RIGID PAVEMENT DESIGN WITH RECYCLED CONCRETE AGGREGATE FOR LOW VOLUME ROADS

This Thesis Submitted to the Department of Civil Engineering of the University of Moratuwa in Partial Fulfillment of the Requirement Towards the Degree of Master of Science

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DECLARATION

"I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any University or other institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person expect where the acknowledgement is made in the text"

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DECLARATION

"I have supervised and accepted this thesis for the submission of the degree"

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DEDICATION

TO MY MOTHER AND FATHER

For their continuous dedication and encouragement for my advancement

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ABSTRACT

The aim of this project is to determine the strength characteristic of recycled aggregates that can be used as an alternative material for rigid pavement construction.

The main consideration of any pavement design is to provide structural alternatives that are feasible both technically and economically. This can be achieved by specifying pavement layer thickness with proper types of materials based on the extent traffic, environmental conditions and life cycle cost analysis.

Since traffic is regarded as the key design parameter, traffic analysis was done for seventeen provincial roads. That analysis was carried out to find vehicle composition, magnitude of the axle loads, axle configuration and frequency of load repetitions.

An experimental campaign was implemented in order to monitor the recycled aggregate properties before utilizing them as a rigid pavement construction material. Properties of recycled aggregate were determined in terms of (i) particle size distribution (ii) particle density (iii) porosity and absorption (IV) particle shape (v) strength and toughness.

Then the development of concrete mix design was done. In this study, various physical and mechanical properties of concretes were examined. The concrete properties were determined by doing the workability test, compressive test, flexural strength and modulus of elasticity test.

Then suitable thicknesses for provincial roads were proposed based on the traffic volume and the recycled aggregate concrete properties.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

All countries are facing a challenge to handle a significant amount of Construction and Demolition (C&D) waste generated every year from local construction activities. Natural disasters such as earthquakes also produce large amounts of C&D waste. A good proportion of these C&D materials are broken concrete and rock pieces, which can be recycled as recycled aggregates and granular materials that can be reused in construction works. Out of this, a large proportion of potentially useful materials are disposed in landfills. Some of these materials are not biodegradable and often leads to waste disposal crisis and environmental pollution.

Carrying waste materials away from the site causes financial and environmental problems. Therefore people try to recycle the waste concretes as aggregate in order to prevent such problems. From a purely economic point of view, recycling of C&D waste is only attractive when the recycled product is competitive with natural resources in relation to cost and quantity. Recycled materials will be more competitive in regions where a shortage of both raw materials and land filling sites exist.

In recent years, the continued wholesale extraction and use of aggregates from natural resources has been questioned even at international level. This is mainly because of the depletion of quality primary aggregates and greater awareness of environmental protection.

COWAM (COnstruction WAste Management) project was initiated by the EU organization to promote recycling process in Sri Lanka and the use of recycled products as far as possible for sustainable development and to help to preserve the precious natural resources. The Galle Municipal council is planning to setup a crusher unit to break the C & D waste in Galle under the assistance of COWAM.

Even though this was initially planed to tsunami debris, in the long run, it will provide a solution to the problem of ever increasing demand for landfill sites within the Galle

City. This increases the life cycle of these materials, thereby reducing the amount of waste dumping and natural resource extraction.

This project aims to highlight the fact that the recycling process is highly applicable to today's construction industry because the recycled materials can be used in value added applications to maximize economic and environmental benefits. Although there are many material-recycling schemes recommended, actual administering of C&D waste recycling is limited to a few types of solid wastes. When considering a recyclable material, three major areas need to be taken into account (Mindess et al., 2003):

(I) Economy

(II) Compatibility with other materials and

(III) Material properties.

There are varieties of markets for C&D materials if they can be recycled into useful material for any application. It is the determination from local recyclers what materials they accept and whether they require them to be separated at the job site. Separation at the jobsite can increase the value of C&D materials. However, some recyclers don't accept mixed loads of materials if separation at the jobsite is not feasible. As a direct result of this, recycling industries in many part of the world converts low-value waste into secondary construction materials at presents such as a variety of aggregate grades and aggregate fines (dust). Often these materials are used for road constructions, backfill for retaining walls, low-grade concrete production, drainage and brickwork and block work for low-cost housing.

Although there is a wide range of application in other countries, construction waste has not been used as a construction material in Sri Lanka. This report focuses on use of construction and demolition waste as a road construction material.

In order to achieve this goal, focus has been placed on demolished material in the construction field. Investigations were carried out to explore the possibility of use of recycled aggregates in the production of concrete for rigid pavement construction in low volume roads.

1.2 OBJECTIVE

The main objective of this research is to investigate the possibility of using recycled aggregate for rigid pavements in low volume roads and to propose suitable pavement dimensions for low volume roads from prepared concrete mix proportion with recycled aggregate.

In this research replacement of natural aggregate in concrete is to be done in two ways.

1. Total replacement of coarse and fine with coarse and fine recycled aggregate
2. Replacement of only coarse aggregate with recycled aggregate

1.3 METHODOLOGY

To accomplish the objective of the research following methodology was adopted.

1. Literature survey on use of recycled aggregate in concrete
2. Traffic estimation of low volume roads
3. Experimental investigation of recycled concrete material (RCM) to determine;
   1. Physical and mechanical properties of recycled aggregate
   2. Suitable mix proportion of concrete with recycled aggregate considering water reducing admixture to improve the properties of fresh and harden concrete and to compare the properties of normal aggregate concrete and recycled aggregate concrete
4. Design of rigid pavement for selected recycled aggregate mix proportions and traffic volume

1.4 SCOPE OF THE REPORT

This thesis is structured as follows

- Chapter 1 describes the background and the objective of the research.
- Chapter 2 provides a review of relevant literature of types of waste, waste composition in Sri Lanka and overview of recycling process, rigid pavement construction and limitation to use of RA (recycled aggregate) and RAC (recycled aggregate concrete). This chapter also discusses the previous investigations and testing done with recycled aggregate.
- Chapter 3 discusses the results of traffic analysis of low volume roads.
- Chapter 4 discuses the experimental investigation of recycled aggregate and analysis of all experimental results obtained from the testing procedures. i.e it includes the preliminary design and information on the recycled aggregate testing, sieve analysis, design of the concrete mix, improvement of concrete mixes using admixtures.
- Chapter 5 discuses the required concrete pavement thickness for provincial roads based on traffic analysis and RAC properties.
- Chapter 6 contains the conclusions of the research and recommendations for future work.

CHAPTER 2

LITREATURE REVIEW

2.1 DEFINITIONS OF CONSTRUCTION WASTE

Waste is simply defined as "any material by product of human and industrial activity that has no residual value" (Serpell and Alacon, 1998 cited Loosemore and Teo, 2001). However this is not true for the construction waste, since it has a residual value.

Construction waste is defined as "the byproducts generated and removed from construction, renovation and demolition work places or sites of building and civil engineering structures" (Hong Kong polytechnic's, 1993; Macdonald and Smithers, 1998).

According to Jayawardane's studies (1992) the amount of waste in most of the construction sites in Sri Lanka is beyond acceptable limits.

Generated solid wastes related construction are in the form of building debris, rubble, earth, concrete, steel, timber, and mixed site clearance materials, arising from various construction activities including land excavation or formation, civil and building construction, site clearance, roadwork, and building renovation.

The construction waste can be classified in to two types.

1. Process waste

Residues produced during manufacturing operations.

2. Demolition waste

The waste generated in dismantling of buildings or infrastructure and consists of high percentage of granular hard materials. The demolition waste can be biodegradable (subject to decomposition by micro-organisms: eg. wood) and non-biodegradable (eg. heavy metal) waste.

While some of these wastes are recyclable and reusable, most of them are usually dumped in landfills. Wastes are often the mixtures of inert and organic materials. The inert wastes are normally used in public filling areas and site formation works and the remaining wastes that can be reused are used for recycling process.

In general, demolition waste at least doubles the content of construction related waste (Peng etal, 1997). Thus, the recovery, reuse and recycle of demolition waste are more daunting and appropriate than the process waste.

So the study only focuses on the demolition waste. Before utilizing them in to an application its composition was also studied.

2.2 WASTE COMPOSITION IN SRI LANKA

A study was conducted on actual demolition waste by source evaluation method to find the composition of waste (Patirana etal, 2007). In that study randomly selected demolition sites and sampling was done using $1m^3$ timber boxes. Figure 2.1 shows the waste quantification process.

Figure 2.1: Waste quantification process

The survey results shows that material like bricks, cabok, motar and mixed waste are available in large quantities. Composition of bricks, cabok, motar and mixed waste are 27.54%, 30.68%, 14.13% and 12.03% respectively. Among those waste, cabok and bricks can be used as backfilling material. Bricks also can be used for fine aggregate replacement in concrete. Figure 2.2 shows the composition of demolition waste in Sri Lanka.

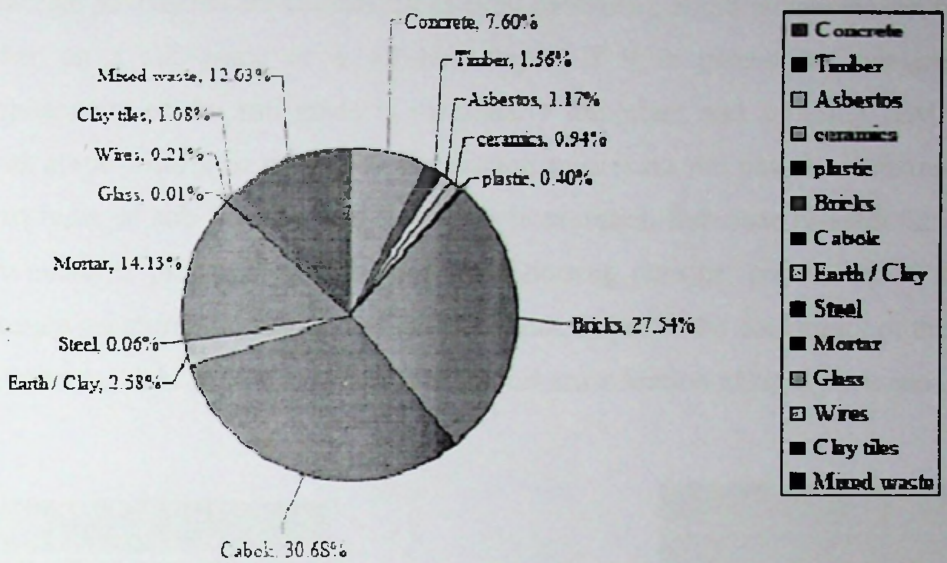

Figure 2.2: Sri Lankan demolition waste composition

Other impurities such as glass, steel and timber are available in minor quantities. Only concrete material was focused in this study. Its availability is 7.60% from the total demolition waste. These materials have been used for road construction, retaining walls backfilling, low-grade concrete production and low-cost housing construction (drainage, brickwork and block work) in other countries. In this project it is focused to use recycled concrete in rigid pavement construction.

2.3 RECYCLED AGGREGATE CONCRETE APPLICATION

There are two types of pavements;

1. Flexible pavement
2. Rigid pavement

Flexible pavements are made out of asphalt. It generally consists of a relatively thin wearing surface of asphalt built over the base course and sub- base course. In contrast to flexible pavements, rigid pavements are made up of cement concrete and they may or may not have a base course between the concrete surface and subgrade.

2.3.1 Rigid Pavement Construction

Concrete pavements are considered as rigid pavement. Rigid pavement can be placed either on a sub-grade or a sub-base layer. If it is placed on sub-grade layer homogeneity of the sub grade is particularly important and avoiding hard and soft spots are a priority in sub-grade preparation to prevent the pavement distresses. For most types of sub-grade, a sub-base layer is essential. Sub-base beneath the concrete pavements is prepared basically for the following reasons; prevention of pumping, enhance the structural strength of the pavement, improve the uniformity of the support given to the slab. Figure 2.3 shows the typical cross section of rigid pavement.

Figure 2.3: Rigid pavement layout

In rigid pavement, main component is the concrete layer. Concrete is a manufactured product, essentially consisting of cement, aggregate, water and admixtures.

Traditionally aggregates have been readily available at economic prices and properties to suit all purposes. However, in recent years extraction and use of aggregates from natural resources has been questioned even at international level. This is mainly because of the depletion of quality primary aggregates and greater awareness of environmental protection. In light of this, the availability of natural resources to future generations has not been realized.

Crushing the waste material and using it as coarse aggregate in new concrete reduces waste and reduces the need for virgin aggregate. When considering the aggregate in concrete, it occupies 60 to 80 percent of the volume of concrete as an inert filler material. Although aggregate are most commonly known to be inert filler in concrete, the different properties of aggregate have a large impact on the strength, workability, durability and economy of concrete. The aggregate properties have direct impact on the strength; workability and durability of concrete are size gradation, shape and texture, moisture content, specific gravity and bulk unit weight etc. Therefore before replacing natural aggregate component with recycled aggregate component, recycled aggregate properties should be determined.

In besides to that, the failure modes of the concrete slab also should be considered before concrete made with recycled aggregate is introduced to rigid pavement. Rigid pavement can be failed by either pumping action or by fatigue.

There are two major types of pavement distress and failures.

(1.) Pumping Action

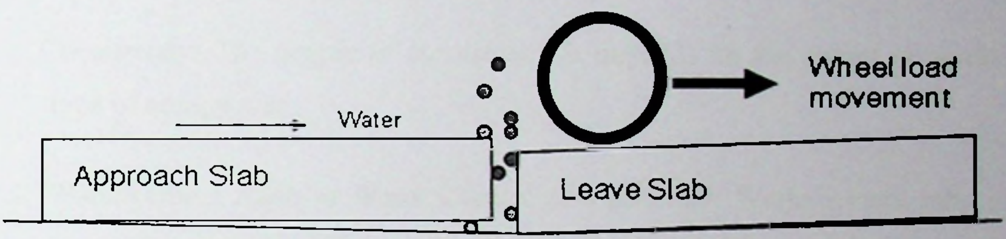

Figure 2.4: Pumping action failure of the slab

If the support condition is not drainable material, water can be accumulated underneath the slab. Then, wheel load is moving from one slab to the other approach slab goes up and down with respect to leaving slab. This mechanism will lead to push retain water up and down. As a result of this pumping action soil particle can be washed out. Therefore the support condition is one of important parameter in rigid pavement design.

(2.) Fatigue failure

Concrete slab will fail if the induced stress exceeds the fatigue limit of the concrete material. If the stress ratio (induced stress / flexural strength) limit to 0.5, unlimited number of repetition can be accommodated without failure.

$$Stress\ Ratio = \frac{Actual\ Generated\ Stress}{Modulus\ of\ Rufture}$$

0.50- unlimited number of repetition without failure

If a flexural strength of recycled aggregate concrete material is twice the generated stress it will never fail in fatigue.

However, optimum concrete properties requirement can be determined depending on the traffic condition of the road. Fresh concrete properties and hardened concrete properties should be determined from trial mixes to obtain an optimum concrete mix.

Fresh properties (Slump)

A good concrete must have workability in the fresh state and also sufficient strength. It also mentioned that there are four factors that can affect the workability. They are as below:

1. Consistency: The degree of consistency is depends on the nature of works and type of compaction.

2. Water/cement Ratio or Water Control of a concrete: Water/cement ratio is the ratio of water in a mix to the weight of cement. The quality of water that required for a mix depends on the mix proportions, types and grading of aggregate.

3. Grading of Aggregate: The smooth and rounded aggregate will produce a more workable concrete than the sharp angular aggregate.

4. Cement Content: The greater workability can be obtained with the higher cement content.

Compressive strength

Compressive strength of concrete can be defined as the measured maximum resistance of a concrete to axial loading. Compressive strength tests on standard 150mm concrete cubes were carried out at age's 7days, 14 days and 28 days.

Elastic Modulus

Modulus of elasticity of concrete is a very important property to determine the deflection of the structural elements. Elastic modulus of concrete is an indication of concrete stiffness. It varies depending on the coarse aggregate type used in the concrete.

The concrete's modulus of elasticity is deeply related to the stiffness of the coarse aggregates, the stiffness of the mortar, their porosity and bond. Therefore, for small replacement aggregate fraction will not significantly influence the overall stiffness because the mortar stiffness is also one of several factors for stiffness loss. But total replacement of the mortar will influence significant stiffness loss of modulus of elasticity of concrete.

Flexural Strength

Flexural strength of concrete is a main parameter in rigid pavement design. The reduction in flexural strength of recycled aggregate concrete would be attributed to the weaker bond among different components of the concrete matrix owing to the cement paste on the surface of recycled aggregate.

2.4 LITERATURE REVIEW OF RECYCLED AGGREGATE CONCRETE

Before using recycled aggregate as an alternative material for production of concrete, the embedded material such as reinforcement should be removed. It is carried out in the recycling process. This section discusses the recycling process and literature review recycled aggregate concrete properties.

Selective demolition and on-site sorting should be adopted for all demolition projects to facilitate recycling as far as possible.

2.4.1 Reviews on Recycled Process

Recycling of material is done by recycling plant. They are normally located in the suburbs of cities due to the noise pollution that make by the equipments that used during recycling process. According to Aggregate and Quarry, all the machinery used has to fit with the effective mufflers to reduce the noise from the processing activity. The recycled process consists of several steps to produce a good quality recycled aggregate material. The steps are given below.

Breaking of the Sources of Recycled Aggregate

Sources of recycled aggregate are mainly from the crushing of Portland concrete pavement and structures building. The equipments that used during recycling process are varying from the site conditions and also country to country.

The equipments used for crushing the Portland cement pavement & structural buildings are given below:

The equipments used for crushing Portland cement Pavement

1. Diesel pile – driving hammer
   It is mounting on a motor grader that sticks in the Portland cement pavement on around 30cm grid pattern.

2. Rhino – horn – tooth – ripper – equipped hydraulic excavator
   It is used to remove all the steel reinforcement that remaining in the Portland cement pavement.

Hong Kong Building Department had been used the following methods to crush the structural building.

1. Mechanical by hydraulic crusher with long boom arm
   The crusher with the long boom arm system breaks the concrete and steel reinforcements. This method is suitable for the dangerous buildings.

2. Wrecking ball
   The building is demolished by the impact energy of the wrecking ball, which suspended from the crawler crane.

3. Implosion
   A design included pre-weakening of the structure; the placement of the explosives and the building collapse in a safe manner has to develop.

Transportation

After the structural buildings and Portland cement pavements are demolished, the concrete debris has to send to the recycling plants for processing. Construction and Demolition Waste Recycling Information mentioned that it is good to use the roll – off containers or large dump body trailers to transport the mixed load of construction and demolition debris. This is the most effective and cost effective means of the transportation. It also mentioned that the construction and demolition debris could be transport by the closed box trailers and covered containers.

Crushing Plant

Crushing is the initial process of producing the construction and demolition debris into recycled aggregate. The concrete debris is crushed into pieces in this process. Aggregate and Quarry (2001) stated that generally the equipments used for crushing process are either jaw or impacted mill crushers. It also stated that all the recycling crushers have a special protection for conveyor belts to prevent damage by the reinforcement steel that in the concrete debris. They are fitted with the magnetic conveyors to remove all the scrap metal.
According to Recycling of Portland_Cement Concrete, the equipments used to crush and size the existing concrete have to include the jaw and cone crushers. The concrete debris will break down to around 3 inches by the primary jaw crusher. It also mentioned that the secondary cone crushers will breaks the materials to the maximum size required which vary between ¾ and 2 inches.

During the crushing process, all the reinforcing steels have to remove away. Professor S. L Bakoss and Dr R Sri Ravindarajah (1999) stated that there are three methods of sorting and cleaning the recycled aggregate, which are electromagnetic separation, dry separation and wet separation. Electromagnetic separation process is removal of reinforcing steel by the magnet that fitted across the conveyor belt in the primary and secondary crushers.

Dry separation process is removing the lighter particles from the heavier stony materials by bowing air. This method always causes lot of dust. Wet separation process is the aquamator, which the low-density contaminants are removed by the water jets and float – sink tank, and this will produces very clean aggregate.

According to COST 337 Unbound Granular Materials for Road Pavements, the wood pieces that contained in the concrete debris can be removed by hand – picking from a special platform over the discharge conveyor.

After finish the crushing process, the materials are then sent to the screening plant.

Screening Plant and Washing Plant

Screening is the process that separates the various sizes of recycled aggregate. The screening plant is made of a series of large sieves separates the materials into the size required.

Recycling of Portland Cement Concrete stated that the size of screen that used to separate the coarse recycled concrete aggregate and fine recycled aggregate is 3/8 inch. The size of screen used to separate the coarse recycled aggregate can be under or over ¾ inches. It also stated that one more screen should be used to separate those particles that more than the specified size. After the screening process, the recycled are then sent to the washing plant. COST 337 Unbound Granular Materials for Road Pavements stated that the recycled aggregate that produced have to be very clean when using in the high quality product situation.

Stockpile

After finishing the recycling process, recycled aggregate are stored in the stockpile and ready to use. All the recycled aggregate is stored according to the different size of aggregate. According to Recycling of Portland_Cement Concrete, the stockpile has to prevent from the contamination of foreign materials. It also mentioned that the vehicles used for stockpiling have to be kept clean of foreign materials.

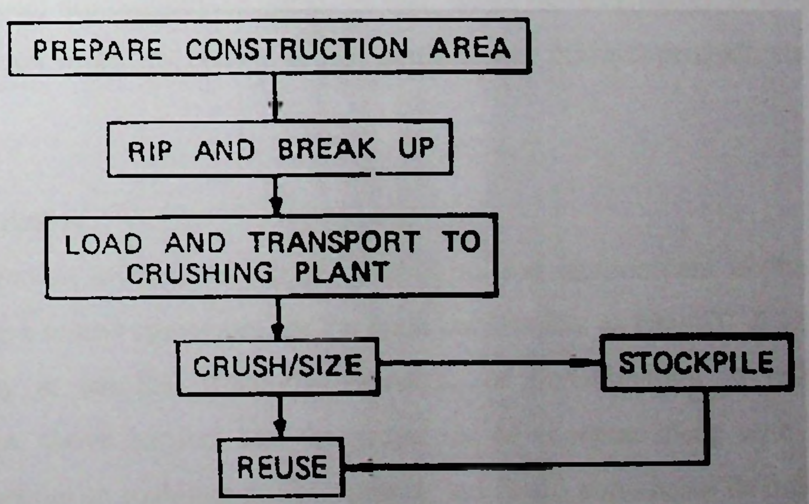

Figure 2.5: Recycling Portland cement Concrete flow chart

2.4.2 Barriers in Promoting Use of RA and RAC

Acceptability of recycled material is hampered due to a poor image associated with recycling activity, and lack of confidence in a finished product made from recycled material. Cost of disposal of waste from construction industry to landfill has a direct bearing on recycling operations. Low dumping costs in developing countries also act as a barrier to recycling activities. Imposition of charge on sanitary landfill can induce builders and owners to divert the waste for recycling. Some of these issues act as barriers in promoting more widespread use of recycled aggregate and concrete made with recycled aggregate.

Lack of Appropriately Located Recycling Facilities

Construction and demolition waste is generated in small quantities at locations, which could be widely separated. Therefore, portable equipment is needed, which can be used and set up close to demolition site. Transporting waste over large distances makes the proposition of using C & D waste uneconomical. Lack of such plants is a major barrier for 'Newcomers' in the field of C & D waste management. Commissioning of appropriately located recycling crusher units in a pilot plant can help in lowering barriers against recycling of C & D waste.

Absence of Appropriate Technology

There are very few commercially viable technologies for recycling construction and demolition wastes, and methods that can be used to crush C & D waste on a commercial scale are urgently required. In fact, when the technology is established, other issues such as quality control of raw material and finished product, etc. can be taken up.

Lack of Awareness

Lack of awareness towards recycling possibilities and environment implication of using only fresh mined aggregates are the main barriers due to which C & D waste is disposed only in landfills. Creating awareness of dissemination of information relating to the above barriers and the properties of concrete made with recycled aggregate essential to mobilize public opinion and instill confidence in favor of the recycling option. There is a need to create a market for recycled products by involving the construction industry and encouraging them to use recycled material in projects.

Lack of Government Support

A lack of government support and commitment towards development of recycling industry is often seen. Developing appropriate policy supported by proper regulatory framework can provide necessary impetus. It will also help in data compilation, documentation and control over disposal of waste material.

Lack of Proper Standards

Apart from the specification of RILEM, 1994 (RILEM - International Union of Laboratories and Experts in Construction Materials, Systems and Structures), JIS (Juggling Information Service) and those used in Hong Kong, only very limited codal specifications/standards regarding use of recycled aggregates are available. In fact, use of concrete with 100% recycled coarse aggregate for lower grade applications is allowed in Hong Kong, though for higher grade applications (above M35 concrete), only 20% replacement is allowed, and the concrete can be used for general applications, expect in water retaining structures. In Japan, JIS has drafted a Technical Report, TRA (Trades Recognition Australia) 0006 "Recycled Concrete Using Recycled Aggregate" to promote the use of concrete made with recycled aggregate. Development of relevant standards for recycled materials would provide producers with targets and users an assurance of quality of material. Standards formulated in the above mentioned countries could be guideline for development of specifications.

Following section describes the recycled aggregate as an alternative material for natural aggregate in concrete with that limitation.

2.4.3 Recycled Aggregate as an Alternative Material for Natural Aggregate in Concrete

In fact, the use of the recycled aggregate has been extensively studied and gaining the wider acceptance in the world. There are many testing based on the recycled aggregate have been carried out all around the world.

Some research results have indicated that not only recycled concrete material but also the coarse brick and tile aggregate, which are also commonly found in the demolition waste stream, can be used as a substitute of coarse natural aggregate in the production of concrete (Khalaf and De Venny, 2004; Kahaloo, 1995). Dhir et al., 1999, Poon et al., 2002 found that the recycled concrete aggregate (RCA) can be used in concrete and in the production of masonry blocks and bricks.

Hanson and Torben (1986) stated that since 1945, the research on recycled aggregate had been carried out in many countries. Limbachiya and Leelawat (2000) found that recycled concrete aggregate had 7% to 9% lower relative density and two times higher water absorption than natural aggregate.

Sagoe, Brown and Taylor (2002) stated that the difference between the characteristic of fresh and hardened recycled aggregate concrete and natural aggregate concrete is relatively narrower than reported for laboratory crush recycled aggregate concrete mixes. There was no difference at the 5% significance level in concrete compressive and tensile strength of recycled concrete and control normal concrete made from natural aggregate.

In the same year, poon (2002) reported that there were not much effect on the compressive strength of brick specimens with the replacement of 25% and 50% of recycled aggregate. But when the percentage of recycled aggregate replacement increased, the compressive strength of the specimens was reducing.

Mandal, Chakarborty and Gupta (2002) also found that there will no effects on the concrete strength with the replacement of 30% of recycled aggregate. But the compressive strength was gradually decreasing when the amount replacement of recycled increased. They concluded that the properties and the strength characteristic of recycled aggregate concrete were deficiency when compared to the specimens that made by the natural aggregate. Limbachiya (2003) found that there is no effect by using up to 30% of coarse recycled concrete aggregate on the standard 100mm concrete cube compressive strength. But when the percentage of recycled concrete aggregate used increased, the compressive strength was reducing.

In 1977, Frondistou-Yannas evaluated and compared the mechanical properties of conventional concrete and containing pieces of concrete from demolition waste in the place of natural coarse aggregate. He found that recycled concrete is enriched in gravel at the expense of mortar. The recycled aggregate concrete has a compressive strength of at least 76% and modulus of elasticity from 60% to 100% of the control mix. With replacement percentage of RCA increases gradual reduction in strength is occurs. Up to 30% of replacement of RCA content has no effect on concrete strength but thereafter a gradual reduction in strength occurs with increasing the RCA amount when comparison to the control mix. In beside to the strength characteristics tensile strength and modulus of elasticity is gradually decreasing as the percentage of recycled aggregate used in the specimens increased.

The porosity of recycled concrete made with substitution of recycled concrete aggregate was studied by Gomez-Soberon. The results showed that porosity increases when natural aggregate is replaced by recycled concrete aggregate. The increase in porosity is accompanied by a reduction in compressive strength as well as in modulus of elasticity.

According to Tavakoli (1996), the strength characteristics of recycled aggregate concrete were influenced by the strength of the original concrete, the ratio of coarse aggregate to fine aggregate in the original concrete, and the ratio of top size of the aggregate in the original concrete in the recycled aggregate. He also mentioned that water absorption and Los Angeles abrasion loss would influence the water cement ratio and top size ratio for the strength characteristic of recycled aggregate. Bodin and Zaharieva (2002) stated that decreasing of the strength of recycled concrete specimen was due to the increase of water/cement ratio that required by the preservation of workability.

Sawamoto and Takehino (2000) found that the strength of the recycled aggregate concrete can be increased by using Pozzolanic material that can absorb the water.

Mandal (2002) stated that adjusted the water/cement ratio when using recycled concrete aggregate during the concrete mixing can be improved the strength of the recycled aggregate concrete specimens. From the obtained result, recycled aggregate concrete specimens had the same engineering and durability performance when compared to the concrete specimens made by natural aggregate within 28days design strength.

Chen and Kuan (2003) found that the strength of the concrete specimens was affected by the unwashed recycled aggregate in the concrete. The effect will more strange at the low water cement ratio. These effects can be improved by using the washed recycled aggregate.

Another improving method is using the fly ash in the recycled aggregate mixing. Mandal (2002) stated that application of fly ash in the recycled concrete aggregate had improved the durability of the recycled aggregate concrete. Poon (2002) also mentioned that the use of fly ash could improve the strength characteristic of recycled aggregate. He stated that the compressive strength of concrete paving blocks was reached 49MPa at 28days by using fly ash. Berry and Malhotra (1980) stated that for high strength concrete, fly ash functions by providing increased strength at late ages of curing (56 to 91 days) that cannot be achieved through the use of additional Portland cement.

Some precautions must be taken while using recycled aggregate in the concrete mixing. According to Bodin and Zaharieva, the precautions must be taken was because of there were some pathological reactions such as alkali – aggregate reaction and sulphate reaction may be include in the performed characterization of industrially produced recycled aggregate. They also mentioned that the mix proportioning of recycled aggregate concrete must be suited when both fine and coarse recycled aggregate were substituted for natural aggregate.

Based on the experimental result, they developed some specification regarding recycled concrete aggregate. In the current specifications, it is allowed to use 100% coarse recycled aggregate in proportioning low-grade concrete (grade 20). In high grade concrete (i.e. grade 25-35), only 20% coarse portion of recycled aggregate content is permitted. The fine portion (< 5mm), together with the coarse portion of recycled aggregate, is usually prohibited in proportioning concrete mixtures, as it is very difficult to control the workability and dimensional stability of the concrete mixtures.

In addition to RILEM (International Union of Laboratories and Experts in Construction Materials, Systems and Structures) committee recommends a design procedure for use of recycled aggregate (RA) in production of concrete based on experimental works.

Given recommendations of RILEM committee for proportioning of RCA (recycled concrete aggregate) is

- When designing a concrete mix using recycled aggregate of variable quality, a higher standard deviation should be employed in order to determine a target mean strength.

- When coarse recycled aggregate is used with natural sand, it may be assumed at the design stage, that the free W/C ratio required for a certain compressive strength will be the same for RAC as for conventional concrete.

- For a recycled aggregate mix to achieve the same slump, the free water content will be approximately 5% more than for conventional concrete.

- Trial mixes are mandatory and appropriate adjustments depending upon the source and properties of the RA should be made to obtain the required workability, suitable W/C ratio, and required strength of RAC.

According to experimental campaign, recycled aggregates can be used as an alternative material in concrete for natural aggregate in the world due to its higher strength characteristic. Nevertheless, it is questioned whether demolished recycled aggregate from structures can be used in concrete production in Sri Lanka. This research is carried out for examining the performance of Portland-cement concrete produced with coarse recycled aggregates. The effects of up to 100% coarse recycled concrete aggregate in replacement of natural aggregate was assessed to check its suitability for use in a rigid pavement construction.

CHAPTER 3

TRAFFIC ESTIMATION OF LOW VOLUME ROADS

It is well known that pavement design and its performance are influenced by the traffic loading on the pavement. Traffic is regarded as the key parameter in road deterioration. It is therefore essential to know its composition in terms of:

- Total traffic volume (AADT)
- Magnitude of axle loads
- Frequency of load repetitions

The vehicles in roads can be categorized in two types i.e. light vehicles and heavy vehicles. AADT value is mainly attributed due to both types of vehicles. Seventeen "C class" roads were selected to get an idea about the traffic behavior of provincial roads (Appendix - A).

Axle load of light good vehicle has a negligible effect on pavement compared with the heavy good vehicle. Heavy vehicle wheel load, tire pressure and frequency together with environmental factors are all important to the performance of the pavements. However, the most significant parameter is the axle load since the damage to a road structure depends greatly on the magnitude of the axle loads. The damage to a pavement will result in pavement failure and increases very rapidly with increasing axle loads.

Accurate traffic estimation is essential for road pavement design and maintenance. Hence, Axle Load Surveys are essential in planning and the design phases of roads. Axle loads surveys are conducted rarely and only limited data available for provincial roads in Sri Lanka. Axle load survey data of five provincial roads were selected for determining the axle load. The selected roads are given below

1. Panawala - Maniyangana Rd
2. Chillaw - Iranawila - Nainamadama Rd
3. Bathuluoya - Dewalahandiya Rd
4. Udupila (Delgoda) of Kirillawala - Udupila Rd
5. Neluwa-Kadihingala- Dellawa- Morawaka Rd

3.1 TRAFFIC ANALYSIS

3.1.1 Traffic Distribution of Provincial Roads

The vehicle composition of seventeen (17) Southern Provincial "C' class roads were expressed as a percentile value (%) from the AADT value as shown in Table 3.1. For estimation of lower and upper limit, "t" distribution (two tail methods) with 90% of confidence level was used.

Table 3.1 Vehicle composition as a % from the AADT

Vehicle Type	Average Value (%)	Standard Deviation	% Value from AADT	
			Lower Limit	Upper Limit
Motor Cycles	39.89	8.05	35	44
Three Wheel	26.66	6.37	23	30
Car	4.23	3.08	2	6
Passenger Van	1.73	2.72	0	3
Light Goods Vehicle	6.22	2.95	4	8
Medium Goods Vehicle	7.02	6.36	3	10
Heavy Goods Vehicle	5.18	3.82	3	7
Medium Bus	4.68	4.39	2	7
Large Bus	1.98	1.76	1	3
Tractor/ Trail	2.38	2.86	0	4

In the traffic analysis the author has found that the percentage of heavy good vehicles is lesser than the mid good vehicles and large buses.

Axle load distribution was further analyzed. Axle load distribution of vehicles was analyzed based on the 6-hour axle load survey data of five provincial roads. Cumulative percentile value of each vehicles category was plot against axle load group. When selection the axle load group, measured axle load were round off. Example for the round off is given below. Axle load of 54 kN (5.4 tons) in 50kN (5 tons) group while the 55 kN (5.5 tons) in group 60 kN (6 tons). Cumulative no. of vehicles and their cumulative percentile value of Panawala Maniyangana road are given in Table 3.2.

Table 3.2 Axle Load Distribution of Panawala Maniyangana Road

Axle Load Tons	Axle Load kN	Cum. Medium Buses	Cum. Pre	Cum. Large Buses	Cum. Pre	Cum. LGV	Cum. Pre	Cum. MGV	Cum. Pre	Cum. HGV	Cum. Pre	Cum. Farm Vehicle	Cum. Pre
1	9.96	4	100.00	76	100.00	40	100.00	30	100.00	9	100.00	18	100.00
2	19.9	4	100.00	75	98.68	1	2.50	13	43.33	8	88.89	10	55.56
3	29.9	1	25.00	64	84.21			5	16.67	3	33.33	3	16.67
4	39.8			32	42.11			3	10.00				
5	49.8			18	23.68			2	6.67				
6	59.8			9	11.84								
7	69.7												
8	79.7							1	3.33				

The graphical representation of axle load distribution of Panawala Maniyangana road is shown in Figure 3.1.

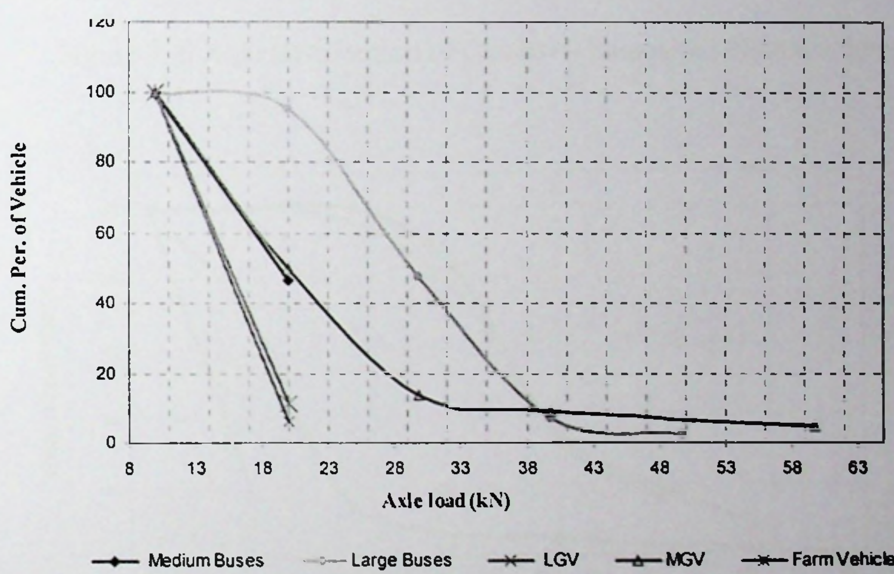

Figure 3.1: Axle Distribution of Panawala - Maniyangana Rd

Figure 3.2 to 3.5 show the axle load distribution of vehicle types for the other selected roads.

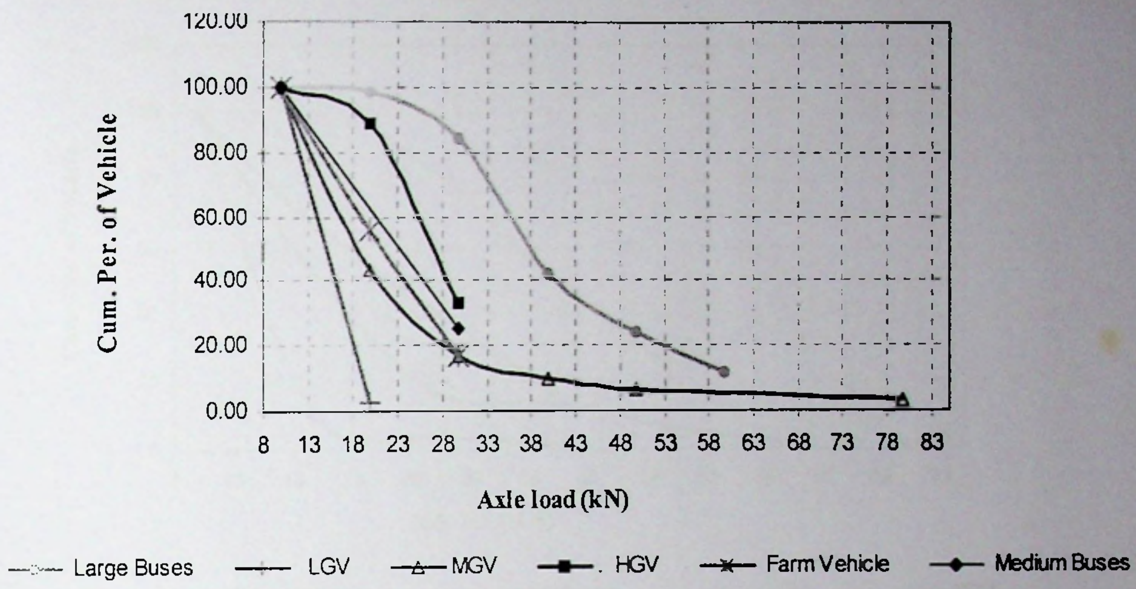

Figure 3.2: Axle Distribution of Chillaw - Iranawila - Nainamadama Rd

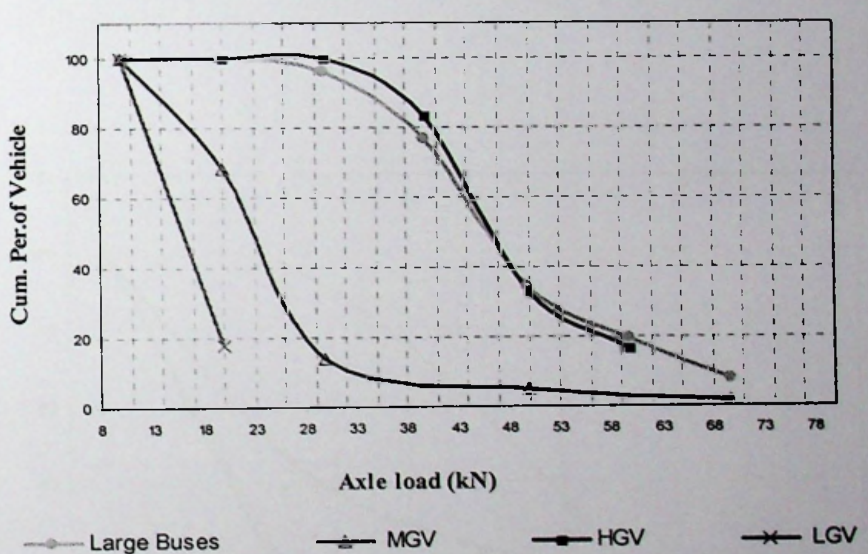

Figure 3.3: Axle Distribution of Bathuluoya - Dewalahandiya Rd

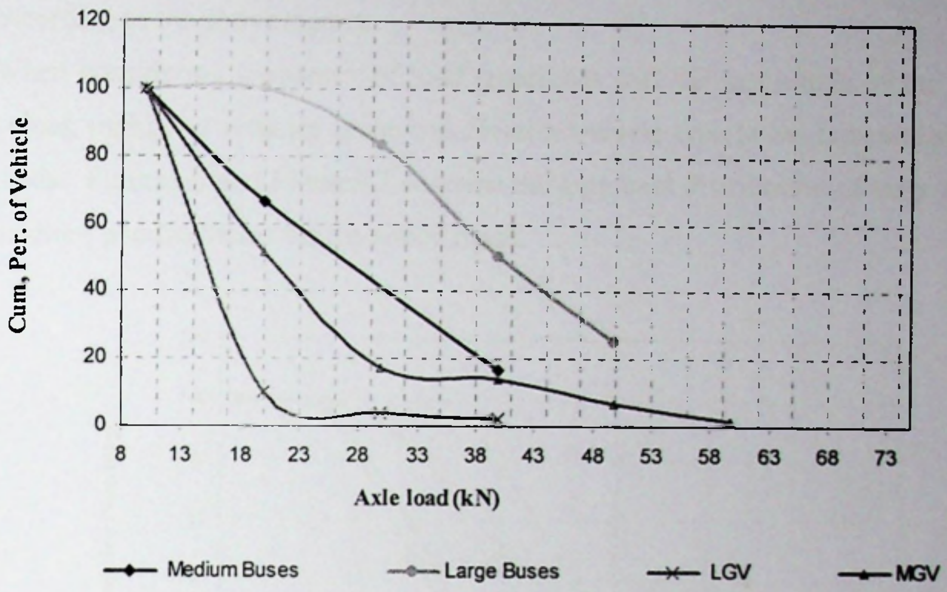

Figure 3.4: Axle Distribution of Udupila (Delgoda) of Kirillawala - Udupila Rd

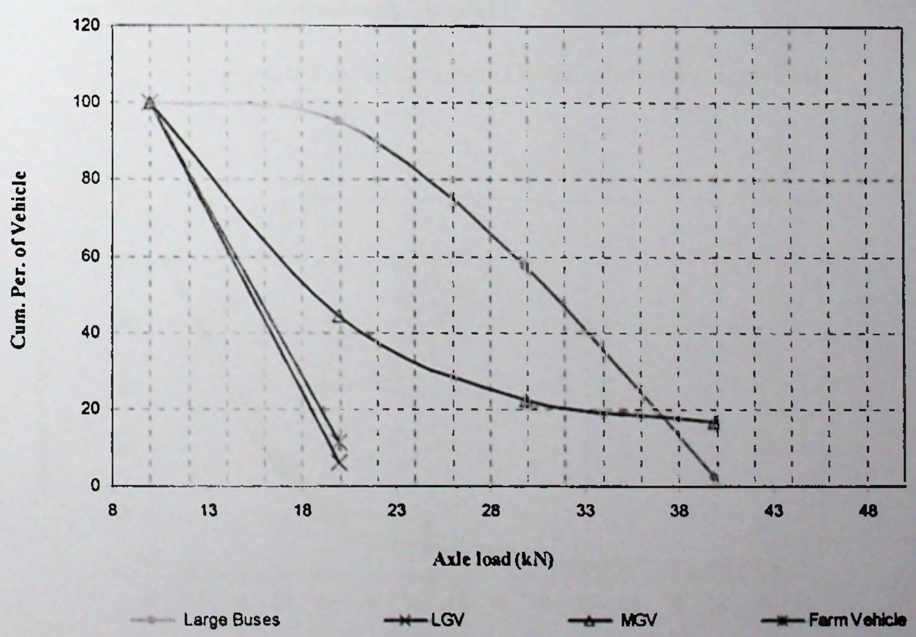

Figure 3.5: Axle Distribution of Neluwa-Kadihingala- Dellawa- Morawaka Rd

When increasing the axle load value, frequency of the load repetition is lower according to the above figures.

When considering frequency of load repetitions and the magnitude of the axle load values, mid good vehicles is the considerable vehicle type in Sri Lankan low volume roads. Figure3.6 and Figure3.7 describe the axle load distribution of large buses and medium good vehicles for the above roads.

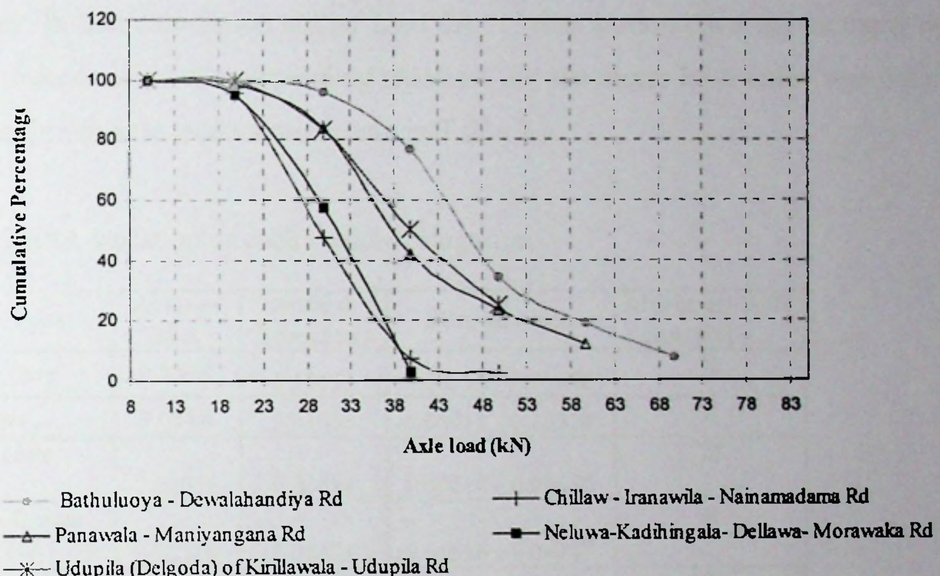

Figure 3.6: Axle Load Distribution of Large Bus

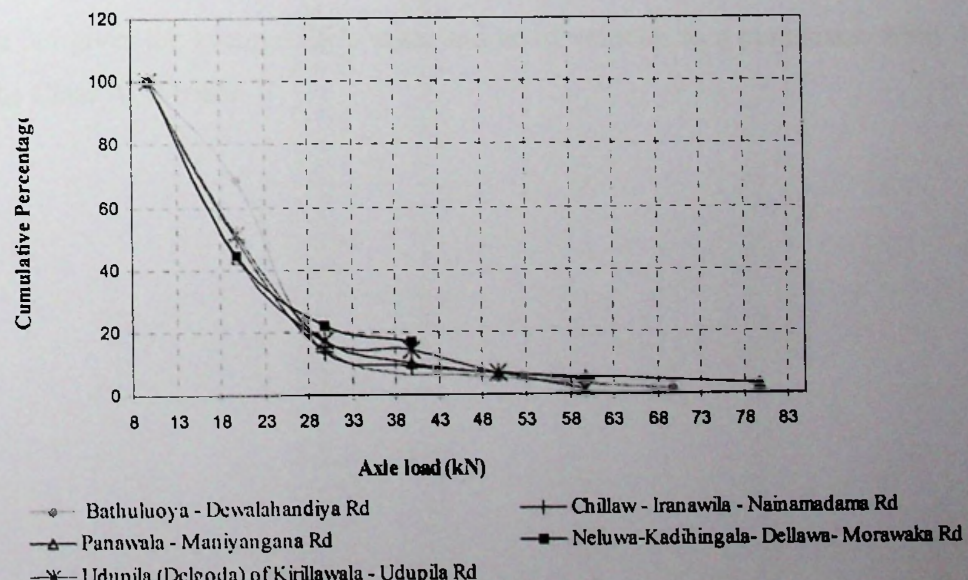

Figure 3.7: Axle Distribution of Medium Good Vehicles

In that analyzing, axle load values vary from 30 kN to 80 kN (3 to 8 tons) (wheel load was varied 15 kN to 40 kN).

The damage to a pavement will increases very rapidly with increasing axle loads. The damaging effect of each type of vehicle can be determined by analyzing the ESA variation of each type of vehicles. The damaging effect of vehicle can be determined relative to a standard axle load (80kN).

Table 3.3 shows the lower and upper limit of ESA value for each of vehicle categories. In that calculation author used the "t" distribution (two tail method) with 90% confidence level. Corresponding axle load for the upper ESA value was entered to the maximum axle load value column in Table 3.3.

Table 3.3 ESA variation of each vehicle categories

Vehicle Type	Average ESA	Standard Deviation	ESA variation	Maximum Axle Load (kN)
Medium Bus	0.0076	0.00655	0.00123 - 0.01396	31
Large Bus	0.0689	0.06656	0.00418 - 0.13354	51
Light Goods Vehicle	0.00059	0.00068	0.00010 - 0.00125	18
Medium Goods Vehicle (<8.5 T)	0.03216	0.01626	0.01636 - 0.04797	41
Large Lorries (>8.5 T)	0.06386	0.07697	0.02021 - 0.13866	52
Farm Vehicles	0.00242	0.00379	0.00010 -0 .00610	25

Table 3.4 gives the average ESA value and no.of vehicles as a percentage from ADT for the Class A, B roads.

Table 3.4 ESA variation of each vehicle categories in Class A-B roads

ROAD NAME :		Weyangoda - Ruwanwella (B445)		Avissawella - Hatton - N'Eliya Rd (A007)		Pelmadulla-Embilipitiya-Nonagama (A018)		Colombo - Horana (B084)	
LOCATION :		Gonagaldeniya -2008		Thalduwa -2009		Embilipitiya - 2008		Kahathuduwa-2009	
	VEHICLE TYPE	AVG. ESA	MCC %	AVG. ESA	MCC %	AVG. ESA	MCC %	AVG. ESA	MCC %
1	Motor Cycle		41.33		24.99		28.78		43.95
2	Three Wheel		29.68		22.12		11.29		13.36
3	Car		4.86		15.16		13.76		12.3
4	Van		6.40		10.05		6.66		9.16
5	Medium Bus	0.0060	2.00	0.0383	1.69	0.0067	0.82	0.0061	1.74
6	Large Bus	0.1044	3.39	0.8395	9.78	0.3397	8.36	0.1345	4.88
7	Light Goods Vehicle	0.0028	2.08	0.0029	4.24	0.0052	8.19	0.0015	4.01
8	Medium Goods Vehicle (<8.5 T)	0.0479	7.17	0.1457	7.20	0.0570	14.72	0.1581	5.11
9	Large Lorries (>8.5 T)	0.8029	2.54	3.3635	4.32	8.4647	5.18	4.7109	4.99
10	Three Axles Vehicle Combined			11.9258	0.20	2.8501	0.66	1.7476	0.29
11	Three Axles Vehicle Articulated						0.00		
12	Four Axles Vehicle Articulated			17.3004	0.07	4.4804	0.63	0.2346	0.12
13	Five Axles Vehicle Articulated			22.8424	0.01		0.03	0.1000	0.04
14	Six Axles Vehicle Articulated						0.03		
15	Farm Vehicles		0.54		0.15	0.0001	0.90	0.0042	0.06
	ADT		1560		10351		4014		6223

There is significance impact due to heavy good vehicles in Class A, B roads since the ESA values of Class A, B roads are higher than ESA value of low volume roads. The damaging effect to the pavement will due to large lorries, three axles vehicle combined and four axles vehicle combined in Class A, B roads. When compared to low volume roads the damaging effect due to only medium good vehicles. So, the damaging effects are high in Class A, B roads relative to low volume roads.

CHAPTER 4
EXPERIMENTAL INVESTIGATIONS

4.1 DETERMINATION OF RECYCLED MATERIAL PROPERTIES

While recycled aggregate is handled similarly to new aggregate, some differences between new and recycled aggregate must be addressed. The tests and specifications, which are applicable for conventional materials, may be inappropriate for evaluation of non-conventional materials, such as industrial wastes. This is because the material properties, for example, particle sizes, grading and chemical structure, may differ substantially from those of the conventional materials. Thus for an appropriate assessment of these materials, new tests are to be devised and new acceptability criteria are to be formed. However, with the advent of performance-based tests, it is expected that the performances of the conventional as well as new materials can be tested on a same set-up and be compared.

Laboratory cast concrete was used as the source of recycled concrete aggregates for the study. Recycling aggregate involves breaking old concrete, removing the reinforcement and crushing the resulting material to a specified size and gradation. Samples used for test were produced in single size fraction (5-20mm) using commercial plant comprising primary jaw and secondary cone crushers and screens.

Recycled aggregate properties were determined in terms of grading, density, water absorption and aggregate impact value test.

4.1.1Gradation of Recycled Aggregate

Grading refers to the distribution of particle size present in aggregates. The grading plays a significant role in influencing concrete properties, including drying shrinkage, workability of concrete and also the production cost. Almost any gradation can be achieved with recycled aggregate. Crushing may leave some residual dust on the aggregate surfaces.

Coarse and fine aggregate are generally sieved separately. Crushing process produces both the coarse and fine fraction. Therefore the overall gradation was also checked. Test was carried out according to the BS standard. Table 4.1 shows sieve analysis test result of RCM. Figure 4.1 shows the gradation curve with specified limits.

Table 4.1: Sieve analysis test result for RCM (Overall Gradation)

Sieve size (mm)	% of Passing	BS Limit	
		Min	Max
37.5	100	100	100
28	99.2	96	100
20	93.6		
14	76.8		
10	64.4		
6.3	45.7		
5	38.8	35	55
3.35	31.7		
2.38	27.3		
1.8	24.5		
1.18	18.9		
0.6	11.8	10	35
0.425	9.7		
0.3	7.8		
0.15	4.6	0	10

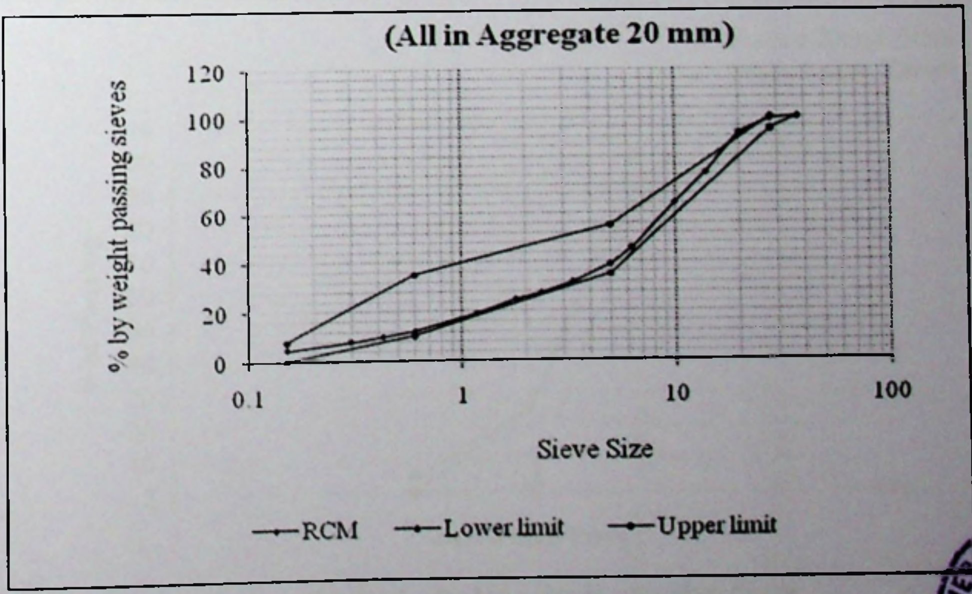

Figure 4.1 Sieve analysis test result of RCM (Overall Gradation)

From test result it was found that coarse fraction and fine fraction is about 68% & 32% of total aggregate content respectively. Therefore, both coarse and fine fraction can be replaced from recycled concrete material. But due to the higher absorption value of fine material the workability of the mix will be less. Since it is also intended to replace only the coarse fraction with recycled material, the gradation of fine and coarse aggregate was checked separately. The grading curves of coarse and fine aggregate are shown in Figure 4.2 and 4.3 respectively.

Grading for Recycled Coarse Aggregate

Nominal maximum size of recycled aggregates is 20 mm. Particle size distribution test result and the specification limits shown in Table 4.2. The grading curve of recycled aggregate is within the limit of 20mm single sized aggregate.

Table 4.2: Sieve analysis test result for RCM (Coarse Fraction)

RCM- Sieve Analysis Results									
Sieve Size	Retained	ΣRetained	% Σ(Ret:)	%Passing	BS 882				
(1) 20mm	Lab				- Graded		Single sized	
37.5					100		100	
25	28.2	28.2	1.124492	98.88				
20	219.2	247.4	9.865221	90.13	90	100	85	100
10	1637.4	1884.8	75.15751	24.84	36	60	10	25
4.75	623	2507.8	100	0.00	0	10	0	5
	2507.8							

- Graded 20mm -5mm
- Single sized -20mm

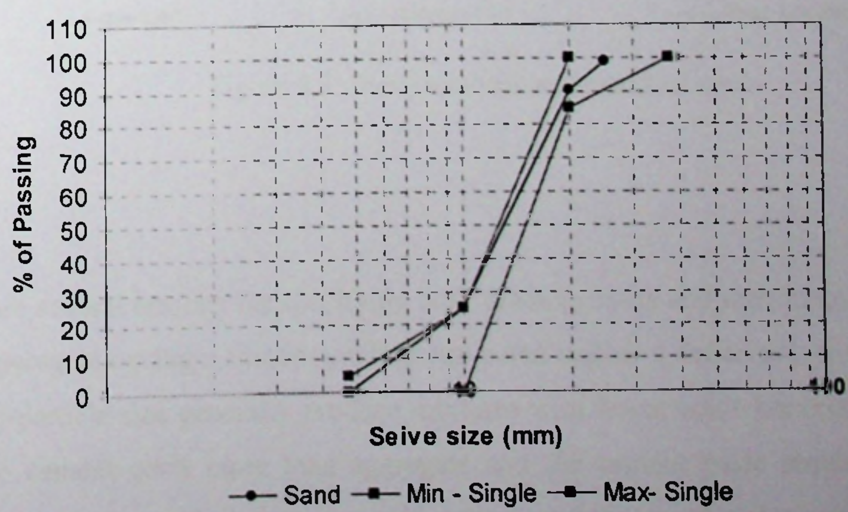

Figure 4.2: Sieve analysis test result of RCM (Coarse Fraction Gradation)

Grading for fines (natural sand)

Test result of sieve analysis of natural sand is given in Table 4.3.

Table 4.3: Sieve analysis test result for sand

Sieve Size	Retained	ΣRetained	% Σ(Ret)	%Passing	BS 882							
(2)Sand					Overall		Coarse		Medium		Fine	
10					100							
5	55.7	55.7	7.467489	92.53	89	100						
2.36	111	166.7	22.34884	77.65	60	100	60	100	65	100	80	100
1.18	211.4	378.1	50.69044	49.31	30	100	39	90	45	100	70	100
0.6	203.3	581.4	77.94611	22.05	15	100	15	54	25	80	55	100
0.3	118.4	699.8	93.81955	6.18	5	70	5	40	5	45	5	70
0.15	36.1	735.9	98.65934	1.34	0	15						
0	10	745.9	100	0.00								
	745.9											

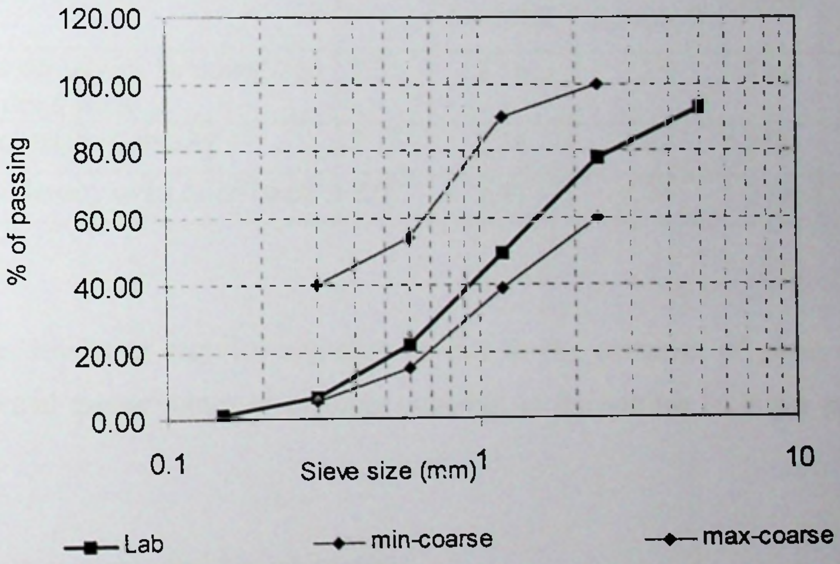

Figure 4.3: Sieve analysis test result of sand

There are several reasons for specifying both grading limits and maximum aggregate size. Aggregate having a smooth grading curve and neither a deficiency nor excess of any one-particle size generally produce mixtures with fewer voids between particles. Because cement costs more than aggregate and the cement paste requirement for concrete increases with increasing void content of the combined aggregate, it is desirable to keep the void content as low as possible.

4.1.2 Density of RCM

Density is the most fundamental classification parameter. Aggregate density constitutes a very important parameter for accurate batching and concrete mix design, which is influenced by variations in the composition of the recycled materials. For coarse recycled aggregate test was carried out for two samples.

The test results are listed in Table 4.4 for fine recycled aggregate (FRA) & coarse recycled aggregate (CRA). Typical density values for fine aggregate (sand) and coarse aggregate (NA) are also listed in Table 4.4.

Table 4.4 Recycled Material Properties

Properties of aggregate	**FRA**	**CRA**		**Sand**	**NA**
		Sample1	**Sample 2**		
Relative density of Saturated and surface dried basis	2.31	2.56	2.39	2.66	2.71
Apparent relative density	2.73	2.76	2.62	2.70	2.70
Relative density oven dried basis	2.07	2.44	2.34	2.64	2.64

The lower density of recycled aggregate is due to the existence of pores and less dense residual mortar lumps or particles adhering to the surface of larger aggregate particles.

Bulk density of coarse and fine aggregate

- Bulk density of coarse aggregate 1303.7 kg/m^3
- Bulk density of fine aggregate 1211.1 kg/m^3

4.1.3 Water Absorption of RCM

Water absorption is the amount of moisture absorbed in the aggregate. The water absorption capacity is based on saturated surface dry condition and oven-dried condition. Australian Standard HB64 (2002) mentioned that the amount of water in concrete mix has direct effect on the setting time and compressive strength of concrete. It also stated that adjustment should be made to moisture content of the aggregate before preparing a mix design.

Water absorption is also one of the key performance indicators for recycled aggregate (RA) and it was determined in accordance with procedure given in ASTM C128 & C127. Water absorption obtained for coarse and fine recycled aggregates are given below.

- Coarse aggregate - 4.75 %
- Fine aggregate - 11.73 %

Water absorption values of sand and natural coarse aggregate are 0.87% and 0.33% respectively. According to the test result the water absorption of recycled aggregate is higher than that of ordinary aggregates.

RA exhibits water absorption higher than 15 % is not acceptable in many countries: a maximum of 10 % is accepted for many construction applications (Jose, 2002; Katz, 2003; Rao, 2005). Since the absorption is a significant parameter in the concrete mix design, it has to be paid greater attention when taking the effective water amount.

4.1.4 Aggregate Impact Value (AIV)

Aggregate impact value indicates the resistance of aggregate to sudden impact. For heavy-duty concrete elements, AIV should be less than 25%. For subbase application it should be less than 35% and 30 % for other lower-grade applications.

Aggregate AIV test was carried out according to the BS standard. Aggregate impact value obtained for recycled coarse aggregate was 14.9 %. It satisfies even for heavy-duty concrete.

4.2 DEVELOPMENT OF MIX DESIGN FOR RCA CONCRETE

Mix Design Procedure

Mix design can be defined as the process of selecting and proportioning the constitutive materials of concrete to produce an economical concrete, which has certain minimum desirable properties such as strength, workability and durability.

DOE method is used for concrete mix proportioning with normal aggregate. Concrete trial mix was also prepared with recycled aggregate based on DOE method.

Normally, specified strength for low volume concrete roads is grade 20. Therefore characteristic strength of 20 N/mm^2 at 28 days was considered for concrete low volume roads design.

Concrete mix design procedure was given below.

Calculation of quantities for trial mix according to DOE method

Specified characteristic strength of concrete = 20 N/mm^2 at 28 days with 10% defective

As there is insufficient data to calculate the variation in strength of concrete produced in the laboratory, the standard deviation was obtained from curve A given Figure 4.4.

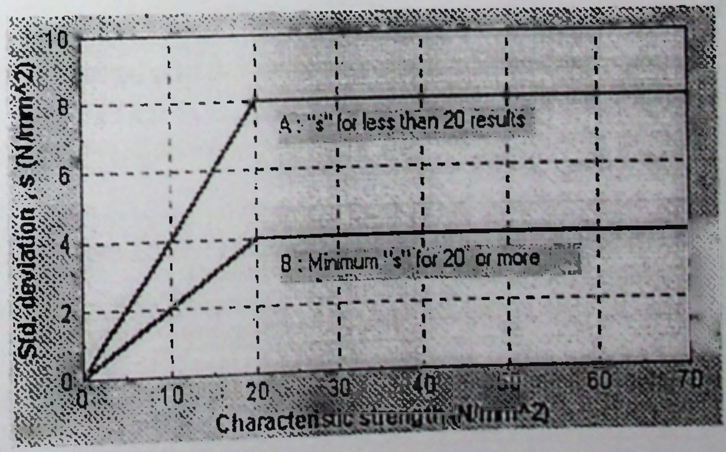

Figure 4.4: Relationship between std.deviation and characteristic strength (DOE method published Figure)

Standard deviation = 8 N/mm^2

K= 1.28 for 10 % defective from Table 4.5

Table 4.5 Probability factor K (DOE method published Table)

% of Defective	K
10	1.28
5	1.64
2.5	1.96
1	2.33

Margin = Kx Standard deviation

= 1.28 x 8

= 10.24 N/mm^2

Target mean Strength = characteristic strength + margin

= 20 N/mm^2 + 10.24 N/mm^2

= 30.24 N/mm^2

Cement Type = Ordinary Portland cement

Aggregate type Coarse: crushed

Fine : uncrushed

From Table 4.6, approximate 28 days compressive strength of a concrete with free water/cement ratio of 0.5 made out of the crushed aggregate and cement is 48 N/mm^2.

Table 4.6 Strength of normal concrete mixes at 0.5 w/c ratio (DOE method published Table)

Type of Cement	Type of coarse aggregate	Age (days)			
		3	7	28	91
O.P.C or S.R.P.C	Uncrushed	22	30	42	49
	Crushed	27	36	48	56
R.H.P.C	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

The curve through (0.5, 48) parallel to the family of curves in Figure 4.5, free water / cement ratio of 0.66 at the target mean strength.

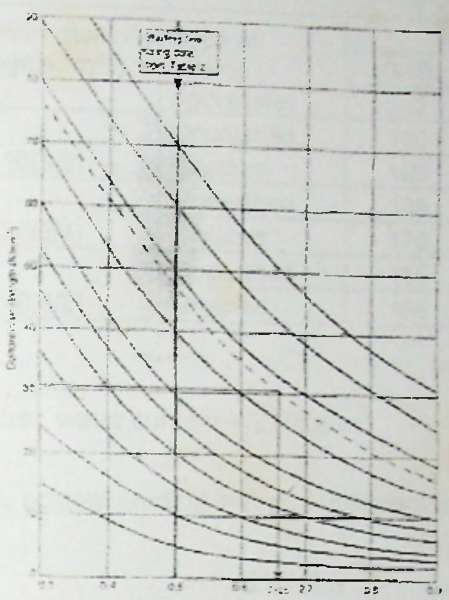

Figure 4.5 : Relation between compressive strength and free water/ cement ratio

Specified maximum free water/ cement ratio 0.60. Use the lower value.

Hence the free water cement ratio = 0.60

The specified slump = 60 mm

The maximum size of aggregate is 20 mm. From Table 4.7, the approximate free water content required to give the specified slump with maximum size of aggregate is 225 kg/m^3 for crushed aggregate and 195 kg/m^3 for uncrushed aggregate.

Table 4.7 Approximate free water content required to give various levels of workability (DOE method published Table)

Maximum size of aggregate (mm) (in)	Type of coarse aggregate	Slump (mm), V-B (sec)			
		0-10	10-30	30-60	60-180
		>12	6-12	3-6	0-3
10(3/8)	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20(3/4)	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40(3/2)	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Used free water content = 210kg/m^3

Hence, cement content = Free water content / (w/c) ratio

= 210 /0.6

= 350 kg /m^3

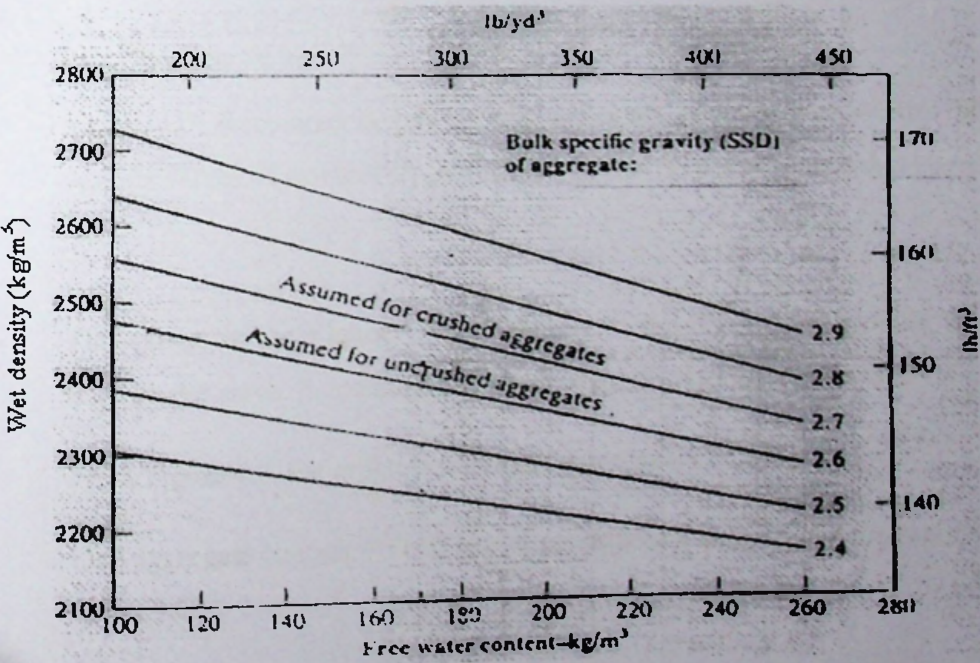

Figure 4.6: Estimated wet density for fully compacted concrete (DOE method published Figure)

The relative density of aggregate on a saturated surface dry basis = 2.56

From Figure 4.6, concrete density = 2350 kg/m^3

(Total aggregate content = concrete density – free water content – cement content)

Total aggregate content = 1790 kg/m^3

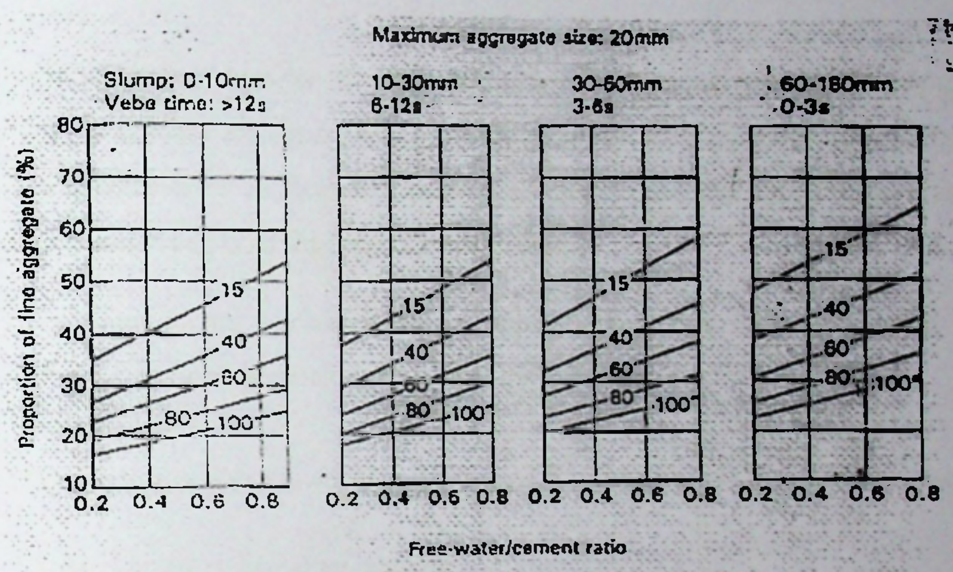

Figure 4.7: Recommended % of fine aggregate as a function of free w/c ratio for various values of workability and max.agg.sizes (DOE method published Figure)

The curves in the Figure 4.7 are relevant to the % of fines passing through a 600 micrometer sieve. Percentage of fines passing through that curve was 70%.

From Figure 4.7, the proportion of fine aggregate is 34.8%.

Fine aggregate content = Total aggregate content x fine aggregate proportion

= 1790 x 34.8 %

= 623 kg/m^3

The fine aggregate content = 623 kg/m3

Coarse aggregate content = Total aggregate content – fine aggregate content

$$= 1790 - 623$$

$$= 1167$$

Coarse aggregate content = 1167 kg/m3

For a mix adjustment for the estimated coarse and fine aggregate contents should be done, to account for the surface moisture after the calculation of required quantities. Adjustments were sequentially made according to the moisture contents and water absorption capacity of the respective aggregates.

To account for the surface moisture, adjustment for the estimated coarse and fine aggregate contents is determined using eq 4.1.

$$\text{Moist aggregate content} = \text{SSD aggregate content} * \left[1 + \left(\frac{MC - WA}{100}\right)\right] \quad \text{—— eq 4.1}$$

Where; MC = Moisture content

WA = Water absorption

To determine the required moist coarse aggregate content and fine aggregate content water absorption value and moisture content of coarse and fine aggregate should be known values. Water absorption value of each aggregates are determined according to ASTM C128 & C127 as in section 4.1.3. Surface moisture is determined by oven drying. Calculation sheet to determine the required moist coarse aggregate content is as follows.

Adjustment of estimated coarse and fine aggregate content to account for the surface moisture

Water absorption of coarse aggregate (WA_c) = ...%

Moisture content of coarse aggregate (MC_c) = ...%

Water absorption of fine aggregate (WA_f) = ...%

Moisture content of fine aggregate (MC_f) = ...%

Moist coarse aggregate content =SSD coarse aggregate content * $\left[1+\left(\frac{MCc-WAc}{100}\right)\right]$

Moist fine aggregate content = SSD fine aggregate content * $\left[1+\left(\frac{MCf-WAf}{100}\right)\right]$

Where; SSD = Saturated surface density

The required fine aggregate proportion was about 34.8%. According to the particle distribution test, the recycled aggregate consists of 62% coarse aggregate and 38% fine aggregate. Natural coarse aggregate and fine aggregate was replaced with recycled aggregate as the first trial (mix-A).

Testing was carried out to find slump, compressive strength, modulus of elasticity and flexural strength for mix A. Compressive strength tests on standard 150 mm concrete cubes were carried out at age's 7days, 14 days and 28 days. Flexural strength and modulus of elasticity test was carried out at 28 days.

Figure 4.8 & Figure 4.9 show the experimental set up for slump test and flexural strength test.

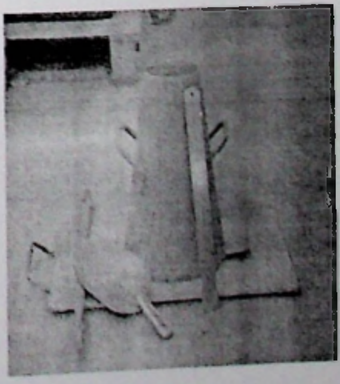


Figure 4.8: Slump test

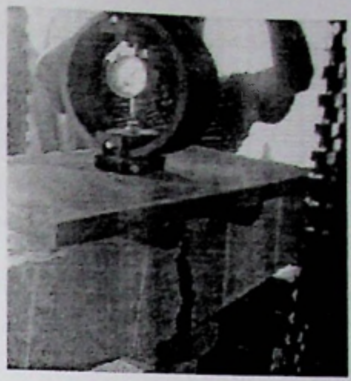

Figure 4.9: Flexural strength test

Obtained concrete properties for mix- A are given below

Slump	- 25mm
Compressive strength	-20.12 N/mm^2
Modulus of elasticity	-12375 MPa
Flexural strength	- 1.919 N/mm^2

Result indicates that it is difficult to obtain workable mix if both fine and coarse fractions are replaced by recycled material. And also it couldn't achieve the target compressive strength from the trial mix-A. Therefore, to obtain a workable mix, mix B-1 was designed by replacing recycled fine aggregate with river sand.

Relative saturated surface dried density of aggregate was taken as 2.39 in the calculation. DOE method was carried out for fixed cement content of 320 kg/m^3. Maximum free water- cement ratio is taken as 0.58. Mix proportion calculation sheet for mix B -1 is given in Table 4.8.

Table 4.8 Concrete mix design form for mix- B-1

	Item	Reference or calculation		Values	
1	Characteristic Strength	Specified		20N/mm^2 at 28 days	
	Standard deviation	Fig 4.4		8N/mm^2	
	Margin	Kx Standard deviation		10.24 N/mm^2	
	Target mean strength	$f_m = f_s + M$		20 + 10.24 = 30.24 N/mm^2	
	Cement type	Specified		OPC	
	Aggregate type: coarse Aggregate type: fine			Crushed Uncrushed	
	Free-water/cement ratio	Table 4.6, Fig 4.5		0.66	
	Maximum free-water/cement ratio	Specified		0.58 Use the lower value 0.58	
2	Slump	Specified		75 mm	
	Maximum aggregate size	Specified		20 mm	
	Free – water content	= 320 * 0.58		185.6 kg/m^3	
3	Cement content			**320 kg/m^3**	
4	Relative density of aggregate (SSD)			2.39	
	Concrete density	Fig 4.6		2225.6 kg/m^3	
	Total aggregate content	= 2225.6-185.6-320		1720 kg/m^3	
5	Grading of fine aggregate	Percentage passing 600 m sieve		78 %	
	Proportion of fine aggregate	Fig 4.7		30%	
	Fine aggregate content	= 1720* 30		516 kg/m^3	
	Coarse aggregate content	=1720-516		1204 kg/m^3	
Quantities		Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
Per trial mix of 1 m^3		320	185.6	516	1204

Testing was carried out to find slump, compressive strength, modulus of elasticity and flexural strength for mix B -1 also.

Slump	- 147mm
Compressive strength @ 28 day	- 29.15 N/mm^2
Modulus of elasticity	-13043 MPa
Flexural strength	- 2.867 N/mm^2

The curve was plot in Figure 4.5 through the point (0.58, 29.15) parallel to the family of curves. Then for compressive strength of 30 N/mm^2 free water cement ratio was determined. For that modified free water/cement ratio of 0.55 another mix proportions was developed for fixed cement content of 320 kg/m^3 according to the above mix design procedure. It was named as mix B-2.

Test results of fresh and harden properties of mix B -2 are given below.

Slump	-38 mm
Compressive strength @ 28 day	-30.99 N/mm^2
Modulus of elasticity	-14825 MPa
Flexural strength	- 3.870 N/mm^2

Since it wasn't a workable mix, it was modified by increasing the water/cement ratio to 0.56. Obtained concrete properties are as follows.

Slump	-75 mm
Compressive strength @ 28 day	-31.12 N/mm^2
Modulus of elasticity	-13564 MPa
Flexural strength	- 3.630 N/mm^2

Obtained fresh and harden concrete properties for each of the trial mixes are summarized in Table 4.9 and Table 4.10 respectively.

Table 4.9 Mix proportions for RAC

Mix	Aggregate Type		Target Strength (N/mm^2)	Mix Proportions, kg/m^3			
				PC	Free Water	Aggregates amount (kg)	
	Coarse	Fine				Coarse	Fine
A (W/C 0.6)	RA	RA	30	350	210	1167	623
B-1 (W/C 0.58)	RA	N	30	320	185.5	1204	516
B-2 (W/C 0.55)	RA	N	30	320	176	1218	522
B-3 (W/C 0.56)	RA	N	30	320	180	1211	519

RA – Recycled aggregate

N- River sand

Table 4.10 Fresh and harden concrete properties with RA

Mix Type	Water/ cement ratio	Fresh Properties	Harden Concrete Properties		
		Slump (mm)	Compressive Strength @ 28 days (N/mm^2)	Elastic Modulus (MPa)	Flexural Strength (N/mm^2)
A	0.6	25	20.12	12375	1.919
B-1	0.58	147	29.15	13043	2.867
B-2	0.55	38	30.99	14825	3.870
B-3	0.56	75	31.12	13564	3.630

The influence of coarse RA on compressive strength development is plotted in Figure 4.10.

Table 4.11 Compressive Strength Data

Age (days)	Compressive Strength (N/mm^2)			
	A W/C 0.6	**B-1** W/C 0.58	**B-2** W/C 0.55	**B-3** W/C 0.56
7	14.26	22.22	26.07	22.44
14	18.47	26.24	29.30	28.22
28	20.12	29.15	30.99	31.12

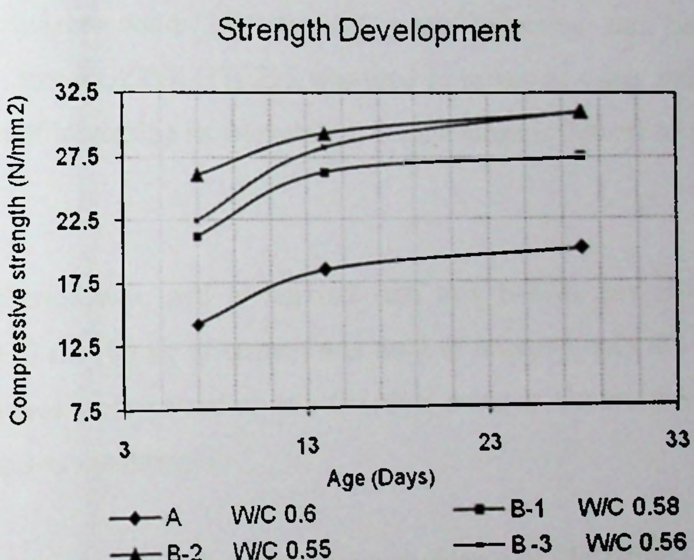

Figure 4.10: Strength development of RCM concrete

4.3 IMPROVEMENT OF THE PROPERTIES OF FRESH AND HARDENED RCA BY USING ADMIXTURE

Admixtures can be used to modify / improve the properties of fresh and hardened concrete. Three advantages could be achieved by using water-reducing admixture. Advantages of water-reducing admixture are;

1. Increase the workability
2. Achieve higher compressive strength and
3. Cement saving

However, all three benefits might not be obtained at the same time.

There are two type of water reducing admixtures. Those two types are normal plasticizers and superplasticizers. Water reduction of 5% to 10% can be obtained from normal plasticizers while 25% to 30% water reduction can be obtained from superplasticizers. POZZOLITH 225 was used in mixes as water reducing admixture with the aim of increasing its workability, dosage range is 280 ml to 560 ml/100 kg of cement.

Minimum dosage was used to improve trial mix B-1 & mix B-3 while average dosage of 420 ml/100 kg of cement was used to improve only the mix B-3. Those improved mixes were named as mix C (when using minimum dosage) and mix D (when using average dosage).

Mix C-1 for improved mix B-1 with minimum dosage of admixture
Mix C-3 for improved mix B-3 with minimum dosage of admixture
Mix D-3 for improved mix B-3 with average dosage of admixture

With aim of improving strength of trial mixes, the water content was reduced by 10%. Test results of concrete properties when using the minimum and average dosage of admixture are given in Table 4.12.

Table 4.12 Improved concrete properties using admixture

Concrete Properties		Minimum dosage of POZZOLITH 225		Average dosage of POZZOLITH 225
		mix C-1	mix C-3	mix D-3
Compressive Strength (N/mm^2)	7 days	23.34	23.45	24.93
	14days	27.87	28.48	28.82
	28days	29.21	31.89	32.56
Slump (mm)		105	67	71
Flexural Strength (N/mm^2)		3.01	3.71	3.78

From the test result there is a little improvement in concrete properties by using the plasticizing admixtures. And also the average dosage of admixture showed better results than minimum dosage of admixture.

4.4 COMPARISON OF NORMAL AGGREGATE CONCRETE PROPERTIES AND RECYCLED AGGREGATE CONCRETE PROPERTIES

To evaluate the economic feasibility of this project mix proportions obtained with natural aggregates and recycle aggregate are given in Table 4.13.

Table 4.13 Comparison of concrete properties for normal aggregate and recycled aggregate

Properties of Concrete Mix	Normal aggregate	Recycled aggregate
Slump (mm)	85	75
Compressive Strength @ 28 days (N/mm^2)	36.92	30.99
Flexural Strength@ 28 days (N/mm^2)	3.98	3.63
Elastic Modulus@ 28 days (MPa)	23521	13564

When compared normal aggregate concrete properties with recycled aggregate concrete properties, slump, compressive strength and flexural strength values of recycle aggregate concrete mix are lower than those of normal concrete aggregate properties. The modulus of elasticity of recycled aggregate concrete is significantly lower than normal aggregate concrete.

Pavement design was carried out for the properties of mix B-3.

CHAPTER 5
DETERMINATION OF PAVEMENT DIMENSION

5.1 Determination of a Suitable Pavement Width for Rigid Pavement Based on the Maximum Axle Load in Provincial Roads

An optimum pavement dimension for provincial roads was proposed based on the traffic volume and the recycled aggregate concrete properties. Fatigue analysis (to control fatigue cracking) and erosion analysis (to control foundation and shoulder erosion, pumping and faulting) are the two design criteria in rigid pavement design. Fatigue analysis will usually control the design of light – traffic pavements while erosion analysis controls the design of medium-and heavy traffic pavement. Therefore erosion analysis was not considered to propose a pavement thickness for provincial roads. Fatigue analysis was regarded as the main parameter to propose a suitable width for rigid pavement. It is speculated that concrete will not fail by fatigue when the stress ratio is smaller than 0.5. The required slab thickness should be obtained such that the stress ratio is limiting to 0.5. The maximum generated stress-strain can be obtained from FEACON software. FEACON is 2D finite element software.

Stress & strain generated within the slab was determined using FEACON based on axle load of provincial road. Three loading panels were considered for the analysis. The loading panel was the mid slab panel. Required flexural strength was determined based on the stress value obtained from FEACON. Required flexural strength was compared with the obtained recycled aggregate concrete properties.

According to axle load analysis in Chapter 3 (Table3.3) maximum axle loads was 52 kN in provincial roads. Stress-strain generated within the slab was determined using 2D finite element modeling software (FEACON) based on axle load of 52 kN to a pavement thickness of 150mm (6in) to find out a suitable pavement width.

Normally the roads with a less traffic volume are designed with a pavement width of 2.4m (8ft), 3.05m (10ft) and 3.66m (12ft)in Sri Lanka. Stress variation was determined for slab width of 2.4m (8ft), 3.05m (10ft) and 3.66m (12ft) to find out a suitable pavement width.

In this analysis three wheel paths were considered; slab edge, middle of slab and 0.3m (1ft) away from the slab edge. Two loading positions were considered for the analysis, i.e. corner and middle. Considered wheel paths and the loading positions are given in Appendix D.

The critical loading position for all wheel paths is the corner loading position since the induced stresses for corner loading are higher than that of middle loading position. Figure 5.2 shows wheel path which gives higher stresses. Therefore stresses were determined for corner loading position (when two wheels at the joint) by varying the pavement widths. The stress variation for typical pavement widths used [2.4m (8ft), 3.05m (10ft) and 3.66m (12ft)] are shown in Figure 5.1.

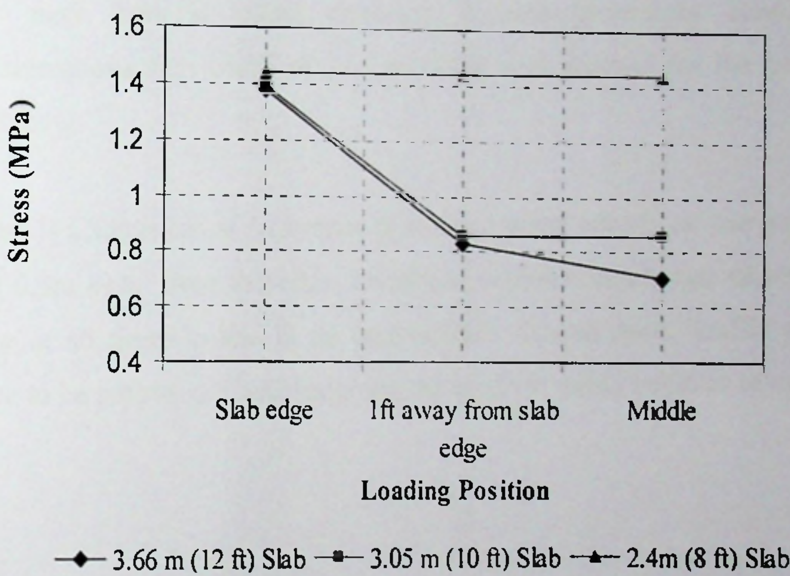

Figure 5.1: Stress Variation according to Slab width

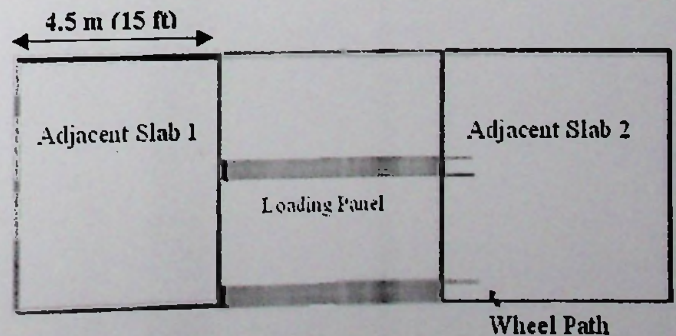

Figure 5.2: Critical wheel path

It can be seen that 2.4m (8ft) slab is under high stresses for all wheel paths. Stresses induced in the concrete pavement slab width of 3.05m (10ft) or 3.66m (12ft) are low compared with that of 8ft when the wheel path is away from slab edge. On the other hand the probability of wheel moves to the edge is very low since the pavement is wide enough to keep lateral clearance.

Induced stresses for the slab width of 3.66m (12ft) are same for the middle wheel path and the wheels are moving 0.3m (1ft) away from slab edge since the lateral clearance is same for two wheel paths.

Probability to move vehicle to edges is same in 3.66 m (12ft) slab and 3.05m (10 ft) slab since there is lateral clearance in both pavements. Based on the above considerations slab width of 3.05 m (10ft) was selected for the continuation of the analyzing.

There is a significance difference in stresses when wheels are moving at the slab edge and 0.3m away from the edge. Therefore vehicles should not allowed to drive to the edge at all times unless in an unavoidable circumstance. Traffic claming measures have to be proposed when designing the roads to avoid vehicles to move to edge.

5.2 Determination of Minimum Required Pavement thickness for RAC and NAC

The obtained elastic modulus values of RAC trial mixes are in the range of 12 x 10^3 N/mm^2 to 15x10^3 N/mm^2. For normal aggregate concrete, elastic modulus was 23521 N/mm^2. Stresses in the loading slab were obtained for a concrete pavement thickness of 100 mm (4in), 125 mm (5in), 137.5 mm (5.5in) & 150 mm (6in) for an axle load of 52 kN for range of elastic modulus of 10x 10^3 N/mm^2 to 25 x 10^3 N/mm^2.

Fig 5.3 shows the stress variation within the slab for pavement thickness of 100 mm (4in), 125 mm (5in), 137.5 mm (5.5in) & 150 mm (6in) with a subgrade CBR value of 12.

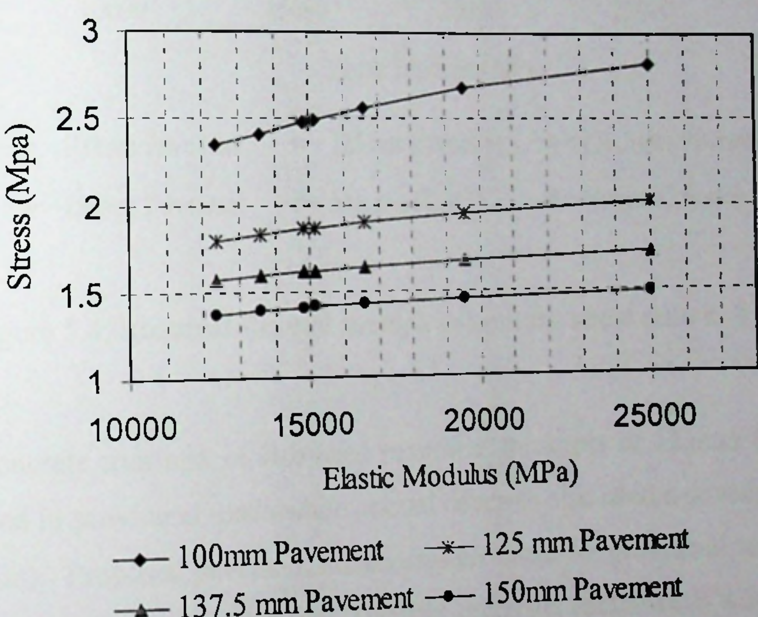

Figure 5.3: Stress variation for different Elastic Modulus for 52 kN axle load

The required flexural strength was computed for the generated stress values to result in an unlimited number of repetitions in fatigue. Stress ratio should be limited to 0.5 for allowing unlimited repetitions without fatigue failure.

$$Stress\ Ratio = \frac{Actual\ Generated\ Stress}{Modulus\ of\ Rufture}$$

$$Required\ Flexural\ Strength = \frac{Generated\ Stress}{0.5}$$

Figure 5.4 shows that the required flexural strength increases with elastic modulus of concrete.

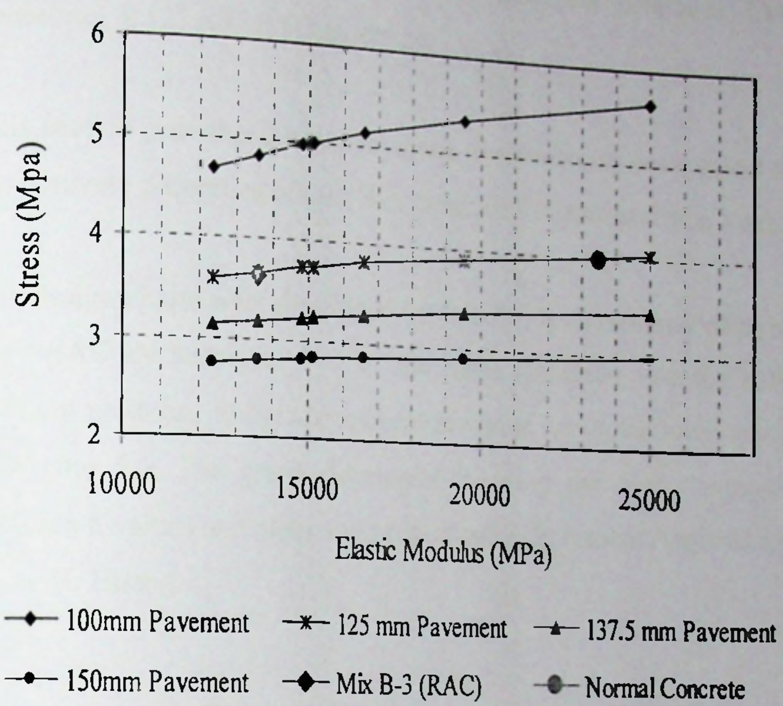

Figure 5.4: Required flexural strength to limit the stress ratio to 0.5

Concrete trial mix of B-3 need pavement thickness of 125mm (5in) for maximum axle load in provincial roads while normal concrete also need a pavement thickness of 125mm (5in). Proposed pavement thicknesses are same for provincial roads with RAC (recycled aggregate concrete) and NAC (normal aggregate concrete). It's due to the higher modulus of elasticity of NAC. With the increase of modulus of elasticity of concrete developed stresses are high. Therefore higher flexural strength is required to result in to an unlimited number of repetitions for NAC. Pavement thickness of 125 mm is satisfied the fatigue requirement.

5.3 Selection of Suitable Thickness for Provincial Roads

The pavement thickness for provincial roads was estimated using the available rigid pavement design guideline; (1) PCA guideline (Portland Cement Association guideline) & (2) AASHTO guideline.

This section provides the design charts to estimate an economical thickness based on the concrete properties of mix B-3, subgrade reaction and axle loads.

The design charts were developed by calculation the stresses of provincial roads using the FEACON software. One of the input parameter into the software is subgrade resilient modulus. Subgrade resilient modulus was determined using developed graph in Figure 5.5. The graph developed by using the chart "approximate relationship between k values and other soil properties" in Pavement Analysis and Design book by Yang H. Huang.

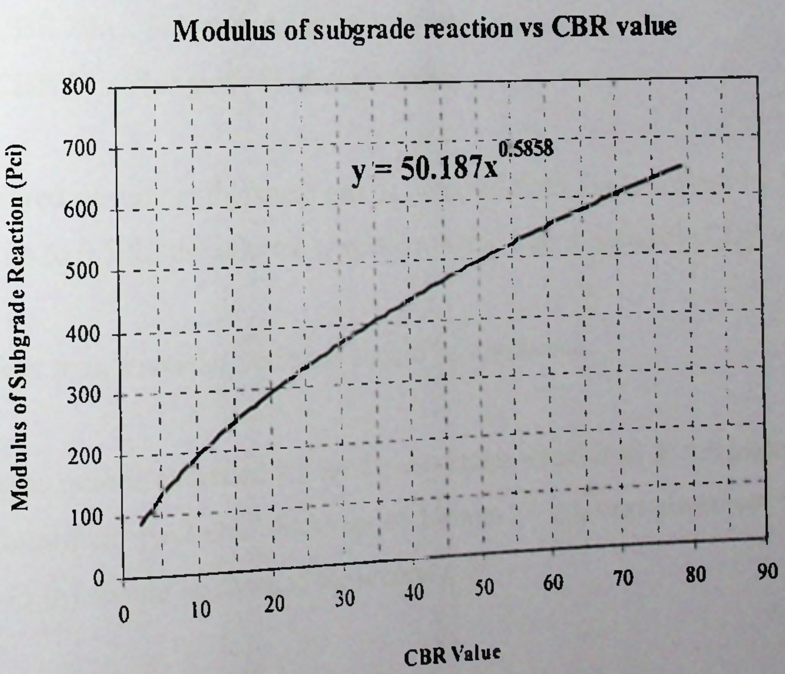

Figure 5.5: Modulus of subgrade reaction vs CBR value

Developed stress within the slab is a function of pavement thickness, modulus of subgrade reaction, elastic modulus of concrete and applied load. Fig 5.6 - 5.9 can be used to estimate stresses in concrete slab for different subgrade conditions and axle loads.

Different pavement thickness of 100mm (4in), 125 mm (5in), 137.5 mm (5.5in) & 150 mm (6in) were considered in developing Fig 5.6 to Fig.5.9.

Design charts have been developed for a fixed elastic modulus value (13564 MPa) (i.e the trial mix B–3's elastic modulus value). The flexural strength of the mix B–3 was 3.63 MPa.

Following subgrade CBR values were considered;

1. CBR 8.5….Subgrade Modulus 0.175kci
2. CBR 12…. Subgrade Modulus 0.215kci
3. CBR 20…. Subgrade Modulus 0.290kci
4. CBR 36.....Subgrade Modulus 0.400kci

The required pavement thickness can be obtained from Fig.'s 5.6-5.9 by limiting the stress ratio to 0.5 for the selected maximum wheel load & subgrade CBR value.

As the first trial, a smaller thickness should be considered.

If the stress ratio is exceeded 0.5 for the maximum wheel load & subgrade CBR value for the minimum pavement thickness of 100mm (4 in), next pavement thickness of 125mm (5 in) should be checked for second trial.

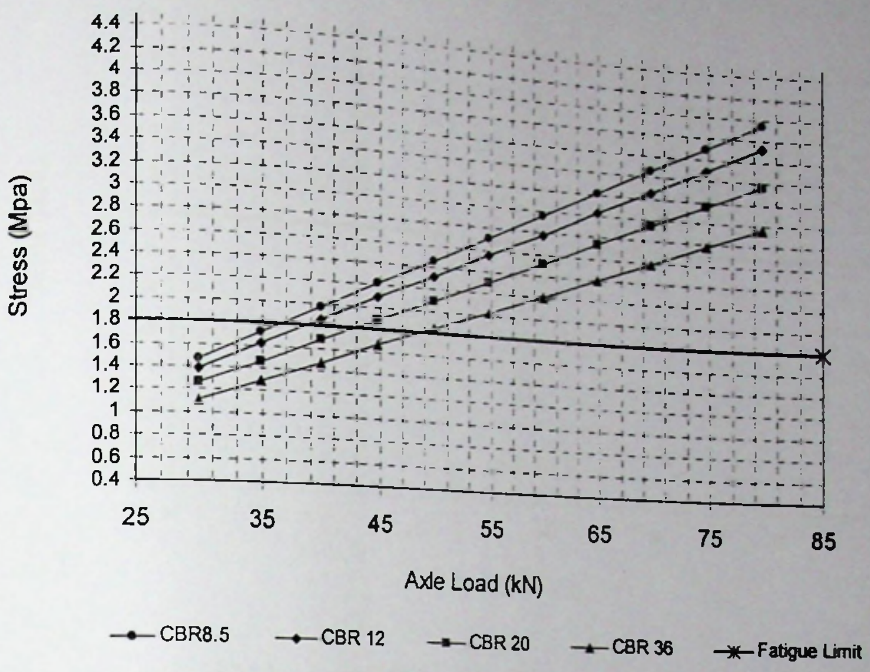

Figure 5.6: Loads vs. Stress relationship for a slab thickness of 100mm

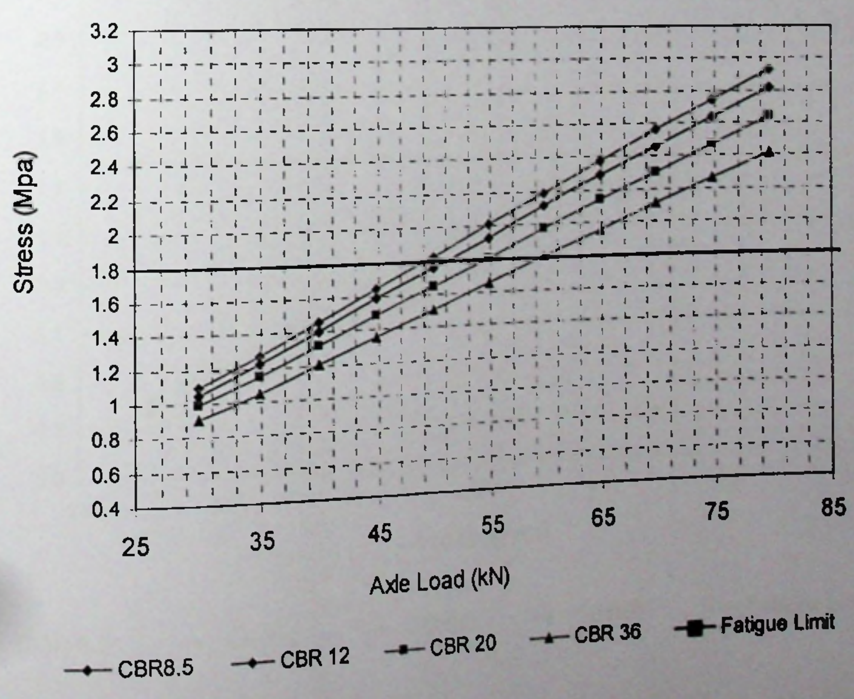

Figure 5.7: Loads vs. Stress relationship for a slab thickness of 125mm

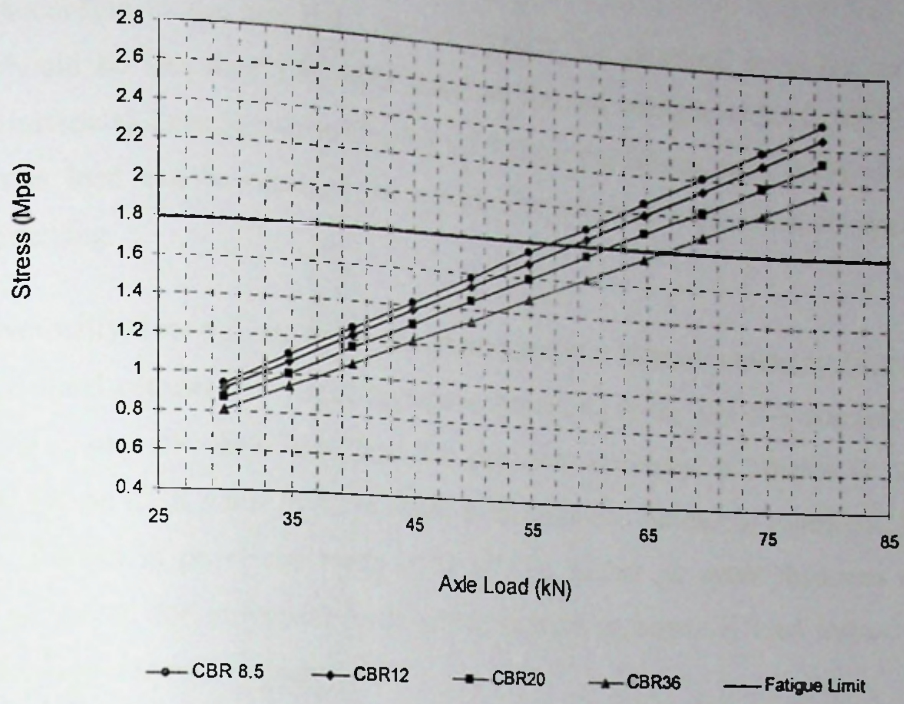

Figure 5.8: Loads vs. Stress relationship for a slab thickness of 137.5 mm

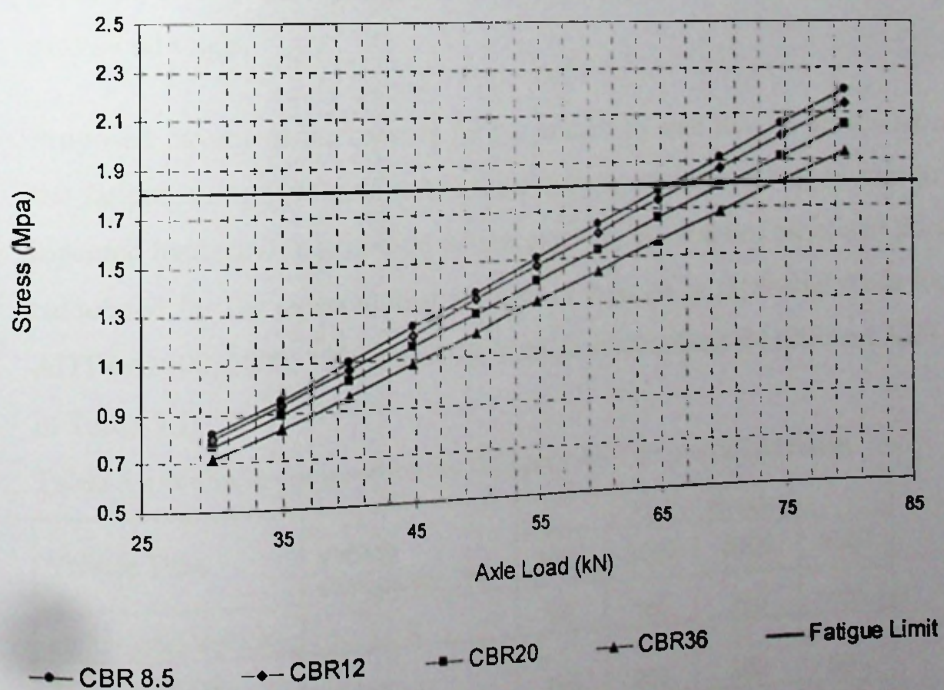

Figure 5.9: Loads vs. Stress relationship for a slab thickness of 150mm

According to the mix B-3 concrete property, the generated stress for applied load should be less than 1.82 MPa since the flexural strength of RAC was 3.63 MPa. Horizontal lines shown in Fig 5.6 - 5.9 show the fatigue limit. Allowed maximum axle load can be obtained for a particular subgrade CBR value to avoid fatigue cracking.

Normally, low volume roads are constructed to a 100mm pavement thickness using portland cement and virgin aggregate. According to the mix B-3 concrete property, maximum allowable axle load for pavement thickness of 100mm is 38 kN for subgrade CBR value of 12 to result in an unlimited number of repetition. Maximum axle load in provincial roads is 52 kN. So, higher pavement thickness should be introduced for provincial roads when recycled aggregate is used instead of virgin aggregate to make concrete.

Allowable maximum axle load for pavement thickness of 125 mm (5in), 137.5 mm (5.5in) & 150 mm (6in) is 51kN, 59kN and 67 kN respectively based on designed chart in Fig 5.7 - 5.9 without any fatigue failure for CBR 12 subgrade.
Pavement thickness of 125 mm (5in) can be proposed for the maximum axle load in provincial roads.

Proposed pavement thickness is for the maximum axle load in provincial roads. But the fatigue design criterion is to keep pavement stresses within the safe limit due to repeated loads and thus prevent fatigue cracking. So required pavement thickness was calculated for the repeated load for each of vehicles in provincial roads for different ADT of 1000, 2000, 3000 and 5000. Vehicle compostions for different ADT are given in Table 5.1.

Table 5.1 Vehicle composition for different ADT in provincial roads

Vehicle Type	Vehicle composition (%)	ADT of Roads			
		1000	2000	3000	5000
Light Good Vehicle	8	80	160	240	400
Medium Good Vehicle (< 8.5T)	10	100	200	300	500
Medium Bus	7	70	140	210	350
Large Bus	3	30	60	90	150
Large Lorries (< 8.5T)	7	70	140	210	350
Farm Vehicle	4	40	80	120	200

To determine the pavement stresses are within the safe limit due to repeated loads, expected axle load repetitions during the design period and allowable repetition need to be calculated to obtain a pavement thickness for above ADT.

Allowable repetition

Allowable repetition can be calculated from fatigue equations developed by previous findings. Figure 5.10 shows the fatigue data obtained by several investigators.

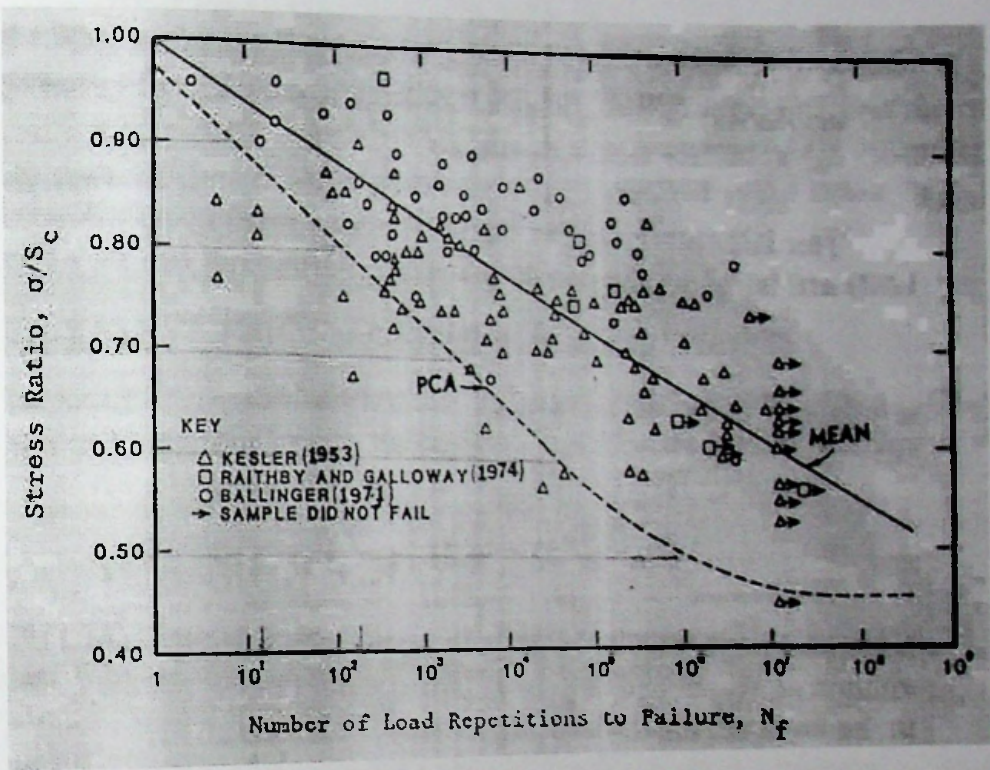

Figure 5.10: Fatigue tests results on concrete

The broken line in Figure 5.11 shows the design curve used by the Portland Cement Association (PCA). It can be seen that the PCA fatigue curve lies below most of the failure points and is very conservative. Therefore the author used that PCA fatigue curve for the calculation of allowable repetition from a particular load value. The equation relevant to that fatigue curve is shown below.

$$\text{Log } N_f = 17.61 - \left[17.61 * \left(\frac{\sigma}{Sc}\right)\right] \quad \text{—— eq. 5.1}$$

Where; N_f - No.of Repetition

σ - Developed Stress

S_c - Flexural Strength

Expected Repetition

The expected repetitions were calculated from the eq 5.2.

$$= \frac{365 * ADT\ of\ Vehicle * \{(1 + Growth\ Rate)\ 20 - 1\}}{Growth\ Rate} \quad \text{.....eq. 5.2}$$

The expected repetition was calculated assuming the growth rate of 3% for design life of 20 years.

Calculation procedure to determine a pavement thickness

Trial thickness – 125mm

Subgrade CBR – 12

Modulus of Rupture – 3.63 MPa

Load safety factor (LSF) – 1.2

Designed period - 20 years

Table 5.2 Cumulative fatigue percent due to 5000 vpd in provincial roads

Vehicle Type	Maximum axle load (kN)	Multified by LSF	Stress (MPa)	Stress Ratio	Fatigue Analysis		Fatigue Percent
					Expected Repitition	Allowable Repetition	
Light Good Vehicle	18	21.6	0.77	0.21	3,923,075	7.31E+13	0.00
Medium Good Vehicle (< 8.5T)	41	49.2	1.72	0.47	4,903,843	1.77E+09	0.28
Medium Bus	31	37.2	1.30	0.36	3,432,690	2.1E+11	0.00
Large Bus	51	61.2	2.15	0.59	1,471,153	14934216	9.85
Large Lorries (< 8.5T)	52	62.4	2.18	0.60	3,432,690	10974630	31.28
Farm Vehicle	25	30	1.05	0.29	1,961,537	3.36E+12	0.00
						Total	41.40806

Total fatigue percent was calculated for ADT of 5000. Total fatigue damage of 41 % shows that the 125mm thickness is adequate for the design condition. The design has

59% reserve capacity available for heavy axle loads and also it raises a question of whether a 100mm thickness would be adequate for the above design. Separate calculations showed that 4in thickness is not adequate because of the excessive fatigue consumption.

Developed stress within the slab is a function of pavement thickness, modulus of subgrade reaction and axle load. Table 5.3 - 5.6 can be used to estimate stresses in concrete slab for different subgrade conditions, pavement thickness and axle loads.

By following the above calculation procedure suitable pavement thickness can be obtained for provincial roads based on load repetition and concrete properties after obtaining stresses from Table 5.3 - 5.6.

Table 5.3 Stresses for subgrade CBR of 8.5

Subgrade CBR 8.5				
Axle Load (kN)	Stress (MPa)			
	4in	5 in	5.5 in	6 in
22	1.082	0.807	0.696	0.604
30	1.475	1.089	0.945	0.820
49	2.413	1.793	1.544	1.338
37	1.820	1.351	1.165	1.014
61	3.013	2.234	1.931	1.675
62	3.054	2.268	1.958	1.696

Table 5.4 Stresses for subgrade CBR of 12

Subgrade CBR 12			
Axle Load (kN)	Stress (MPa)		
	4in	5 in	6 in
22	1.020	0.772	0.590
30	1.386	1.048	0.800
49	2.268	1.724	1.310
37	1.717	1.296	0.986
61	2.834	2.151	1.634
62	2.875	2.179	1.655

Table 5.5 Stresses for subgrade CBR of 20

Subgrade CBR 20			
Axle Load (kN)	Stress (MPa)		
	4in	5 in	6 in
22	0.924	0.724	0.564
30	1.255	0.986	0.765
49	2.055	1.606	1.248
37	1.551	1.213	0.945
61	2.565	2.013	1.565
62	2.599	2.041	1.586

Table 5.6 Stresses for subgrade CBR of 36

Subgrade CBR 36			
Axle Load (kN)	Stress (MPa)		
	4in	5 in	6 in
22	0.814	0.665	0.530
30	1.103	0.903	0.717
49	1.806	1.475	1.179
37	1.365	1.110	0.889
61	2.255	1.841	1.469
62	2.289	1.868	1.489

For the concrete property of mix B-3, suitable pavement thickness can be obtained from Table 5.7 based on the subgrade condition and ADT of the provincial roads.

Table 5.7 Pavement thickness for different ADT

Subgrade CBR	Pavement Thickness for ADT (in)			
	1000 vpd	2000 vpd	3000 vpd	5000 vpd
8.5	5	5	5	5.5
12	5	5	5	5
20	5	5	5	5
36	4	4	4	5

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1CONCLUSION

The research was carried out to explore the possibility of using recycled aggregates in rigid pavement construction. It was found that, the recycled aggregate could be used as an alternative material for normal aggregate in rigid pavement construction. Concrete mixes with recycled concrete aggregate can be designed in the same way as with natural aggregate, but the water content should be adjusted for water absorption of recycled aggregate.

When recycled fine portion together with coarse portion of recycled aggregate is used, it is very difficult to obtain a workable mix and other desired properties. This was due to the fact that recycled fine aggregates contain a large amount of adhered mortar, which results in difficulties in low slump, as well as a substantial drop in the modulus of elasticity and strengths. To overcome this problem only coarse fraction of recycled aggregate should be used.

Compressive strength of concrete made with recycled aggregate with a 100% replacement is less than normal aggregate concrete. The strength of recycled concrete is 15% lower than that of conventional concrete made with natural coarse aggregate.

The recycled aggregate concrete has a modulus of elasticity of at least 58% of the normal aggregate concrete.

Plasticizing admixture (POZZOLITH 225) was used to reduce the water/cement ratio enabling either higher strength or cement economy. Recycled aggregate concrete was achieved a little improvement in strength of concrete by decreasing the water/cement ratio. So cement economy couldn't be achieved using plasticizing admixtures for recycled aggregate concrete mix. Therefore, it is recommended to use superplaticizer to improve the workability of recycled aggregate concrete.

Rigid pavement design and its performance depends not only the concrete properties but also the traffic loading in the pavement. Suitable pavement dimension was proposed based on the traffic loading and the recycled aggregate concrete properties.

Following table provides summary of the axle load analysis in provincial road.

Vehicle Type	Vehicle Composition (%)	ESA Variation		Maximum Axle Load (kN)
		Lower	Upper	
Light Good Vehicle	8	0.00123	0.01396	31
Medium Good Vehicle (< 8.5T)	10	0.00418	0.13354	51
Medium Bus	7	0.0001	0.00125	18
Large Bus	3	0.01636	0.04797	41
Large Lorries (< 8.5T)	7	0.02021	0.13866	52
Farm Vehicle	4	0.0001	0.0061	25

Fatigue analysis (to control fatigue cracking) and erosion analysis (to control foundation and shoulder erosion, pumping and faulting) are the two design criteria in rigid pavement design. Fatigue analysis will usually control the design of light – traffic pavements while erosion analysis controls the design of medium-and heavy traffic pavement. Therefore erosion analysis was not considered to propose a pavement thickness for provincial roads. Fatigue analysis was regarded as the main parameter to propose a suitable width for rigid pavement.

Fatigue design criterion is to keep pavement stresses within the safe limit due to repeated loads and thus prevent fatigue cracking.

Based on the analysis result of traffic loading stresses are high when wheels are moving at the slab edge. Therefore vehicles should not allowed to drive to the edge at all times unless in an unavoidable circumstance. Traffic claming measures have to be proposed when designing the roads to avoid vehicles to move to the edge. Based on traffic loading in provincial road 3.05m slab width can be proposed for those roads with traffic claming measures.

Total fatigue damage due to repeated load in provincial roads for 125mm trial thickness was 41 %. It shows that the 125 mm thickness is adequate for the design condition. Although the design has 59% reserve capacity available for heavy axle loads and also it raises a question of whether a 100mm thickness would be adequate for the above design. Separate calculations showed that 100 mm thickness is not adequate because of the excessive fatigue consumption. That proposed thickness is 125mm for subgrade CBR value of 12, mix B-3 concrete properties and 5000 vpd.

Provincial roads can be constructed to a pavement width of 3.05m and a pavement thickness of 125 mm with the following limitations.

subgrade CBR value of 12
mix B-3 concrete properties
and ADT of 5000

For the concrete property of mix B-3, suitable pavement thickness can be obtained from following table based on the subgrade condition and ADT of the provincial roads.

Subgrade CBR	Pavement Thickness for ADT (in)			
	1000 vpd	2000 vpd	3000 vpd	5000 vpd
8.5	5	5	5	5.5
12	5	5	5	5
20	5	5	5	5
36	4	4	4	5

6.2 RECOMMENDATIONS

Coarse and fine recycled aggregate should not be used together to entirely replace both the coarse and fine natural aggregate in concrete mixes because the strength and durability of concrete would be adversely affected. The use of the recycled fine aggregate is not recommended as the aggregate has high water absorption, which is detrimental to both fresh and hardened properties of concrete. As of today, most research and field applications on recycled aggregate have been focused on the coarse fraction.

Fine recycled aggregate constitutes a large fraction of the end products of any C & D waste recycling operation. It is desirable to maximize the amount of coarse aggregate produced when concrete is recycled and initial separation of fine and coarse fractions is required at the end product of waste recycling operation.

Traffic claming measures should be used at the design stage such that vehicles not to move to edges. The design width of the pavement should be wide enough to keep a lateral clearance.

Pavement thickness of 125 mm can be used to construct rigid pavement for provincial road based on the concrete mix B-3 properties. The design has 59% reserve capacity available for heavy axle loads with the subgrade CBR of 12.

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APPENDICES

Appendix – A	ADT of Southern Provincial roads
Appendix – B	Axle load Survey data
Appendix – C	ESA of vehicles
Appendix – D	Vehicle path and loading position

Appendix – A

AADT value of Southern Province Road

No	Road Name	Motor Cycles	Three Wheel	Car	Pass. Van	Light Goods Vehicle	Medium Goods Vehicle	Heavy Goods Vehicle	Medium Bus	Large Bus	Tractor /Trail	AADT	
1	Weligatta-Bundala Road	196	103	32	5	39	22	26	18	19	41	501	B
2	Batahena-Habarakada-Dunhene Road	170	98	5	20	19	58	6	8	9	4	397	B
3	Mahalweaya-Gonnoruwa-Meegahajandua Rd	847	581	255	0	49	52	197	22	39	79	2121	C
4	Weligama-Panchaliya Road	1369	1270	108	24	186	107	24	52	0	37	3177	C
5	Neluwa-Kadihingala-Dellwa-Morawaka Road	486	157	9	71	43	93	6	8	60	36	969	C
6	Kadduwa-Kotadupe-Dampalla Road	62	55	9	0	11	3	11	13	6	0	170	C
7	Deniyaya-Pallegama Road	684	429	117	14	198	131	126	75	73	113	1960	C
8	Udugama-Bangama Road	347	193	15	58	75	86	20	25	9	39	867	C
9	Daiyandara-Parapamulla Kirama Road	353	185	58	8	70	39	46	32	34	73	898	C
10	Kapuduwa-Uduwa-Kadawedduwa Road	166	151	8	0	11	124	20	6	9	0	495	C
11	Bovitiyamulla-Thalawa Road	530	200	3	53	40	38	3	11	9	7	894	C
12	Henegama-Thelijjaawila Road	69	58	7	0	19	29	29	36	10	0	257	C
13	Welewtta-Navimana-Kekanadura Road	735	750	70	0	106	6	105	252	23	0	2047	C
14	Mawarala-Puwakgahahena-Handugala Road	88	63		13	0	40	0		0	0	204	C
15	Kotawila-Kirimetimulla Road	192	195	53	0	70	35	87	48	7	0	687	C
16	Mapalana-Narandeniya Road	500	411	104	0	155	75	62	11	0	64	1382	C
17	Kongala-Naaelpita Road	98	51	16	2	20	11	13	9	9	20	249	C
18	Welipitiya-Radampola Road	177	65	9	0	17	7	11	42	4	0	332	C
19	Kirinaliy-Radampola Road	203	164	19	0	33	19	56	28	0	0	522	C
20	Eramudugaha-Heenatigala Road	471	237	201	50	216	237	109	42	62	25	1650	D
21	Meetiyagoda-Ampegama Road	815	209	20	0	95	74	0	91	79	0	1383	D
22	Arachchigewatta-Ampegama Road	238	163	88	18	79	28	1	4	40	6	665	D
23	Akmeemana- Kurunduwatta roa	4241	1196	280	8	704	414	128	19	213	0	7203	E
24	Ampegama-Aluthwala Road	1323	345	60	0	186	77	118	19	213	0	2341	E
25	Udayala-Aluthwala Road	425	92	8	0	53	31	43	27	55	53	787	E
26	Urubokka-Ginnliya Road	295	154	48	7	59	33	38	27	28	61	750	E
27	Sooriyawewa-Meegahajandura Road	986	949	510	0	281	199	451	412	401	613	4802	E
28	Kirinda-Walakanda Road	137	72	23	3	27	15	18	12	13	28	348	E
29	Pilana-Pinnaduwa Road	360	319	97	0	102	37	11	42	9	30	1007	E

AADT value of Southern "C" class Road

No	Road Name	Motor Cycles	Three Wheel	Car	Pass. Van	Light Goods Vehicle	Medium Goods Vehicle	Heavy Goods Vehicle	Medium Bus	Large Bus	Tractor /Trail	AADT	
1	Mahalweaya-Gonnoruwa-Meegahajandua Ro	847	581	255	0	49	52	197	22	39	79	2121	C
2	Weligama-Panchaliya Road	1369	1270	108	24	186	107	24	52	0	37	3177	C
3	Neluwa-Kadihingala-Dellwa-Morawaka Road	486	157	9	71	43	93	6	8	60	36	969	C
4	Kadduwa-Kotadupe-Dampalla Road	62	55	9	0	11	3	11	13	6	0	170	C
5	Deniyaya-Pallegama Road	684	429	117	14	198	131	126	75	73	113	1960	C
6	Udugama-Bangama Road	347	193	15	58	75	86	20	25	9	39	867	C
7	Daiyandara-Parapamulla Kirama Road	353	185	58	8	70	39	46	32	34	73	898	C
8	Kapuduwa-Uduwa-Kadawedduwa Road	166	151	8	0	11	124	20	6	9	0	495	C
9	Bovitiyamulla-Thalawa Road	530	200	3	53	40	38	3	11	9	7	894	C
10	Henegama-Thelijjaawila Road	69	58	7	0	19	29	29	36	10	0	257	C
11	Welewtta-Navimana-Kekanadura Road	735	750	70	0	106	6	105	252	23	0	2047	C
12	Mawarala-Puwakgahahena-Handugala Road	88	63		13	0	40	0		0	0	204	C
13	Kotawila-Kirimetimulla Road	192	195	53	0	70	35	87	48	7	0	687	C
14	Mapalana-Narandeniya Road	500	411	104	0	155	75	62	11	0	64	1382	C
15	Kongala-Naaelpita Road	98	51	16	2	20	11	13	9	9	20	249	C
16	Welipitiya-Radampola Road	177	65	9	0	17	7	11	42	4	0	332	C
17	Kirinaliy-Radampola Road	203	164	19	0	33	19	56	28	0	0	522	C
	Mean	**406.24**	**292.82**	**53.75**	**14.29**	**64.88**	**52.65**	**48.00**	**41.88**	**17.18**	**27.53**	1014	
	Standard Deviation	**340.35**	**311.47**	**64.83**	**22.69**	**59.98**	**40.91**	**51.95**	**57.36**	**21.21**	**34.46**		
		582.14	**453.81**	**87.26**	**26.02**	**95.88**	**73.79**	**74.85**	**71.52**	**28.14**	**45.34**		
		230.33	**131.84**	**20.24**	**2.57**	**33.88**	**31.50**	**21.15**	**12.23**	**6.22**	**9.72**		

No.of Vehicle as a % from AADT

No	Road Name	Motor Cycles	Three Wheel	Car	Pass. Van	Light Goods Vehicle	Medium Goods Vehicle	Heavy Goods Vehicle	Medium Bus	Large Bus	Tractor /Trail
1	Mahalweaya-Gonnoruwa-Meegahajandua Ro	39.93	27.39	12.02	0.00	2.31	2.45	9.29	1.04	1.84	3.72
2	Weligama-Panchaliya Road	43.09	39.97	3.40	0.76	5.85	3.37	0.76	1.64	0.00	1.16
3	Neluwa-Kadihingala-Dellwa-Morawaka Road	50.15	16.20	0.93	7.33	4.44	9.60	0.62	0.83	6.19	3.72
4	Kadduwa-Kotadupe-Dampalla Road	36.47	32.35	5.29	0.00	6.47	1.76	6.47	7.65	3.53	0.00
5	Deniyaya-Pallegama Road	34.90	21.89	5.97	0.71	10.10	6.68	6.43	3.83	3.72	5.77
6	Udugama-Bangama Road	40.02	22.26	1.73	6.69	8.65	9.92	2.31	2.88	1.04	4.50
7	Daiyandara-Parapamulla Kirama Road	39.31	20.60	6.46	0.89	7.80	4.34	5.12	3.56	3.79	8.13
8	Kapuduwa-Uduwa-Kadawedduwa Road	33.54	30.51	1.62	0.00	2.22	25.05	4.04	1.21	1.82	0.00
9	Bovitiyamulla-Thalawa Road	59.28	22.37	0.34	5.93	4.47	4.25	0.34	1.23	1.01	0.78
10	Henegama-Thelijjaawila Road	26.85	22.57	2.72	0.00	7.39	11.28	11.28	14.01	3.89	0.00
11	Welewtta-Navimana-Kekanadura Road	35.91	36.64	3.42	0.00	5.18	0.29	5.13	12.31	1.12	0.00
12	Mawarala-Puwakgahahena-Handugala Road	43.14	30.88	0.00	6.37	0.00	19.61	0.00	0.00	0.00	0.00
13	Kotawila-Kirimetimulla Road	27.95	28.38	7.71	0.00	10.19	5.09	12.66	6.99	1.02	0.00
14	Mapalana-Narandeniya Road	36.18	29.74	7.53	0.00	11.22	5.43	4.49	0.80	0.00	4.63
15	Kongala-Naaelpita Road	39.36	20.48	6.43	0.80	8.03	4.42	5.22	3.61	3.61	8.03
16	Welipitiya-Radampola Road	53.31	19.58	2.71	0.00	5.12	2.11	3.31	12.65	1.20	0.00
17	Kirinaliy-Radampola Road	38.89	31.42	3.64	0.00	6.32	3.64	10.73	5.36	0.00	0.00
	Mean	**39.90**	**26.66**	**4.23**	**1.73**	**6.22**	**7.02**	**5.19**	**4.68**	**1.99**	**2.38**
	Standard Deviation	**8.06**	**6.37**	**3.08**	**2.72**	**2.95**	**6.36**	**3.82**	**4.39**	**1.76**	**2.86**
		44.06	**29.95**	**5.82**	**3.14**	**7.74**	**10.30**	**7.16**	**6.95**	**2.90**	**3.86**
		35.73	**23.37**	**2.64**	**0.33**	**4.70**	**3.73**	**3.21**	**2.41**	**1.08**	**0.90**

Appendix – B

Vehicle Type -

5- Medium Passenger Vehicles

6- Large Passenger Vehicles

7- Light Goods Vehicles

8- Medium Goods Vehicles

9- Large Lorries

10 - Three Axles Vehicles (Combined)

11- Three Axles Vehicles (Articulated)

12- Four Axles Vehicles (Articulated)

13- Five Axles Vehicles (Articulated)

14- Six Axles Vehicles (Articulated)

15 - Farm Vehicles

AXLE LOAD Survey at Panawala - Maniyangana Rd on 2007/12/12

Mode of Analysis	Vehicle Classification		Both Direction		To Panawala		To Maniyangana	
	Code	Name	# of Vehicle	ESA	# of Vehicle	ESA	# of Vehicle	ESA
Measured	4	Van						
	5	Medium Bus	2	0.0062	1	0.0092	1	0.0031
	6	Large Bus	39	0.1010	19	0.1309	20	0.0727
	7	Light Goods Vehicle	20	0.0002	8	0.0004	12	0.0001
	8	Medium Goods Vehicle (<8.5 T)	15	0.0604	8	0.0952	7	0.0207
	9	Large Lorries (>8.5 T)	3	0.0050	2	0.0043	1	0.0064
	10	Three Axles Vehicle Combined	1	0.0202	1	0.0202		
	11	Three Axles Vehicle Articulated						
	12	Four Axles Vehicle Articulated						
	13	Five Axles Vehicle Articulated						
	14	Five Axles Vehicle Articulated						
	15	Farm Vehicles	6	0.0068			6	0.0068

AXLE LOAD Survey at Chillaw - Iranawila - Nainamadama Rd on 2007/11/29

Mode of Analysis	Vehicle Classification		Both Direction		To Chillaw		To Iranawila	
	Code	Name	# of Vehicle	ESA	# of Vehicle	ESA	# of Vehicle	ESA
Measured	4	Van						
	5	Medium Bus	7	0.0018	5	0.0018	2	0.0017
	6	Large Bus	21	0.0181	13	0.0229	8	0.0103
	7	Light Goods Vehicle	40	0.0003	21	0.0001	19	0.0004
	8	Medium Goods Vehicle (<8.5 T)	11	0.0400	6	0.0043	5	0.0828
	9	Large Lorries (>8.5 T)						
	10	Three Axles Vehicle Combined						
	11	Three Axles Vehicle Articulated						
	12	Four Axles Vehicle Articulated						
	13	Five Axles Vehicle Articulated						
	14	Five Axles Vehicle Articulated						
	15	Farm Vehicles	3	0.0004	1	0.0009	2	0.0001

AXLE LOAD Survey at Bathuluoya - Dewalahandiya Rd on 2007/12/14

Mode of Analysis	Vehicle Classification		Both Direction		To Bathuluoya		To Dewalahandiya	
	Code	Name	# of Vehicle	ESA	# of Vehicle	ESA	# of Vehicle	ESA
Measured	4	Van						
	5	Medium Bus						
	6	Large Bus	13	0.1848	8	0.2270	5	0.1172
	7	Light Goods Vehicle	14	0.0008	10	0.0005	4	0.0015
	8	Medium Goods Vehicle (<8.5 T)	29	0.0266	18	0.0409	11	0.0031
	9	Large Lorries (>8.5 T)	3	0.1570	3	0.1570		
	10	Three Axles Vehicle Combined						
	11	Three Axles Vehicle Articulated						
	12	Four Axles Vehicle Articulated						
	13	Five Axles Vehicle Articulated						
	14	Five Axles Vehicle Articulated						
	15	Farm Vehicles	1	0.0001	1	0.0001		

AXLE LOAD Survey at Udupila (Delgoda) of Kirillawala - Udupila Rd on 28-11-2007

Mode of Analysis	Vehicle Classification		Both Direction		To Kirillawala		To Udupila	
	Code	Name	# of Vehicle	ESA	# of Vehicle	ESA	# of Vehicle	ESA
Measured	4	Van	-	-	-	-	-	-
	5	Medium Bus	3	0.0170	2	0.0249	1	0.0011
	6	Large Bus	6	0.0721	4	0.0642	2	0.0879
	7	Light Goods Vehicle	25	0.0019	9	0.0034	16	0.0010
	8	Medium Goods Vehicle (<8.5 T)	71	0.0223	42	0.0268	29	0.0158
	9	Large Lorries (>8.5 T)	10	0.0112	5	0.0059	5	0.0165
	10	Three Axles Vehicle Combined	1	1.0502	1	1.0502	-	-
	11	Three Axles Vehicle Articulated	-	-	-	-	-	-
	12	Four Axles Vehicle Articulated	-	-	-	-	-	-
	13	Five Axles Vehicle Articulated	-	-	-	-	-	-
	14	Six Axles Vehicle Articulated	-	-	-	-	-	-
	15	Farm Vehicles	-	-	-	-	-	-

AXLE LOAD Survey at Neluwa-Kadihingala- Dellawa- Morawaka Road on 05-12-

Mode of Analysis	Vehicle Classification		Both Direction		To Neluwa		To Morawaka	
	Code	Name	# of Vehicle	ESA	# of Vehicle	ESA	# of Vehicle	ESA
Measured	4	Van						-
	5	Medium Bus						
	6	Large Bus	20	0.0142	13	0.0137	7	0.0152
	7	Light Goods Vehicle	8	0.0003	4	0.0004	4	0.0001
	8	Medium Goods Vehicle (<8.5 T)	9	0.0140	4	0.0134	5	0.0144
	9	Large Lorries (>8.5 T)	2	0.0074	1	0.0074	1	0.0073
	10	Three Axles Vehicle Combined						
	11	Three Axles Vehicle Articulated						
	12	Four Axles Vehicle Articulated						
	13	Five Axles Vehicle Articulated						
	14	Six Axles Vehicle Articulated						
	15	Farm Vehicles	13		6		7	

Appendix – C

AXLE LOAD Survey at Panawala - Maniyangama Rd on 2007/12/12

Sr NO	DIR	VEH TYPE	AXLE CONFIG	LOAD	ORIG	DESTI	Axle Load AXLE1	AXLE2	AXLE3
1	1	6	1.2	Passengers	Wijerama	Avissawella	3	3.335	
2	1	6	1.2	Passengers	Wijerama	Avissawella	3.115	3.4	
3	2	6	1.2	Passengers	Avissawella	Wijerama	3.31	4.11	
4	1	7	1.1	Empty	Wijerama	Avissawella	0.98	0.72	
5	2	6	1.2	Passengers	Avissawella	Wijerama	3.11	3.33	
6	1	5	1.2	Empty	Wijerama	Avissawella	2.11	2.75	
7	1	6	1.2	Passengers	Wijerama	Avissawella	2.95	3.11	
8	1	8	1.2	Empty	Ehaliyagoda	Avissawella	1.01	0.72	
9	2	7	1.1	Food Items	Avissawella	Wijerama	1.035	0.685	
10	1	8	1.2	Timber,T/Logs,Tru	Wijerama	Avissawella	2.52	7.66	
11	2	6	1.2	Empty	Avissawella	Wijerama	1.855	1.995	
12	1	7	1.1	Hardwere Items	Ehaliyagoda	Avissawella	0.98	1.13	
13	1	7	1.1	Passengers	Ehaliyagoda	Avissawella	1.38	1.94	
14	1	8	1.2	Empty	Wijerama	Avissawella	1.735	1.325	
15	1	8	1.2	Empty	Wijerama	Avissawella	1.71	1.375	
16	2	6	1.2	Passengers	Avissawella	Ehaliyagoda	3.115	3.75	
17	2	5	1.2	Passengers	Avissawella	Wijerama	1.525	2.215	
18	1	6	1.2	Passengers	Wijerama	Avissawella	3.41	5.63	
19	1	9	1.2	Empty	Ehaliyagoda	Avissawella	2.15	2.26	
20	2	15	1.1.1	Matal	Avissawella	Wijerama	0.63	2.46	2.72
21	1	10	1.22	Timber,T/Logs,Tru	Wijerama	Avissawella	0.61	2.53	3.26
22	1	6	1.2	Passengers	Ehaliyagoda	Avissawella	3.03	4.765	
23	2	6	1.2	Passengers	Avissawella	Wijerama	3.66	4.96	
24	1	7	1.1	Food Items	Wijerama	Deraniyagala	1.1	1.05	
25	1	9	1.2	Empty	Wijerama	Avissawella	2.165	1.81	
26	1	6	1.2	Passengers	Wijerama	Avissawella	2.8	5.315	
27	2	15	1.1.1	Asphalt	Avissawella	Wijerama	0.445	1.99	3.08
28	2	6	1.2	Passengers	Avissawella	Wijerama	2.9	4.09	
29	2	6	1.2	Passengers	Avissawella	Wijerama	0.465	2.53	3.4
30	1	7	1.2	Wooden Prod	Wijerama	Puwakpitiya	1.39	1.17	
31	2	15	1.1.1	Empty	Avissawella	Wijerama	0.605	0.97	0.675
32	1	6	1.2	Passengers	Wijerama	Avissawella	2.335	3.08	
33	1	6	1.2	Passengers	Wijerama	Avissawella	3.585	4.91	
34	1	8	1.2	Empty	Avissawella	Avissawella	2.31	1.41	
35	2	6	1.2	Passengers	Avissawella	Wijerama	2.485	3.52	
36	2	7	1.1	Empty	Avissawella	Wijerama	1.39	1.035	
37	2	7	1.1	Wooden Prod	Avissawella	Wijerama	1.085	0.87	
38	2	9	1.2	Empty	Wijerama	Avissawella	1.725	2.61	
39	2	6	1.2	Passengers	Wijerama	Avissawella	2.87	4.46	
40	2	8	1.2	Empty	Wijerama	Avissawella	1.545	1.045	
41	2	7	1.1	Empty	Wijerama	Avissawella	1.335	1.305	
42	2	6	1.2	Passengers	Avissawella	Wijerama	3.53	3.66	
43	2	7	1.1	Empty	Avissawella	Wijerama	0.985	0.75	
44	2	6	1.2	Passengers	Avissawella	Wijerama	2.54	3.2	
45	2	7	1.1	Passengers	Avissawella	Wijerama	1.09	0.72	
46	2	8	1.2	Wooden Prod	Kandy	Wijerama	2.19	3.735	
47	1	6	1.2	Passengers	Wijerama	Avissawella	2.315	5.76	
48	2	8	1.2	Matal	Avissawella	Wijerama	2.14	4.97	
49	1	6	1.2	Passengers	Wijerama	Avissawella	2.31	5.405	
50	2	7	1.1	Wooden Prod	Wijerama	Talduwa	0.84	0.51	
51	2	6	1.2	Passengers	Avissawella	Wijerama	1.37	2.735	
52	2	8	1.2	Rubber/Rubber Pro	Avissawella	Wijerama	1.43	1.52	
53	1	6	1.2	Passengers	Wijerama	Avissawella	3.28	5.775	
54	2	6	1.2	Passengers	Avissawella	Wijerama	2.075	4.315	
55	1	8	1.2	Wooden Prod	Wijerama	Ehaliyagoda	0.99	0.695	
56	2	7	1.1	Empty	Avissawella	Pinnawala	0.715	0.445	
57	1	8	1.2	Wooden Prod	Wijerama	Avissawella	1.305	1.21	
58	2	6	1.2	Passengers	Avissawella	Wijerama	2.25	3.68	
59	1	6	1.2	Passengers	Wijerama	Avissawella	3.71	5.54	
60	1	6	1.2	Passengers	Wijerama	Avissawella	1.67	3.28	
61	2	7	1.1	Groceries	Kandy	Wijerama	1.125	1.16	
62	2	6	1.2	Passengers	Avissawella	Wijerama	2.605	3.61	
63	1	7	1.1	Empty	Wijerama	Deraniyagala	0.865	0.43	
64	1	8	1.2	Empty	Wijerama	Avissawella	0.92	0.87	
65	1	7	1.1	Empty	Wijerama	Avissawella	0.79	0.4	
66	1	6	1.2	Passengers	Wijerama	Avissawella	2.76	4.605	
67	2	7	1.1	Passengers	Avissawella	Wijerama	0.92	0.87	
68	2	7	1.1	Electrical Goods	Meegoda	Wijerama	0.445	0.42	
69	1	6	1.2	Passengers	Wijerama	Avissawella	2.505	4.01	

70	2	8	1.2	Empty	Hanwella	Wijerama	1.225	1.03	
71	2	15	1.1.1	Sand	Avissawella	Wijerama	0.43	1.71	2.83
72	2	8	1.2	Empty	Avissawella	Wijerama	1.41	1.045	
73	1	7	1.1	Empty	Wijerama	Avissawella	0.96	0.94	
74	2	6	1.2	Passengers	Avissawella	Wijerama	2.045	2.85	
75	1	6	1.2	Passengers	Wijerama	Avissawella	3.39	5.88	
76	2	15	1.1.1	Matal	Avissawella	Wijerama	0.61	1.96	2.29
77	2	6	1.2	Empty	Avissawella	Wijerama	2.43	5.9	
78	2	6	1.2	Passengers	Avissawella	Wijerama	2.43	4.73	
79	1	6	1.2	Passengers	Wijerama	Avissawella	2.69	5.865	
80	2	7	1.1	Wooden Prod	Avissawella	Wijerama	0.68	0.47	
81	2	15	1.1.1	Bricks	Avissawella	Wijerama	0.505	2.05	1.565
82	1	6	1.2	Passengers	Wijerama	Avissawella	2.625	5.95	
83	2	6	1.2	Passengers	Avissawella	Wijerama	3.245	5.18	
84	2	8	1.2	Food Items	Avissawella	Wijerama	1.375	2.47	
85	2	6	1.2	Passengers	Avissawella	Wijerama	3.465	6.4	
86	1	6	1.2	Passengers	Wijerama	Avissawella	3.4	5.4	

Note:

Direction :

1- Panawala

2- Maniyangana

AXLE LOAD Survey at Chillaw - Iranawila - Nainamadama Rd on 2007/11/29

To Chillaw

To Iranawila

Sr NO	DIR	VEH TYPE	AXLE CONFIG	LOAD	ORIG	DISTI	Axle Load		
							AXLE1	AXLE2	AXLE3
1	1	8	1.2	Passengers	Wilpattu Sanctuary	Chilaw	1.72	2.16	
2	2	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	1.925	2.73	
3	2	7	1.1	Fish/dry Fish	Chilaw	Wilpattu Sanctuary	0.705	0.5	
4	1	5	1.2	Passengers	Wilpattu Sanctuary	Chilaw	1.195	1.43	
5	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	0.605	0.445	
6	1	5	1.2	Passengers	Wilpattu Sanctuary	Chilaw	1.175	2.205	
7	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	1.21	0.715	
8	2	7	1.1	Coconuts	Chilaw	Wilpattu Sanctuary	0.835	0.62	
9	2	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	2.175	3.43	
10	2	7	1.1	Fish/dry Fish	Chilaw	Wennappuwa	0.42	0.495	
11	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	1.84	2.74	
12	1	7	1.1	Fish/dry Fish	Wilpattu Sanctuary	Chilaw	0.8	0.52	
13	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	1.93	3.12	
14	2	5	1.2	Passengers	Chilaw	Wilpattu Sanctuary	1.21	2.06	
15	2	8	1.2	Empty	Chilaw	Mahawewa	1.69	1.575	
16	2	15	1.1.1	Empty	Chilaw	Wilpattu Sanctuary	0.485	1.06	0.545
17	2	7	1.1	Empty	Chilaw	Wilpattu Sanctuary	0.68	0.365	
18	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	2.64	4.445	
19	2	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	2.01	2.725	
20	2	7	1.1	Livestock	Chilaw	Negombo	1.595	1.43	
21	2	7	1.1	Empty	Chilaw	Wilpattu Sanctuary	0.58	0.43	
22	2	7	1.2	Empty	Chilaw	Wilpattu Sanctuary	0.975	0.62	
23	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	2.35	2.85	
24	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	1.04	0.92	
25	1	5	1.2	Passengers	Wilpattu Sanctuary	Chilaw	1.075	1.89	
26	2	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	2.28	2.38	
27	1	5	1.2	Passengers	Wilpattu Sanctuary	Chilaw	1.32	1.625	
28	2	7	1.1	Salt Bags	Chilaw	Wilpattu Sanctuary	0.77	1.715	
29	2	7	1.1	Empty	Chilaw	Wilpattu Sanctuary	1.025	0.59	
30	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	1.555	3.405	
31	1	7	1.1	Livestock	Mahawewa	Chilaw	0.535	0.67	
32	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	0.835	0.56	
33	1	8	1.2	Machines	Marawila	Chilaw	1.25	1.84	
34	2	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	2.16	2.78	
35	2	6	1.2	Empty	Chilaw	Wilpattu Sanctuary	1.75	1.965	
36	2	7	1.1	Fish/dry Fish	Chilaw	Mahawewa	0.87	0.835	
37	2	15	1.1.1	Water	Chilaw	Wilpattu Sanctuary	0.435	1.12	0.45
38	2	8	1.2	Food Items	Chilaw	Wilpattu Sanctuary	1.29	1.45	
39	2	7	1.1	Empty	Chilaw	Wilpattu Sanctuary	0.955	0.49	
40	2	7	1.1	Rice/Paddy	Chilaw	Wilpattu Sanctuary	0.99	1.32	
41	2	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	1.835	2.53	
42	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	0.96	0.635	
43	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	2.29	3.48	
44	2	5	1.2	Passengers	Chilaw	Wilpattu Sanctuary	1.26	1.84	
45	1	8	1.2	Faulty Foods	Wennappuwa	Chilaw	1.44	3.515	
46	1	7	1.1	Electrical Goods	Wilpattu Sanctuary	Chilaw	0.69	0.48	
47	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	0.885	0.49	
48	1	7	1.1	Fish/dry Fish	Wilpattu Sanctuary	Chilaw	0.98	0.82	
49	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	2.07	2.74	
50	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	0.945	0.445	
51	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	1.96	1.705	
52	1	8	1.2	Water	Wilpattu Sanctuary	Chilaw	1.505	1.67	
53	2	7	1.1	Empty	Chilaw	Wilpattu Sanctuary	1.025	0.46	
54	2	7	1.1	Empty	Chilaw	Wilpattu Sanctuary	2.455	1.54	
55	1	15	1.1.1	Water	Wilpattu Sanctuary	Chilaw	0.69	1.246	1.64
56	2	7	1.1	Empty	Chilaw	Wilpattu Sanctuary	0.835	0.435	
57	2	8	1.2	Wooden Prod	Chilaw	Wilpattu Sanctuary	1.015	1.415	
58	1	7	1.1	Food Items	Anamaduwa	Marawila	0.45	0.435	
59	1	8	1.2	Empty	Wilpattu Sanctuary	Chilaw	1.4	1.55	
60	1	7	1.1	Empty	Chilaw	Wilpattu Sanctuary	1.03	0.63	
61	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	2.065	3.595	
62	1	8	1.2	Empty	Wilpattu Sanctuary	Chilaw	1.05	0.925	
63	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	2.13	3.285	
64	2	7	1.1	Empty	Chilaw	Wilpattu Sanctuary	1.185	0.79	
65	2	7	1.2	Food Items	Chilaw	Wilpattu Sanctuary	1.33	0.78	
66	2	7	1.2	Fruits	Chilaw	Chilaw	0.87	1.155	
67	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	1.18	0.795	
68	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	1.955	3.325	
69	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	2.585	4.545	

70	2	8	1.2	Food Items	Madampe (Chi)	Wilpattu Sanctuary	3.22	6.65	
71	2	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	1.24	0.83	
72	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	0.69	0.79	
73	1	8	1.2	Groceries	Wilpattu Sanctuary	Chilaw	1.375	1.18	
74	2	8	1.2	Fish/dry Fish	Chilaw	Wennappuwa	1.705	2.11	
75	1	7	1.1	Tea	Nattandiya	Puttalam	0.92	1.04	
76	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	0.87	1.63	
77	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	1.01	0.575	
78	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	0.87	0.58	
79	2	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	2.32	3.275	
80	1	7	1.1	Fish/dry Fish	Negombo	Chilaw	0.505	0.67	
81	1	5	1.2	Passengers	Wilpattu Sanctuary	Chilaw	1.345	2.34	
82	1	7	1.1	Food Items	Wilpattu Sanctuary	Chilaw	1.335	0.85	

Note:

Direction :

1- Chillaw

2- Iranawila

AXLE LOAD Survey at Bathuluoya - Dewalahandiya Rd on 2007/12/14

Sr NO	DIR	VEH TYPE	AXLE CONFIG	LOAD	ORIG	DESTI	Axle Load AXLE1	AXLE2	AXLE3
1	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	2.6	3.4	
2	2	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	2.75	3.825	
3	1	9	1.2	Wooden Prod	Wilpattu Sanctuary	Chilaw	3.8	6.2	
4	1	8	1.2	Empty	Wilpattu Sanctuary	Chilaw	1.695	1.315	
5	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	3.655	6.545	
6	1	8	1.2	Empty	Wilpattu Sanctuary	Chilaw	1.85	1.835	
7	1	7	1.1	Fruits	Wilpattu Sanctuary	Minuwangoda	1.67	1.835	
8	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	1.13	0.97	
9	2	8	1.2	Empty	Battulu Oya	Wilpattu Sanctuary	1.99	1.635	
10	2	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	3.755	4.335	
11	1	6	1.2	Passengers	Kurunegala	Chilaw	3.8	5.515	
12	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	1.055	0.445	
13	1	8	1.2	Empty	Wilpattu Sanctuary	Battulu Oya	1.685	1.41	
14	1	8	1.2	Bricks	Wilpattu Sanctuary	Madampe (Chi)	3.01	7.12	
15	1	8	1.2	Empty	Wilpattu Sanctuary	Kiriyankalli	1.58	1.15	
16	1	8	1.2	Empty	Wilpattu Sanctuary	Chilaw	1.33	0.855	
17	1	8	1.2	Empty	Wilpattu Sanctuary	Chilaw	1.71	1.59	
18	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	4.23	5.43	
19	1	8	1.2	Food Items	Wilpattu Sanctuary	Wennappuwa	2.05	4.55	
20	1	8	1.2	Food Items	Wilpattu Sanctuary	Wennappuwa	2.27	4.815	
21	2	8	1.2	Plastic Product	Chilaw	Katupotha	1.47	2.68	
22	1	9	1.2	Empty	Wilpattu Sanctuary	Chilaw	3.54	3.045	
23	2	7	1.1	Empty	Chilaw	Wilpattu Sanctuary	0.805	0.545	
24	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	0.785	0.53	
25	2	8	1.2	Rubber/Rubber Pro	Chilaw	Wilpattu Sanctuary	1.935	2.61	
26	2	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	3.845	4.68	
27	1	8	1.2	Empty	Katupotha	Battulu Oya	1.37	1.39	
28	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	4.27	6.26	
29	1	7	1.1	Empty	Wilpattu Sanctuary	Chilaw	0.765	0.495	
30	1	8	1.2	Motor Spare Parts	Wilpattu Sanctuary	Chilaw	1.81	1.355	
31	2	8	1.2	Plastic Product	Battulu Oya	Katupotha	1.73	2.095	
32	2	7	1.1	Food Items	Dummalasuriya	Katupotha	0.73	0.595	
33	1	7	1.2	Empty	Katupotha	Chilaw	1.105	0.72	
34	2	8	1.2	Food Items	Palugassegama	Katupotha	2.085	2.68	
35	1	8	1.2	Livestock	Katupotha	Kandana	2.025	1.93	
36	2	8	1.2	Concrete Beams	Palugassegama	Katupotha	1.655	1.69	
37	2	6	1.2	Passengers	Chilaw	Katupotha	3.395	5.695	
38	1	6	1.2	Passengers	Katupotha	Chilaw	2.125	5.42	
39	1	8	1.2	PVC Product	Arachchikattuwa	Kurunegala	1.985	2.575	
40	1	7	1.2	Empty	Katupotha	Chilaw	1.355	0.78	
41	1	6	1.2	Passengers	Wilpattu Sanctuary	Chilaw	3.41	4.305	
42	2	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	3.65	5.03	
43	2	7	1.1	Coconut Prod	Chilaw	Andigama	1.225	1.125	
44	1	8	1.2	Empty	Katupotha	Chilaw	1.46	1.3	
45	1	8	1.2	Plastic Product	Katupotha	Chilaw	1.61	1.475	
46	1	7	1.1	Groceries	Anamaduwa	Chilaw	1.305	2.065	
47	2	8	1.2	Steel Prod	Chilaw	Katupotha	1.66	1.76	
48	2	7	1.1	Cement	Chilaw	Katupotha	1.895	2.47	
49	2	8	1.2	Rubber/Rubber Pro	Negombo	Katupotha	1.545	1.3	
50	2	8	1.2	Empty	Chilaw	Katupotha	1.64	1.285	
51	1	8	1.2	Empty	Katupotha	Chilaw	1.555	1.55	
52	2	8	1.2	Plastic Product	Palugassegama	Katupotha	1.17	1.36	
53	1	8	1.2	Empty	Katupotha	Chilaw	1.145	0.63	
54	1	7	1.1	Coconut Prod	Wennappuwa	Katupotha	0.64	0.53	
55	1	6	1.2	Passengers	Chilaw	Wilpattu Sanctuary	4.15	6.535	
56	1	8	1.2	Empty	Katupotha	Negombo	1.515	1.715	
57	1	7	1.1	Empty	Katupotha	Chilaw	0.71	0.44	
58	1	15	1.1.1	Empty	Katupotha	Battulu Oya	0.56	1.07	0.655
59	2	8	1.2	Cement Prod/Terra	Katupotha	Kiriyankalli	1.655	1.52	
60	1	9	1.2	Cement	Colombo	Katupotha	2.715	5.055	

Note:

To Bathuluoya / To Dewalahandiya

Direction :

1- Bathuluoya

2- Dewalahandiya

XLE LOAD Survey at Udupila (Delgoda) of Kirillawala - Udupila Rd on 28-11-2007

NO	DIR	VEH TYPE	AXLE CONFIG	LOAD TYPE	ORIGIN	DISTINATION	Axle Load		
							AXLE1	AXLE2	AXLE3
1	2	5	1.2	Passengers	Kirillawala	Delgoda	1.44	1.66	
2	2	7	1.1	Empty	Kirillawala	Kaduwela	1.28	0.845	
3	2	8	1.2	Empty	Kelaniya	Delgoda	1.545	0.975	
4	2	7	1.1	Salt Bags	Kirillawala	Kaduwela	1.195	1.19	
5	1	8	1.2	Non Durable Items	Delgoda	Kirillawala	1.305	1.44	
6	1	7	1.1	Empty	Delgoda	Colombo	1.1	0.945	
7	1	9	1.2	Empty	Kelaniya	Nawagamuwa	3.285	3.03	
8	1	8	1.2	Empty	Delgoda	Kirillawala	1.385	0.98	
9	2	8	1.2	Empty	Kirillawala	Delgoda	1.545	1.205	
10	2	7	1.1	Empty	Kirillawala	Delgoda	0.725	0.285	
11	1	8	1.2	Empty	Delgoda	Kirillawala	1.415	1.325	
12	2	7	1.1	Motor Spare Parts	Kirillawala	Rajagiriya	0.615	0.385	
13	1	8	1.2	Empty	Delgoda	Kirillawala	1.465	1.14	
14	1	8	1.2	Empty	Delgoda	Kadawata	3.735	3.615	
15	1	8	1.2	Empty	Weboda	Dekatana	1.67	1.29	
16	2	7	1.1	Empty	Weboda	Kirillawala	0.74	0.335	
17	1	9	1.2	Empty	Delgoda	Kirillawala	1.375	1.005	
18	1	7	1.1	Food Items	Delgoda	Kirillawala	0.745	0.44	
19	2	9	1.2	Empty	Kirillawala	Delgoda	1.345	1.285	
20	1	9	1.2	Empty	Delgoda	Kirillawala	1.345	1.285	
21	2	7	1.1	Empty	Kirillawala	Kirindiwela	1.105	0.75	
22	2	8	1.2	Hardwere Items	Kirillawala	Delgoda	0.94	0.715	
23	2	7	1.1	Empty	Kirillawala	Delgoda	1.4	1.065	
24	2	8	1.2	Empty	Ja-Ela	Delgoda	1.61	1.37	
25	1	8	1.2	Empty	Delgoda	Kadawata	2.29	2.165	
26	1	6	1.2	Empty	Kirillawala	Kirillawala	2.12	4.85	
27	1	7	1.1	Empty	Delgoda	Kadawata	0.96	0.505	
28	2	6	1.2	Passengers	Colombo	Delgoda	4.18	4.99	
29	1	8	1.2	Medince	Weliweriya	Kirillawala	1.715	1.705	
30	1	7	1.1	Empty	Weliweriya	Kirillawala	1.21	0.95	
31	2	7	1.1	Empty	Kirillawala	Delgoda	1.315	1.385	
32	2	7	1.1	Earth/Soil/Clay	Minuwangoda	Delgoda	2.04	3.06	
33	2	8	1.2	Empty	Kirillawala	Delgoda	1.48	1.215	
34	1	8	1.2	Matal	Dekatana	Kirillawala	2.175	4.975	
35	2	7	1.1	Empty	Kirillawala	Delgoda	0.84	0.64	
36	2	8	1.2	Empty	Kirillawala	Delgoda	1.51	1.17	
37	2	8	1.2	Plastic Product	Kadawata	Kalutara North	1.33	1.08	
38	2	8	1.2	Empty	Mahabage	Delgoda	1.45	1.195	
39	1	7	1.1	Wooden Prod	Delgoda	Kirillawala	1.275	2.03	
40	1	8	1.2	Matal	Delgoda	Imbulgoda	2.01	5.68	
41	1	6	1.2	Passengers	Delgoda	Colombo	3.54	4.55	
42	1	8	1.2	Matal	Kaduwela	Kirillawala	1.7	4.5	
43	1	10	1.22	Cement	Colombo	Kirillawala	4.05	6.905	7.13
44	1	7	1.1	Empty	Kiriliawala	Kirillawala	0.81	0.935	
45	2	7	1.1	Empty	Kirillawala	Delgoda	1.265	0.955	
46	1	8	1.2	Soap	Delgoda	Kirillawala	1.805	1.935	
47	1	8	1.2	Cement	Delgoda	Kirillawala	1.695	3.205	

48	1	8	1.2	Matal	Kadawata	Kirillawala	1.705	3.685	
49	1	8	1.2	Empty	Delgoda	Kirillawala	1.54	4.895	
50	1	8	1.2	Vegetables	Negombo	Kirillawala	1.25	1.035	
51	1	7	1.1	Empty	Delgoda	Kirillawala	1.265	0.955	
52	1	8	1.2	Empty	Kaduwela	Kirillawala	0.95	0.66	
53	2	8	1.2	Empty	Kirillawala	Delgoda	1.46	0.92	
54	1	8	1.2	Empty	Delgoda	Kirillawala	1.345	1.285	
55	1	8	1.2	Plastic Product	Delgoda	Ganemulla	1.71	1.875	
56	2	8	1.2	Empty	Kirillawala	Delgoda	1.53	1.06	
57	2	8	1.2	Earth/Soil/Clay	Kirillawala	Biyagama	1.47	1.175	
58	1	8	1.2	Earth/Soil/Clay	Mahabage	Kirillawala	2.17	4.33	
59	2	8	1.2	Earth/Soil/Clay	Mahabage	Weliweriya	2.56	5.96	
60	1	8	1.2	Matal	Delgoda	Kirillawala	1.785	3.755	
61	1	8	1.2	Empty	Biyagama	Kirillawala	1.45	0.87	
62	1	8	1.2	Matal	Delgoda	Kirillawala	2.035	4.91	
63	2	8	1.2	Hardwere Items	Kirillawala	Kadawata	1.795	1.86	
64	1	8	1.2	Empty	Imbulgoda	Moratuwa	1.08	0.575	
65	2	7	1.1	Hardwere Items	Radawana	Delgoda	1.24	1.14	
66	2	9	1.2	Empty	Kadawata	Delgoda	2.185	1.955	
67	1	9	1.2	Rubber/Rubber Pro	Kadawata	Kirillawala	1.58	1.455	
68	1	9	1.2	Empty	Delgoda	Kirillawala	1.44	1.35	
69	2	9	1.2	Rice/Paddy	Kirillawala	Delgoda	2.74	3.395	
70	2	8	1.2	Asbestos	Kirillawala	Aturugiriya	1.58	0.995	
71	2	7	1.1	Empty	Kadawata	Delgoda	0.465	0.395	
72	2	7	1.1	Food Items	Kirillawala	Delgoda	0.76	0.5	
73	1	8	1.2	Matal	Delgoda	Kirillawala	2.09	4.56	
74	2	8	1.2	Empty	Ganemulla	Delgoda	1.68	1.4	
75	2	8	1.2	Empty	Kirillawala	Kaduwela	1.24	0.74	
76	2	8	1.2	Empty	Ganemulla	Delgoda	2.635	3.73	
77	1	8	1.2	Empty	Kottawa	Kirillawala	1.475	1.545	
78	2	8	1.2	Empty Barrel	Ganemulla	Delgoda	2.175	2.47	
79	2	9	1.2	Earth/Soil/Clay	Kirillawala	Delgoda	2.36	4.525	
80	2	9	1.2	Food Items	Kadawata	Weliweriya	1.76	2.23	
81	1	7	1.1	Empty	Delgoda	Gampaha	0.85	0.93	
82	2	8	1.2	Empty	Kirillawala	Delgoda	1.44	1.15	
83	1	8	1.2	Empty	Malwana	Kirillawala	1.64	1.46	
84	2	6	1.2	Passengers	Kirillawala	Kaduwela	2.26	3.395	
85	1	8	1.2	Empty	Delgoda	Kirillawala	1.46	1.215	
86	1	8	1.2	Empty	Delgoda	Kirillawala	1.595	0.965	
87	1	8	1.2	Empty	Delgoda	Kirillawala	1.335	1.49	
88	2	8	1.2	Empty	Kirillawala	Delgoda	2.05	4.085	
89	2	8	1.2	Empty	Kirillawala	Delgoda	1.011	1.033	
90	1	8	1.2	Empty	Delgoda	Kirillawala	0.955	1.025	
91	1	8	1.2	Empty	Delgoda	Kirillawala	1.4	1.075	
92	1	8	1.2	Empty	Delgoda	Kirillawala	1.585	0.87	
93	1	6	1.2	Empty	Delgoda	Colombo	3.185	3.095	
94	1	8	1.2	Empty	Delgoda	Kirillawala	2.32	3.49	
95	1	8	1.2	Matal	Kirillawala	Kadawata	2.155	4.565	
96	1	8	1.2	Empty	Malwana	Kirillawala	1.61	1.175	
97	1	8	1.2	Sand	Pugoda	Kadawata	1.835	4.225	
98	1	7	1.1	Matal	Kirillawala	Kadawata	1.785	3.68	
99	1	8	1.2	Wooden Prod	Kaduwela	Kadawata	1.225	0.82	

100	1	6	1.2	Empty					
101	2	8	1.2	Earth/Soil/Clay	Delgoda	Colombo	3.28	3.675	
102	2	8	1.2	Empty	Kirillawala	Kirillawala	2.15	3.925	
103	2	7	1.2	Textiles	Kirillawala	Delgoda	1.265	0.785	
104	1	5	1.2	Passengers	Nugegoda	Delgoda	1.22	1.27	
105	1	5	1.2	Passengers	Delgoda	Kirillawala	2.035	4.165	
106	2	8	1.2	Empty	Thihariya	Kirillawala	1.355	1.74	
107	1	8	1.2	Empty	Kadawata	Kaduwela	1.735	1.55	
108	2	8	1.2	Empty	Delgoda	Kirillawala	1.35	1.315	
109	2	7	1.1	Empty	Kelaniya	Kirillawala	1.25	1.425	
110	2	8	1.2	Medince	Kadawata	Biyagama	1.135	0.64	
111	2	9	1.2	Empty	Ragama	Delgoda	1.805	1.605	
112	1	8	1.2	Empty	Delgoda	Kirillawala	1.785	1.87	
113	1	8	1.2	Empty	Delgoda	Kirillawala	1.49	1.163	
114	2	8	1.2	Empty	Delgoda	Kirillawala	1.525	1.1	
115	2	8	1.2	Earth/Soil/Clay	Kirillawala	Delgoda	1.445	1.055	
116	1	8	1.2	Matal	Kirillawala	Delgoda	2.235	4.16	
					Delgoda	Kadawata	2.1	5.185	

Note:

Direction :

1- Kirillawala

2- Udupila

AXLE LOAD Survey at Neluwa-Kadihingala- Dellawa- Morawaka Road on 05-12-2007

Sr NO	DIR	VEH TYPE	AXLE CONFIG	LOAD TYPE	ORIGIN	DESTINATION	Axle Load		
							AXLE1	AXLE2	AXLE3
1	1	6	1.2	Passengers	Morawaka	Galle	3.45	3.35	
2	1	8	1.2	Wooden Prod	Middeniya	Neluwa	2.065	4.23	
3	2	6	1.2	Passengers	Neluwa	Morawaka	2.31	2.74	
4	1	6	1.2	Passengers	Morawaka	Neluwa	2.625	2.54	
5	2	6	1.2	Empty	Galle	Morawaka	1.92	2.24	
6	1	6	1.2	Passengers	Morawaka	Galle	1.97	2.41	
7	2	15	1.1.1	Sand	Neluwa	Morawaka	0.5	1.65	1.98
8	2	15	1.1.1	Empty	Neluwa	Morawaka	0.525	1.035	0.49
9	2	6	1.2	Passengers	Neluwa	Morawaka	2.29	2.7	
10	1	6	1.2	Passengers	Morawaka	Neluwa	2.28	2.99	
11	2	7	1.1	Empty	Neluwa	Morawaka	0.985	0.58	
12	1	6	1.2	Empty	Udugama	Neluwa	2.35	1.98	
13	2	8	1.2	Empty	Neluwa	Morawaka	1.055	1.135	
14	1	15	1.1.1	Empty	Morawaka	Neluwa	0.45	1.045	0.75
15	1	6	1.2	Empty	Morawaka	Neluwa	2.35	1.98	
16	2	6	1.2	Passengers	Udugama	Morawaka	1.89	2.9	
17	1	15	1.1.1	Empty	Morawaka	Neluwa	0.44	1.05	0.76
18	2	15	1.1.1	Fertiliser	Neluwa	Morawaka	0.44	1.635	1.8
19	2	8	1.2	Sand	Neluwa	Morawaka	1.435	2.965	
20	1	7	1.1	Empty	Ratnapura	Neluwa	1.095	0.89	
21	1	6	1.2	Empty	Morawaka	Neluwa	1.9	2.85	
22	1	8	1.2	Food Items	Morawaka	Neluwa	1.165	1.55	
23	1	15	1.1.1	Sand	Morawaka	Neluwa	0.38	1.32	1.565
24	2	6	1.2	Empty	Udugama	Morawaka	1.86	2.065	
25	2	7	1.1	Empty	Neluwa	Morawaka	1.095	0.89	
26	1	6	1.2	Empty	Morawaka	Udugama	1.86	2.065	
27	1	9	1.2	Empty	Morawaka	Neluwa	2.5	2.25	
28	1	8	1.2	Milk	Waralla	Neluwa	1.2	1.45	
29	2	8	1.2	Sand	Neluwa	Morawaka	1.915	3.675	
30	1	6	1.2	Passengers	Morawaka	Galle	2.75	3.09	
31	2	9	1.2	Empty	Neluwa	Morawaka	2.45	2.3	
32	1	6	1.2	Passengers	Galle	Neluwa	2.65	2.9	
33	1	7	1.1	Empty	Morawaka	Neluwa	1.05	0.9	
34	1	8	1.2	Empty	Morawaka	Neluwa	1.06	1.15	
35	2	6	1.2	Passengers	Galle	Morawaka	3.475	3.34	
36	2	15	1.1.1	Empty	Neluwa	Morawaka	0.53	1.105	0.62
37	1	15	1.1.1	Empty	Morawaka	Neluwa	0.53	1.15	0.59
38	1	7	1.1	Empty	Morawaka	Neluwa	0.935	0.595	
39	1	6	1.2	Empty	Morawaka	Galle	2.585	3.45	
40	2	15	1.1.1	Sand	Neluwa	Morawaka	0.53	1.835	2.44
41	2	7	1.1	Empty	Neluwa	Morawaka	0.99	0.795	
42	1	6	1.2	Passengers	Morawaka	Galle	2.785	2.86	
43	1	15	1.1.1	Empty	Morawaka	Neluwa	0.54	1.15	0.7
44	2	15	1.1.1	Passengers	Neluwa	Morawaka	0.59	1.395	0.815
45	2	15	1.1.1	Empty	Neluwa	Morawaka	0.55	1.14	0.8
46	2	7	1.1	Empty	Neluwa	Morawaka	1.1	0.89	

47	1	7	1.1	Passengers	Morawaka	Neluwa	1.35	1.8	
48	2	8	1.2	Sand	Neluwa	Morawaka	1.755	3.84	
49	2	8	1.2	Steel Prod	Meegoda	Morawaka	1.245	1.1	
50	1	15	1.1.1	Empty	Kotapola	Neluwa	0.56	1.12	0.65
51	1	6	1.2	Empty	Morawaka	Galle	2.6	2.75	
52	2	6	1.2	Empty	Neluwa	Morawaka	2.84	3.565	

Note:

Direction :

1- Neluwa

2- Morawaka

Appendix – D

Middle, 1ft Away from Corner

64 in

0	16	32	48	64	80	96
48	1	2	3	4	5	6
96	7	8	9	10	11	12
120	13	14	15	16	17	18
144	19	20	21	22	23	24
168	25	26	27	28	29	30
180	31	32	33	34	35	36
180						
192	37	38	39	40	41	42
204	43	44	45	46	47	48
216	49	50	51	52	53	54
228	55	56	57	58	59	60
240	61	62	63	64	65	66
252	67	68	69	70	71	72
264	73	74	75	76	77	78
276	79	80	81	82	83	84
288	85	86	87	88	89	90
300	91	92	93	94	95	96
312	97	98	99	100	101	102
336	103	104	105	106	107	108
360	109	110	111	112	113	114
360						
384	115	116	117	118	119	120
432	121	122	123	124	125	126
480	127	128	129	130	131	132
528	133	134	135	136	137	138
540	139	140	141	142	143	144

Corner

64 in

0	16	32	48	64	80	96
48	1	2	3	4	5	6
96	7	8	9	10	11	12
120	13	14	15	16	17	18
144	19	20	21	22	23	24
168	25	26	27	28	29	30
180	31	32	33	34	35	36
180						
192	37	38	39	40	41	42
204	43	44	45	46	47	48
216	49	50	51	52	53	54
228	55	56	57	58	59	60
240	61	62	63	64	65	66
252	67	68	69	70	71	72
264	73	74	75	76	77	78
276	79	80	81	82	83	84
288	85	86	87	88	89	90
300	91	92	93	94	95	96
312	97	98	99	100	101	102
336	103	104	105	106	107	108
360	109	110	111	112	113	114
360						
384	115	116	117	118	119	120
432	121	122	123	124	125	126
480	127	128	129	130	131	132
528	133	134	135	136	137	138
540	139	140	141	142	143	144

Element No

Middle

64 in

0	16	32	48	64	80	96	112	120
48	1	2	3	4	5	6	7	8
96	9	10	11	12	13	14	15	16
120	17	18	19	20	21	22	23	24
144	25	26	27	28	29	30	31	32
168	33	34	35	36	37	38	39	40
180	41	42	43	44	45	46	47	48
180								
192	49	50	51	52	53	54	55	56
204	57	58	59	60	61	62	63	64
216	65	66	67	68	69	70	71	72
228	73	74	75	76	77	78	79	80
240	81	82	83	84	85	86	87	88
252	89	90	91	92	93	94	95	96
264	97	98	99	100	101	102	103	104
276	105	106	107	108	109	110	111	112
288	113	114	115	116	117	118	119	120
300	121	122	123	124	125	126	127	128
312	129	130	131	132	133	134	135	136
336	137	138	139	140	141	142	143	144
360	145	146	147	148	149	150	151	152
360								
384	153	154	155	156	157	158	159	160
432	161	162	163	164	165	166	167	168
480	169	170	171	172	173	174	175	176
528	177	178	179	180	181	182	183	184
540	185	186	187	188	189	190	191	192

Corner

64 in

0	16	32	48	64	80	96	112	120
48	1	2	3	4	5	6	7	8
96	9	10	11	12	13	14	15	16
120	17	18	19	20	21	22	23	24
144	25	26	27	28	29	30	31	32
168	33	34	35	36	37	38	39	40
180	41	42	43	44	45	46	47	48
180								
192	49	50	51	52	53	54	55	56
204	57	58	59	60	61	62	63	64
216	65	66	67	68	69	70	71	72
228	73	74	75	76	77	78	79	80
240	81	82	83	84	85	86	87	88
252	89	90	91	92	93	94	95	96
264	97	98	99	100	101	102	103	104
276	105	106	107	108	109	110	111	112
288	113	114	115	116	117	118	119	120
300	121	122	123	124	125	126	127	128
312	129	130	131	132	133	134	135	136
336	137	138	139	140	141	142	143	144
360	145	146	147	148	149	150	151	152
360								
384	153	154	155	156	157	158	159	160
432	161	162	163	164	165	166	167	168
480	169	170	171	172	173	174	175	176
528	177	178	179	180	181	182	183	184
540	185	186	187	188	189	190	191	192

1 ft Away from Corner

64 in

0	16	32	48	64	80	96	112	120
48	1	2	3	4	5	6	7	8
96	9	10	11	12	13	14	15	16
120	17	18	19	20	21	22	23	24
144	25	26	27	28	29	30	31	32
168	33	34	35	36	37	38	39	40
180	41	42	43	44	45	46	47	48
180								
192	49	50	51	52	53	54	55	56
204	57	58	59	60	61	62	63	64
216	65	66	67	68	69	70	71	72
228	73	74	75	76	77	78	79	80
240	81	82	83	84	85	86	87	88
252	89	90	91	92	93	94	95	96
264	97	98	99	100	101	102	103	104
276	105	106	107	108	109	110	111	112
288	113	114	115	116	117	118	119	120
300	121	122	123	124	125	126	127	128
312	129	130	131	132	133	134	135	136
336	137	138	139	140	141	142	143	144
360	145	146	147	148	149	150	151	152
360								
384	153	154	155	156	157	158	159	160
432	161	162	163	164	165	166	167	168
480	169	170	171	172	173	174	175	176
528	177	178	179	180	181	182	183	184
540	185	186	187	188	189	190	191	192

Element No

Middle

64 in

0	16	32	48	64	80	96	112	128	144
48	1	2	3	4	5	6	7	8	9
96	10	11	13	14	15	16	17	18	19
120	19	20	21	22	23	24	25	26	27
144	28	29	30	31	32	33	34	35	36
168	37	38	39	40	41	42	43	44	45
180	46	47	48	49	50	51	52	53	54
180									
192	55	56	57	58	59	60	61	62	63
204	64	65	66	67	68	69	70	71	72
216	73	74	75	76	77	78	79	80	81
228	82	83	84	85	86	87	88	89	90
240	91	92	93	94	95	96	97	98	99
252	100	101	102	103	104	105	106	107	108
264	109	110	111	112	113	114	115	116	117
276	118	119	120	121	122	123	124	125	126
288	127	128	129	130	131	132	133	134	135
300	136	137	138	139	140	141	142	143	144
312	145	146	147	148	149	150	151	152	153
336	154	155	156	157	158	159	160	161	162
360	163	164	165	166	167	168	169	170	171
360									
384	172	173	174	175	176	177	178	179	180
432	181	182	183	184	185	186	187	188	189
480	190	191	192	193	194	195	196	197	198
528	199	200	201	202	203	204	205	206	207
540	208	209	210	211	212	213	214	215	216

Corner

Element No

64 in

0	16	32	48	64	80	96	112	128	144
48	1	2	3	4	5	6	7	8	9
96	10	11	13	14	15	16	17	18	19
120	19	20	21	22	23	24	26	26	27
144	28	29	30	31	32	33	34	35	36
168	37	38	39	40	41	42	43	44	45
180	46	47	48	49	50	51	52	53	54
180									
192	55	56	57	58	59	60	61	62	63
204	64	65	66	67	68	69	70	71	72
216	73	74	75	76	77	78	79	80	81
228	82	83	84	85	86	87	88	89	90
240	91	92	93	94	95	96	97	98	99
252	100	101	102	103	104	105	106	107	108
284	109	110	111	112	113	114	115	116	117
276	118	119	120	121	172	123	124	125	126
288	127	128	129	130	131	132	133	134	135
300	136	137	138	139	140	141	142	143	144
312	145	146	147	148	149	150	151	152	153
336	154	155	156	157	158	159	160	161	162
360	163	164	165	166	167	168	169	170	171
360									
384	172	173	174	175	176	177	178	179	180
432	181	182	183	184	185	186	187	188	189
480	190	191	192	193	194	195	196	197	198
528	199	200	201	202	203	204	205	206	207
540	208	209	210	211	212	213	214	215	216

1 ft Away from Corner

Element No

64 in

0	16	32	48	64	80	96	112	128	144
48	1	2	3	4	5	6	7	8	9
96	10	11	13	14	15	16	17	18	19
120	19	20	21	22	23	24	25	26	27
144	28	29	30	31	32	33	34	35	36
168	37	38	39	40	41	42	43	44	45
180	46	47	48	49	50	51	52	53	54
180									
192	55	56	57	58	59	60	61	62	63
204	64	65	66	67	68	69	70	71	72
216	73	74	75	76	77	78	79	80	81
228	82	83	84	85	86	87	88	89	90
240	91	92	93	94	95	96	97	98	99
252	100	101	102	103	104	105	106	107	108
264	109	110	111	112	113	114	115	116	117
276	118	119	120	121	122	123	124	125	126
288	127	128	129	130	131	132	133	134	135
300	136	137	138	139	140	141	142	143	144
312	145	146	147	148	149	150	151	152	153
336	154	155	156	157	158	159	160	161	162
360	163	164	165	166	167	168	169	170	171
360									
384	172	173	174	175	176	177	178	179	180
432	181	182	183	184	185	186	187	188	189
480	190	191	192	193	194	195	196	197	198
528	199	200	201	202	203	204	205	206	207
540	208	209	210	211	212	213	214	215	216