying shrinkage cracking, but, as mentioned above, only one crack was noted in the footpath.

Table 8 shows a relatively low slump for the concrete. The contractor who placed the footpath also noted that the recycled aggregate concrete seemed to ‘go off’, or harden, more quickly than the concrete made with virgin aggregate. The reason for this may have been that the recycled aggregates had not been fully saturated, and as they tend to be considerably more porous than virgin aggregates, they would have soaked up some of the mix water from the concrete. This would have reduced the slump and increased the speed with which the concrete set.

The performance of these sections of footpath will continue to be monitored.

4. CONCLUSIONS

- Recycled aggregate concrete will be weaker than the same concrete mix design made with virgin aggregates. This can be compensated for by adding extra cement to the mix.

- The hardened density of concrete made using recycled aggregates will be lower due to the lower density of the recycled aggregate itself.

- The flexural tensile strength of concrete made using recycled aggregates will be lower than the same concrete made with virgin aggregates. This can not be as easily compensated for by adding cement, as can be done for the loss in compressive strength.

- There is a marked increase in drying shrinkage when using recycled aggregates in concrete. This must be allowed for when using this concrete in practice.

- The modulus of elasticity of concrete made using recycled aggregates is much lower than the same concrete made using virgin aggregates. This is due to the physical properties of the aggregates in question.

- The field trial of a footpath made using recycled aggregate concrete, supplied by a ready-mixed concrete producer, shows that recycled aggregate concrete is able to be produced in New Zealand, and that it is technically feasible.

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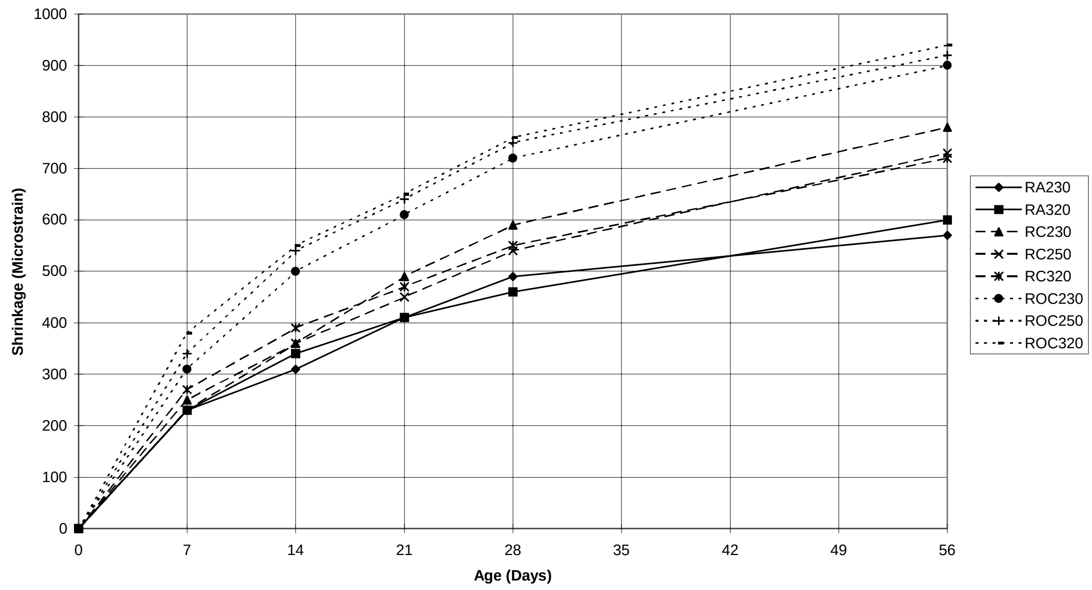

Figure 1. Drying shrinkage of all concretes tested.

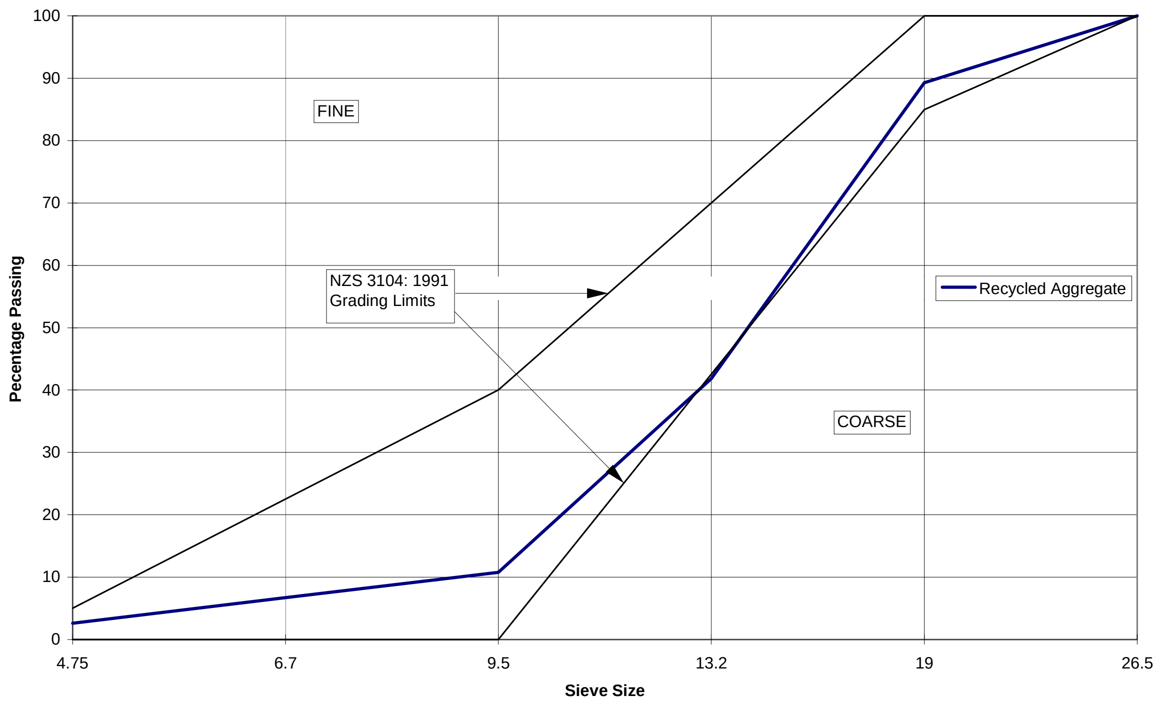

Figure 2. Coarse aggregate grading curve with envelope from NZS 3104 (SANZ 1991).

Figure 3. General layout.

Figure 4. Transition point between the two concretes.

Figure 5. Crack at transition point.

Figure 6. Cross-section of slab.