USE OF RECYCLED CRUSHED DEMOLITION MATERIALS AS BASE AND SUB-BASE IN ROAD CONSTRUCTION

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PROFILE

Colin Leek is the Manager of Construction Services at the City of Canning. He has 26 years experience in Local Government Engineering, with City's of Canning and Perth, and 11 years previous experience with Westrail, Public Works Department, and Water Authority, as an Engineer and Engineering Assistant. He has an Associateship in Civil Engineering from the WA Institute of Technology, and a Master of Technology (Pavements) from Deakin University.

ABSTRACT

This paper reviews the upgrading of Welshpool Rd between Leach Hwy and Sevenoaks St in Welshpool using recycled demolition materials as a base and sub-base. The paper details the decision process leading to the adoption of recycled materials as an alternative to newly quarried materials, the experience gained during the construction process and details of testing and assessment of the completed pavement.

1 INTRODUCTION

The City of Canning has over a number of years been keen to foster the development of innovative solutions for new road construction, rehabilitation of failed pavement sections, and the maintenance of the remainder of its road network. One such method is method is assessing new or alternative pavement materials, and in this particular case, the use of various grades of roadbase manufactured from recycled demolition materials.

This is not a new process in Australia, as recycled materials have been used extensively in Victoria and New South Wales, but the adoption of recycled materials in WA has been slow to gain acceptance.

Whilst the City has used recycled pavement materials (profilings) sourced from old reclaimed pavements extensively, it has been reluctant to use recycled demolition materials due to the lack of quality control and the quantity of undesirable materials contained in early attempts by recyclers to manufacture a good quality roadbase.

Previously, the City has opted for either:

- Limestone as a base on low traffic volume roads or sub-base on major roads
- Reclaimed pavements (profilings) as a base on low traffic volume roads or sub-base on major roads
- Crushed Granite Roadbase for base construction on major roads (CRB)

And has on a limited basis experimented with

- Emulsion stabilized limestone (ESL)
- Hydrated Cement Treated CRB
- Insitu cement treated CRB
- Crushed laterite gravels (Ferricrete)
- CRB modified with concrete slurry washout from concrete batch plants.

When C & D Recycling approached the City with a proposal to use recycled demolition material as an alternative material, City staff inspected the stockpile and process control records and was confident that the recyclers had developed very good control over material being recycled, and that the quantity if undesirable organic materials was minimal. It was decided to upgrade a major road using some recycled material to assess the workability, consistency and performance of a pavement constructed using recycled materials available in WA.

This was not considered a true “trial” pavement, as interstate experience has demonstrated the value of recycled materials, but as a demonstration project giving the recycling industry the opportunity to prove their ability to produce a consistent quality product, and to assess the properties of various classes of recycled materials.

The original aim was to replace the limestone sub-base with recycled material and use CRB as a base. However after completion of one section of pavement, the City had sufficient confidence to construct a second section in all recycled material.

It is as important to road construction and rehabilitation as in any other area of engineering activity to review the available options, assess the implications of each option, and to progress in the full knowledge of the assessment.

However in the adoption of any new pavement construction method or material, this should not be considered a linear progression. The method should be reviewed in the light of available knowledge, assessed for suitability and performance, and the method progressed to a more reliable design process, which in itself is reviewed for soundness, assessed for suitability and progressed to greater refinement.

Thus any introduction of a new material should be supported with thorough testing and on going monitoring of the pavement performance, with dissemination of the success or otherwise made publicly available for others to build upon.

2 DETAILS OF CONSTRUCTED PAVEMENT

The pavement under consideration is an 860m section of Welshpool Road from a point west of Sevenoaks St to Leach Hwy in Welshpool. The road was a 4 lane undivided road, being widened to include a 6m median, wider lanes and turn pockets. This involved a 4.5m widening each side or the existing pavement.

Welshpool Road carries a significant number of heavy vehicles including road trains serving two stock food manufacturers, and extra wide low loaders serving several heavy engineering construction companies.

The road carries approximately 8,030vpd with approximately 15% of the vehicles being trucks giving a design traffic of approximately 20 million standard axles over a 30 year design life.

3 PRECONSTRUCTION INVESTIGATIONS & TESTING

Prior to commencement of construction, it was noted that there were two main types of material available:

- Pure crushed concrete
- Mixed concrete, tile, brick asphalt and other “hard” demolition materials

Of concern was the possibility of asbestos contamination, but the process controls for delivery of demolition material are stringent, and results of analysis over many months by an independent laboratory failed to detect any asbestos contamination.

It was therefore decided to have samples of the material tested using the Repeat Load Tri-axial Test, which is used to determine the modulus value of a pavement material under various load conditions. Whilst the modulus values may not be able to be used with reliability in the design of pavements, they can be used to compare the performance of different pavement materials.

RLT testing of the recycled roadbase products was undertaken by MRWA, and the modulus values at 98% of MDD, 80% of OMC, 240kPa vertical stress and 125kPa confining stress were compared to testing previously undertaken by ARRB Transport Research for the City. The comparisons are shown below:

➢ Co-mingled 25mm C & D Recycled Base	500MPa
➢ Pure crushed concrete 25mm C & D Recycled Base	430MPa
➢ Conventional 20mm Non Plastic Roadbase Company A	410MPa
➢ Conventional 20mm Low Plasticity Roadbase Company A	370MPa
➢ Cement Modified 20mm Roadbase Company A	470MPa
➢ Conventional 20mm Low Plasticity Roadbase Company B	650MPa

Based on the above testing, it was decided to proceed using the recycled material as a sub-base only in Welshpool Road

During construction it was also decided to undertake shear box testing on samples of the material to gain further insight as to the characteristics of the materials. It was postulated that shear box testing may be an alternative to RLT testing. The results of the shear box test determine the apparent cohesion and shear strength of a material, and are shown in Table 1:

Table 1: Shear Box Test Results

Material	Normal Stress (kPa)	Max Shear Stress (kPa)	Apparent Cohesion (kPa)	Shear angle (Deg)
Roadbase	146	339	16	64
	299	630		
	445	987		
Commingled Recycled	146	390	237	47
	229	592		
	445	724		
Recycled Concrete	146	414	24	68
	229	729		
	445	1185		

Care must be taken with this test, as it is only applicable to the test conditions of normal stress and moisture conditions, which are undertaken on saturated samples. What is apparent is the very high apparent cohesion demonstrated by the commingled recycled material, and it is likely that this is due to particle shear rather than internal friction influencing the results at high normal load.

The normal load in these tests is significantly lower than applicable during trafficking by truck tyres, and it is possible that this test may indicate caution is required when using this material in heavy traffic conditions.

Subsequent to testing by MRWA, additional samples were sent to ARRB Group for further Repeat Load Triaxial Testing at a range of moisture contents. Samples of quarried road base, commingled and concrete demolition materials were tested and results are tabulated in Table 2.

Table 2: Repeat Load Triaxial Test Results (ARRB)

Material	Dry Density (%MDD)	Moisture Content (%OMC)	Resilient Modulus (MPa)		
			Stage 1	Stage 2	Stage 3
Quarried Road Base	98.2	76	210	Failed	Failed
	98.3	66	250	260	Failed
	99.4	47	380	440	460
Recycled Commingled Base	97.5	77	250	270	220
	97.9	65	330	350	350
	98.0	60	400	430	440
Recycled Concrete Base	98.6	74	320	340	330
	98.3	66	500	530	490
	98.1	59	630	690	670

These results are most significant as they were undertaken by the same operator under identical test methods, although the moisture of the quarried roadbase in its driest state was considerably less that the recycled materials.

These results indicate that the base manufactured from recycled concrete performs well under a range of moisture conditions and had the highest modulus values, followed by the recycled commingled material. The quarried roadbase failed during three stages at higher moisture contents.

4 CONSTRUCTION EXPERIENCE

Road construction commenced in November 2007, with widening by 4.5m on the South side of the existing road between Leach Hwy and Railway Parade. The verge was boxed out with an excavator, and concrete kerbs, paths and crossovers were separated from the sand sub-grade at source and carted to C & D Recycling in Hazelmere, where crushed roadbase manufactured from recycled demolition materials was backloaded to the job site.

The roadbase was manufactured from co-mingled demolition material, and contained mainly concrete with some brick, tile and asphalt. The material has a slightly lower Maximum Dry Density than conventional roadbase (1.95t/m^3 compared to 2.21t/m^3) and higher Optimum Moisture Content (11% compared to 6%).

The material was easily worked and compacted well with normal working. There were no spongy areas and the surface finish on the sub base was such that it was felt that it would perform well as a base layer. It was therefore decided to construct one section with a recycled sub-base and conventional roadbase, and a second section using recycled material as a sub-base and base layer on the south side of Welshpool Road.

In order to assess the performance characteristics of co-mingled recycled roadbase with that produced from pure concrete, it was decided to construct the widened section on the north side of Welshpool road with a roadbase manufactured from pure crushed concrete for the full pavement depth, and to trial a 50mm co-mingled recycled sub-base with a pure crushed concrete base.

In all cases, the recycled materials were easily compactable, but the pure concrete material did exhibit a greater tendency to develop spongy patches during working, and was. Like conventional roadbase, susceptible to movement when over wet. However the material dried back quickly under the prevailing weather conditions.

The roadbase manufactured from recycled crushed concrete had a similar MDD and OMC to the co-mingled material.

5 PAVEMENT TESTING

Testing on the completed sub-base on the north side of Welshpool Rd, and on the completed base course prior to asphalt surfacing on both sides of the pavement was undertaken by MRWA using the Falling Weight Deflectometer. The results are shown in Table 3:

Table 3: Falling Weight Deflectometer Testing

Pavement Construction	Test Level	Deflection			Curvature		
		Mean (mm)	Std Dev (mm)	95th %ile (mm)	Mean (mm)	Std Dev (mm)	95th %ile (mm)
250mm Co-mingled recycled/150mm Roadbase	Top base	0.59	0.06	0.65	0.21	0.03	0.25
400mm Co-mingled recycled	Top base	0.46	0.05	0.53	0.15	0.02	0.17
250mm 50mm Co-mingled recycled	Top sub-base	0.79	0.08	0.89	0.21	0.04	0.25
250mm Recycled concrete	Top sub-base	0.81	0.22	1.09	0.23	0.07	0.31
250mm 50mm Co-mingled recycled/150mm Recycled concrete	Top base	0.46	0.05	0.51	0.13	0.02	0.16
400mm Recycled concrete	Top base	0.49	0.05	0.57	0.15	0.03	0.20

From the above, it can be seen that all deflection values are low, and well within that required to handle the heavy traffic carried by Welshpool Road. However the curvature values are the more applicable value top consider when comparing the performance of pavement materials. When analyzing the results of FWD testing on the 400mm Recycled concrete base, two results of the 11 drops appeared uncharacteristic, and when removed, the 95th percentile value drooped to 0.16mm.

When considering the curvature values for the FWD tests undertaken on the completed base, it can be seen that the curvature values for the recycled pavements were significantly less than that for the pavement constructed with a new quarried roadbase, indicating that the recycled materials are providing at least initially, a stiffer pavement than a good quality roadbase.

The difference in the initial curvature value is significant, but the effect on asphalt fatigue cannot be quantified for pavements where asphalt thickness is less than 40mm However using Fig A6.2.3 in the Austroads Pavement Rehabilitation Guide (2004) for a 50mm asphalt layer at Weighted Mean Annual Pavement Temperature of 30^0C, a curvature value of 0.25mm equates to approximately $3x10^6$ESA, and a curvature value of 0.16mm equates to approximately $2x10^7$ESA.

EfromD3, developed by ARRB Transport Research, is a powerful programme used to back-calculate pavement modulus values from deflection data. The results of analysis using EformD3 are shown in Table 4.

Table 4: Back-calculated Layer Modulus

Pavement Construction	EfromD3 Layer Modulus (MPa)			
	Test at Base Level		Test at Sub-base Level	
	Base Layer	Sub-base Layer	Top Sub-base	Bottom Sub-base
150mm Roadbase/250mm Commingled Recycled	641	722		
400mm Commingled Recycled	1024	678		
250mm 50mm Commingled Recycled			1366	357
250mm Recycled Concrete			940	484
150mm Recycled Concrete/250mm 50mm Commingled Recycled	1275	505		
400mm Recycled Concrete	1042	527		

It was apparent when compacting the special run of 50mm co-mingled sub base material that some particle breakdown did occur. In order to assess the degree of breakdown, a particle size distribution (PSD) was undertaken on the incoming material, and on material extracted during the nuclear density testing procedure. Table 5 shows the before and after compaction PSD test results.

Table 5: PSD Changes During Construction

Sieve (mm)	% Passing before compaction	% Passing after compaction
75	100	100
53	100	100
37.5	97	99
26.5	77	82
19.0	65	68
13.2	53	58
9.5	45	50
6.7	39	46
4.75	34	43
2.36	28	38
1.18	23	35
0.600	18	31
0.425	15	28
0.300	11	24
0.150	6	21
0.075	3	19

Whilst it is apparent that there is a considerable degree of breakdown occurring during construction, the FWD testing indicates that this is having little effect on the pavement stiffness.

Ideally, a pavement material should have a grading curve matching Fullers Curve with an exponent of n = 0.3 to 0.5, where Fullers Curve is generated by the equation:

$$p_1/p_2 = (d_1/d_2)^n$$

where p_1 = %age of particles smaller than d_1
p_2 = %age of particles smaller than d_2
n = exponent between 0.3 and 0.5

Before compaction, the material matched a Fullers Curve with an exponent of between 0.4 and 0.5, but after compaction, the material matched a Fullers Curve with an exponent of approximately 0.3.

Whilst many materials may perform well with Fullers Curve exponent outside the range of 0.3 to 0.5, generally a material with a Fullers Curve with an exponent of > 0.5 is likely to be permeable, difficult to obtain a surface suitable for sealing and may lack stability. A material with a Fullers Curve with an exponent of < 0.3 may lack stability when wet.

Unfortunately similar testing was not undertaken on any other of the base materials used, so that a comparative breakdown for new roadbase during construction cannot be made at this time.

6 CONSISTENCY LIMITS

There is considerable differing opinions on the required consistency limits required in a pavement material, with some pavement engineers insisting that a degree of cohesion is essential in a good base course, and others of the opinion that zero cohesion with a good grading and high internal friction is the best option.

In truth, either may be correct, depending on the shape of the smaller particles. A material with very angular and well graded aggregate will have high internal friction and, whilst requiring more compactive effort, should perform well as a base. A material with more rounded particles, particularly in the sand size range, will need a degree of cohesion to overcome a lack of internal friction.

Thus the fact that the recycled roadbase has a high Liquid Limit, but is non plastic, and has zero shrinkage, should not be considered itself detrimental to its value as a road making material, as the low curvature values demonstrated by FWD testing indicates that the internal friction is high.

7 ECONOMIC & ENVIRONMENTAL CONSIDERATIONS

There are other benefits of using recycled pavement materials as opposed to new quarried products, some of which can be quantified, others not. For the Welshpool Road project, there were significant cost savings realized.

The cost comparison per compacted cubic meter of the recycled material delivered to site is shown in Table 6:

Table 6: Cost of Materials to Site

Material	Base price ($/t)	Transport Cost ($/t)	Max Dry Density (t/m^3)	Insitu Cost ($/m^3)
Limestone	6.60	5.50	1.85	22.38
Roadbase	10.80	3.14	2.21	30.80
Recycled Roadbase	8.80	2.36*	1.95	21.76**

* The effective cost due to backloading is taken as 50% or $1.18/t
** The effective cost due to ability to backload is $20.58/m^3

However there were additional savings realized, as “box out” material including concrete paths, kerbs and old concrete footings were carted to the recycling yard for processing, and sand box out was also carted to the same location for screening and reuse. The disposal costs in comparison to landfill are shown in Table 7.

Table 7: Disposal Cost

Material	To landfill		To C&D Recycling	
	Base price ($/t)	Transport Cost ($/t)	Base price ($/t)	Transport Cost ($/t)
Concrete	25.00	5.50	8.46	2.36*
Mixed sand and concrete	25.00	5.50	8.46	2.36*
Sand	5.00	5.50	4.23	2.36*
Mixed sand and grass	60.50	5.50	12.69	2.36*

* The effective cost due to backloading is taken as 50% or $1.18/t

The advantage of being able to backload materials resulted in considerable savings in transport costs, with associated savings in fuel, greenhouse gas emissions, and road wear and tear is not quantified, but an obvious environmental advantage. In addition, approximately 2000m^3 of material was diverted from landfill, and 2000m^3 of new materials were saved from extraction from the environment.

Approximately 2750m^3 of material was removed from site and replaced with 2000m^3 of roadmaking material. Where trucks may have traveled empty as more material was boxed out than replaced, material was stockpiled in bins at the City’s depot for future use. It is estimated that the savings in transport costs were in the order of $35,000 for this project.

8 DISCUSSION

The Welshpool project whilst demonstrating that recycled materials can be used successfully in road construction, has raised interesting issues with the analysis of test results. The testing undertaken has been very limited, and a significant amount of further testing on a range of projects is required to give a statistically significant number of samples on which to base reliable conclusions.

With the tests undertaken to date, there are dangers in basing conclusions on tests without understanding the implications of the test conditions. For example, shear box testing and repeat load triaxial testing are both undertaken at high moisture contents, and the method of sample preparation does not give the same particle orientation as that which occurs in road construction.

Performance of a pavement material depends on many factors, but importantly, cohesion, internal friction (shear strength), the ability to not break down under repeated loads or chemically under the action of moisture, air or time and the possibility of cementing with time are the main contributors to the material performance.

The relationship between cohesion and internal friction is very important. A material with high cohesion and low internal friction may perform extremely well in dry conditions, but not well in wet conditions. Those who have traveled in remote locations will know that travel on a dry clay pan in dry conditions gives excellent support, but in wet conditions, becomes completely impassable. Clay has high cohesion, but low internal friction. In sand country, the travel is more consistent, but better in wet conditions, and as a sub-base, sand has fairly consistent performance across a range of conditions. Sand has higher internal friction but zero cohesion.

Therefore repeat load triaxial testing and shear box testing may give good comparison to materials when wet, but may not indicate true reflection of material properties when dry. The falling weight deflectometer gives a good indication of pavement conditions at that time of testing, which is generally in a much drier and close to equilibrium moisture conditions. However a material that continues to break down with time will give an ever changing response to FWD testing.

It is considered however that the FWD test results give the better indication of pavement performance, as they are undertaken on the completed pavement. The shear box and RLTT do rate materials well, but under different moisture conditions and particle orientation. They are useful tools for rating different materials and understanding how they might perform relative to each other, but are unlikely to give definite values that can be used in pavement design.

Whilst the change in particle size distribution for the commingled recycled before and after compaction was of concern, it is considered that further breakdown under traffic is unlikely, and FWD testing indicates that this pavement under dry conditions expected in Welshpool with a permeable sand subgrade, should perform very well.

9 CONCLUSION

The Welshpool Road project has demonstrated that roadbase manufactured from recycled concrete and recycled co-mingled demolition materials can generate considerable economic benefits, particularly when recycling plants are favorably located within range of the worksite.

Testing on construction materials is limited, with only two Repeat Load Triaxial test and one Shear Box Test result for each material, and this is not a sufficiently robust sample base to form reliable conclusions.

Falling Weight Deflectometer testing whilst confined to small test areas, was repeated 10 times for each pavement type, and may be regarded with a more certainty, but again, testing over a larger number of sites is required for more definitive comparisons.

However testing undertaken on material pre construction, being Repeat Load Triaxial testing, Particle Size Distribution before and after compaction, Shear Box Testing, and post construction testing with the Falling Weight Deflectometer seem to be somewhat contradictory in predicting pavement performance.

There is some indication that the commingled material does break down during compaction, and this may give rise for concern with some practitioners. However the in-service strains within the material are unlikely to cause continued breakdown in service, particularly under an asphalt surface.

The FWD testing demonstrated that at least after construction, the pavement produced using recycled material, particularly the commingled recycled material, is at least as strong, and possibly stronger than conventional roadbase, and this has the potential to increase asphalt fatigue life.

It is considered that for low volume roads, or high volume roads with minor truck traffic, that recycled materials could be safely used as a base, and as a sub base in heavy traffic roads. However it is also considered that the risk in using recycled materials as a base in heavy traffic conditions is minimal, and long term monitoring of the performance of trial sections in Welshpool Road should confirm this.

There are sound environmental benefits to be made from the reuse of recycled demolition materials in reducing the draw on new materials, and conserving landfill sites. When box out material can be recycled at the same location as the supply of recycled materials, savings in transport costs, fuel, greenhouse gas emissions and road wear are also realized.

Monitoring over a longer period of time is required to ensure that the material does not breakdown under traffic, but it is likely that due to the low strain rates applicable under traffic, the material will not breakdown any further than occurred during construction.