PERGAMON

Computers and Structures 79 (2001) 1617–1624

Computers & Structures

www.elsevier.com/locate/compstruc

# Optimum rigid pavement design by genetic algorithms

M.N.S. Hadi [a,*], Y. Arfiadi [b]

[a] *Faculty of Engineering, Department of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia*

[b] *Department of Civil Engineering, Faculty of Engineering – Atma Jaya, Yogyakarta University, Jalan Babarsari 44, P.O. Box 1086, Yogyakarta 55281, Indonesia*

Received 1 November 1999; accepted 22 February 2001

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## Abstract

The design of rigid pavements according to AUSTROADS involves assuming a pavement structure then using a number of tables and figures to calculate the two governing design criteria, the flexural fatigue of the concrete base and the erosion of the sub-grade/sub-base. Each of these two criteria needs to be less than 100%. The designer needs to ensure that both criteria are near 100% so that safe and economical designs are achieved. This paper presents a formulation for the problem of optimum rigid road pavement design by defining the objective function, which is the total cost of pavement materials, and all the constraints that influence the design. A genetic algorithm is used to find the optimum design. The results obtained from the genetic algorithm are compared with results obtained from a Newton–Raphson based optimisation solver. The latter being developed using spreadsheets. © 2001 Civil-Comp Ltd. and Elsevier Science Ltd. All rights reserved.

*Keywords:* Optimum design; Rigid pavements

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## 1. Introduction

The initial cost of building rigid pavements is relatively higher than that involved in constructing flexible pavements. However, the overall cost of building and maintaining flexible pavements outweighs those of rigid pavements. In 1996, DECICORP [1] were commissioned by the Steel Reinforcement Institute of Australia, SRIA to study the factors that influence the design and construction of rigid pavements. They studied the cost of construction of a 38 km 8-lane road, i.e. 304 lane km. The assumed design life of the pavement was 40 years, 1998–2037 being built on a three CBR sub-grade. Five types of pavement construction were considered, continuously reinforced concrete pavement, plain concrete pavement, full depth asphalt with an asphalt overlay, cement treated base and asphalt overlay, and granular overlay with an asphalt riding course. DECICORP conducted a cost analysis for all types of pavements including the initial construction cost and the cost of maintenance during the life of the pavement, this included the disruption to the traffic during maintenance periods. The comparison revealed that continuously reinforced concrete pavement option had the lowest overall cost, including both initial construction and continuing maintenance costs.

DECICORP's [1] report concludes that it is cheaper to build rigid pavements that require less maintenance and provide pavements with longer life spans. These pavements prove to be more economical in the long run. This economical advantage coupled with the fact that rigid pavements provide higher strengths thus being able to carry higher traffic loadings.

Rigid pavements have been used all over the world for several decades and different road authorities and organisations have developed design methods that suit their locale. To name a few, the American Association of State Highway and Transportation Officials (AASHTO), the Portland Cement Association (PCA),

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[*] Corresponding author. Tel.: +61-2-4221-4762; fax: +61-2-4221-3238.

*E-mail address:* mhadi@uow.edu.au (M.N.S. Hadi).

PII: S0045-7949(01)00038-4

and the Corps of Engineers of the US Army. These methods and others are documented in several textbooks (e.g. Refs. [2,3]).

Most design methods are complex where the designer needs to refer to several tables and charts and use some rather lengthy design formulas. The iterative design methods invite the user to use several iterations in order to obtain a solution that satisfies the design requirements. Due to the lengthy design procedure most designers would stop after two or three iterations thus yielding designs that are safe but not necessarily economical. This over-design, which comes with a higher cost as a penalty, jeopardises the viability of using rigid pavements and reduces its effectiveness as a viable alternative for building road pavements. There has been a number of attempts to optimise the design of pavements, but none of these attempts are for the optimum design of rigid pavements and none by using Genetic Algorithm (GA).

In this paper, the design method of the Australian pavement design guide, AUSTROADS [4] which is based on the recommendations of the PCA [5] is presented and the optimisation problem is developed for this method. GA is chosen as the optimisation tool where a number of design examples are solved and compared with other optimisation techniques.

## 2. Rigid pavements

As the name indicates, rigid pavements deflect much less due to the application of vehicular loading than do flexible pavements. Rigid pavements are built by compacting the sub-grade, then adding a layer that represents the sub-base, which is an option that is more frequently chosen. This layer has better material properties compared to the sub-grade. The idea behind using this layer is to provide a strong working platform and to help distribute the vehicular loading when applied at the surface of the base.

There are three types of rigid pavements: jointed plain (unreinforced) concrete pavements (PCP), jointed reinforced concrete pavements (JRCP), and continuously reinforced concrete pavements (CRCP). The choice of which type of pavement is to be used depends on the vehicular load, the strength of the sub-grade, available material and cost. In the recent years, CRCP has been more widely used as it provides pavements with better riding quality.

### *2.1. Calculating pavement response*

An important step in designing rigid pavements is calculating the stresses induced in the concrete base and the sub-grade. The pioneering work of Westergaard in the year 1926, for calculating stresses in rigid pavements due to vehicular loads, forms the basis of the design methodology of all current design methods of rigid pavements. Westergaard produced equations for calculating stresses and deflections in the concrete base when a vehicular load is applied at the centre of the base, at the edge of the base and at the corner of the base. His initial work was modified in 1948.

Ioannides et al. [6] presented a study of Westergaard's equations and compared the results with the output from a finite element program. Also they presented their own improved expressions for calculating maximum corner loading responses. Finally, they established slab size requirements for the development of Westergaard responses. It is to be noted that Westergaard's equations are closed form solutions and they take the modulus of sub-grade reaction of the sub-base and the modulus of concrete as part of their input parameters.

Fordyce and Yrjanson [7] presented a design method for rigid pavements that is the background of the current design method of the PCA. This method takes into consideration the stresses induced in the concrete slab due to the application of vehicular load and those induced due to concrete contraction and warping. This forms the basis of the design method of the PCA [5] and hence of AUSTROADS [4].

In 1980, Tabatabaie and Barenberg [8] presented a finite element based program, ILLI-SLAB for the analysis of concrete pavement systems. They also presented the development, verification, and application of the developed program.

MacLead and Monismith [9] examined methods for calculating stresses in plain jointed Portland cement concrete pavements. The methods compared include plate on dense-liquid sub-grades, plate on elastic solid, and layered elastic system. For all the methods, they used the closed form solution and the finite element solution. It was concluded that for fatigue analysis, two-dimensional finite element analysis that uses a layered elastic solid rather than a dense liquid sub-grade as the idealisation of the materials underlying the concrete layer is more suitable. Also, they showed that the maximum tensile stress, which is a controlling factor for the fatigue life of rigid pavements, occurs near the edge at the midslab position for the representative highway load configuration examined in the investigation.

Ozbeki et al. [10] developed a finite element computer program, JSALB for the evaluation of jointed rigid pavements and used it in a parametric study to determine which variables have the most significant effect on the performance of transverse joints. They concluded that the variables that have the most significant effects are the modulus of sub-grade reaction and the modulus of dowel–concrete interaction. Accordingly, they concluded that a rigid pavement could be structurally evaluated if the above two parameters were known.

It is obvious that the problem of calculating induced stresses in rigid pavements due to vehicular loading is a rather complicated problem. The non-deterministic nature of vehicular loadings and their location, and changes in material properties due to creep and moisture content variation are among the factors that add complexity to the problem in hand. In addition, changes in temperature and fluctuation in precipitation rate are significant effects. However, it seems that most pavement engineers now-a-days agree on Westergaard's equations and solutions of well known finite element programs developed specifically for rigid pavement analysis, e.g. ILLSLAB and KENSLAB. Moreover, values in Tables 9.2 and 9.3 of AUSTROADS [4] are mainly based on Westergaard's equations.

### 2.2. AUSTROADS design method of rigid pavements

The design method for rigid pavements presented by Fordyce and Yrjanson [7] is the background of the current design method of PCA. This method takes into consideration the stresses induced in the concrete slab due to the application of vehicular load and those induced due to concrete contraction and warping. This forms the basis of the PCA [5] design method and hence of AUSTROADS [4].

#### 2.2.1. Design input parameters

The input parameters that influence the design of rigid pavements based on the design procedure of AUSTROADS [4] are

*Type of pavement*

- Dowelled or undowelled pavement.
- The existence of shoulders.
- Spacing of joints, which affects reinforcement rate.

*Traffic loading*

- Total number of commercial vehicles.
- Locality of the pavement, rural or urban.
- Distribution of the different axle groups, i.e. single with single wheels, SS, single axles with dual wheels, SD, Tandem axles with dual wheels, TAD, and triaxles with dual wheels, TRD.
- Distribution of wheel loads within each axle group.
- Design life of the pavement.
- Growth factor.
- Load safety factor.

*Sub-grade strength*

- The strength of the sub-grade represented by its California bearing ratio (CBR).
- Based on the sub-grade strength and total vehicular load, the type of sub-base is determined which yields the effective CBR.

*Material properties*

- The strength of concrete presented in terms of its 28-day flexural strength.
- The tensile strength of reinforcing steel.

#### 2.2.2. Design output

The designer uses the design method described below and inputs the design parameters to produce the following output:

- Thickness of concrete slab.
- Type and thickness of sub-base.
- If reinforced, amount of reinforcement.
- If jointed, the spacing of joints.

#### 2.2.3. The design method

The design method of AUSTROADS can be summarised as

1. Decide on the type of pavement, i.e. PCP, JRCP, or CRCP.
2. Decide whether concrete shoulders are to be provided.
3. Estimate the daily number of commercial vehicular loading, $C$.
4. Estimate the growth rate for the pavement, $r$.
5. Decide on the design life of the pavement, $N$.
6. Calculate the total number of commercial vehicles to be applied on the pavement throughout its design life, CVAG. This is done by applying Eq. (1).

$$\mathrm{CVAG} = C \times 365 \times \frac{(1+r)^N - 1}{r} \tag{1}$$

where $C$ is the daily number of commercial vehicles, $r$ is the growth rate in percent and $N$ is the pavement life in years.

7. Estimate the CBR of the sub-grade.
8. Based on CVAG and sub-grade CBR and by using Fig. 9.1 of AUSTROADS, determine the minimum sub-base requirement.
9. Choose type and thickness of the sub-base and by using Fig. 9.2 of AUSTROADS, determine the effective CBR.
10. Choose the design compressive strength of concrete, $f'_c$ which should have a minimum value of 32 MPa. From this and by applying Eq. (2), the flexural strength of concrete, $f'_{cf}$ is to be calculated.

$$f'_{cf} = 0.75\sqrt{f'_c} \tag{2}$$

11. Choose a trial thickness of the base, $h$ which should be at least 150 mm.

12. Based on *h,* the effective CBR, the existence of shoulders and whether the pavement is dowelled or undowelled, use Table 9.2 or 9.3 to calculate the stress factor and erosion factor for each type of axle.
13. Choose a load safety factor (LSF). This depends on the locality and importance of the road.
14. For each type of axle group and based on whether the pavement is located in a rural or urban area, determine the percentages of each of the axle groups and the distribution of the different axle loads in each group. This is given in Appendix I of AUSTROADS. Multiply this distribution by the total vehicular load, CVAG and multiply it by the LSF. This will yield the expected load repetitions for each axle load within the axle groups.
15. For each axle load of each axle group, calculate the allowable load repetitions based on limiting the fatigue of concrete and the erosion of the sub-base/sub-grade. These can be calculated either by using the monographs shown in Figs. 9.4, 9.5 and 9.6 of AUSTROADS or by using the following equations as given by Packard and Tayabji [11]. The equations for the fatigue of concrete are

$$\log(N_{\mathrm{f}}) = \left[\frac{0.9718 - S_{\mathrm{r}}}{0.0828}\right] \text{ when } S_{\mathrm{r}} > 0.55 \tag{3}$$

$$N_{\mathrm{f}} = \left[\frac{4.2577}{S_{\mathrm{r}} - 0.4325}\right]^{3.268} \text{ when } 0.45 \leqslant S_{\mathrm{r}} \leqslant 0. \tag{4}$$

$N_{\mathrm{f}}$ is undefined when $S_{\mathrm{r}} < 0.45$

where

$$S_{\mathrm{r}} = \frac{S_{\mathrm{e}}}{f'_{\mathrm{cf}}}\left[\frac{P \times \mathrm{LSF}}{4.45F_1}\right]^{0.94} \tag{5}$$

and

$N_{\mathrm{f}}$ is the allowable load repetitions based on fatigue; $S_{\mathrm{e}}$, the equivalent stress, MPa; $f'_{\mathrm{cf}}$, the design flexural strength of concrete, MPa; $P$, the axle load, kN; LSF, the load safety factor; $F_1$, the load adjustment factor, 9 for single axle with single wheel, 18 for single axle with dual wheel, 36 for tandem axle with dual wheel, 54 for triaxle with dual wheel.

For erosion,

$$\log(F_2 N_{\mathrm{e}}) = 14.524 - 6.777\left[\left(\frac{P \times \mathrm{LSF}}{4.45F_1}\right)^2 \frac{10^{F_3}}{41.35} - 9.0\right]^{0.103} \tag{6}$$

where

$P$, LSF and $F_1$ are similar to the previous definitions; $N_{\mathrm{e}}$, the allowable load repetitions based on erosion; $F_2$, the adjustment factor for slab edge effects, 0.06 for base with no shoulder, 0.94 for base with shoulder; $F_3$, the erosion factor.

16. For each axle load of each axle group, divide the applied load repetitions by the allowable one obtained from fatigue and multiply by 100% to obtain the fatigue percentage. Add the fatigue percentages for all the axle loads to obtain the fatigue factor.
17. Repeat step 16 for all axle loads to calculate the erosion factor by summing up the percentage damage for each axle load which is calculated by dividing the expected load repetitions by the allowable one to prevent erosion.
18. If either the fatigue factor or the erosion factor is more than 100%, the designer has two options. Either to increase the base thickness, *h* thus to repeat steps 11–17 or to use a stronger sub-base thus to repeat steps 8–18.
19. After the designer is satisfied with the structural design of the pavement, the final step of the design process is to calculate the amount of reinforcement required.

It is clear that the design of rigid pavements based on the recommendation of AUSTROADS is a lengthy process that requires several steps of elaborate calculations. Moreover, after calculating the fatigue and erosion factors, the designer is to make the decision whether a redesign is necessary or not. In the case when either of the factors is greater than 100% a redesign is necessary. However in the case when either or both of the factors is much less than 100%, in other words an over design, it becomes the decision of the designer to whether to repeat the design by assuming a smaller base course or a weaker sub-base or accepting the over design. The cost of the pavement is not explicitly specified in AUSTROADS as a design factor for both rigid and flexible pavements. It is the responsibility of the designer to ensure a safe and an economical design. It is to be noted here that the saving in the design of road pavements can be considerable due to the vast amount of materials involved in constructing the pavement structure.

This cost factor leads to the call to include the cost of initial construction and continuing maintenance of the pavement as an explicit design objective and to include the fatigue and erosion factors among other factors as design constraints. Using optimisation techniques, as compared to "fully stressed designs", will yield an optimum design quickly using routine calculations. These designs satisfy the requirements of the design guide as well as being the most economical ones.

## 3. Optimum design of pavements

Optimisation is a branch of operations research that was developed and flourished during the second world war for several military applications. After the war, methods of operations research in general and optimisation in particular are increasingly being applied to solve engineering problems. During the seventies a large number of design problems were solved using these optimisation techniques.

Pavement engineers have identified the importance of taking advantage of the available routines for the optimum design of pavement structures, and as such in 1985 Rouphail [12] developed a formulation for the optimum design of flexible pavements based on the AASHTO design method. Mixed integer-linear programming was used in the development. The method produces design with minimum construction cost.

Nicholls [13] developed an optimisation computer program that acts as a framework for the optimum design of rigid pavements. The program, DNSPO86, interacts with the AASHTO based pavement design program, DNPS86. It was designed in such a way that any future amendments to DNSP86 program can be easily made without a major impact on the overall program.

Vorobieff [14] proposed to use the RIGID 5 computer program to manually search for the optimum design of a rigid pavement. Although RIGID 5 serves as a design tool for rigid pavements, its employment for optimum design may lead to designs that are based on local optima. Moreover, using manual search methods in general may not lead to any optimum solution. Nevertheless, using RIGID 5 is a good and may be viable alternative to achieve optimum designs.

Hadi [15] presented a framework for the optimum design of rigid pavements problem and solved 1680 pavement structures using the implemented frame work.

It is clear that there is a need to develop optimum design equations for rigid pavements. Moreover, as the nature of the problem is based on discrete variables, advantage should be made by using discrete optimisation methods. One such method is genetic algorithms.

## 4. The rigid pavement optimisation problem

The first step in any optimisation problem is to define the problem, including the objective function and the constraints that control the solution. The formulation that is presented herein is based on the requirements of AUSTROADS. However, other methods of design can be incorporated by extending the scope of the problem.

The objective function for which the minimum value is sought is presented as

$$C_{\mathrm{p}} = C_{\mathrm{c}} \times h + C_{\mathrm{LMC}} \times h_{\mathrm{LMC}} + C_{\mathrm{bound}} \times h_{\mathrm{bound}} + C_{\mathrm{s}} \times A_{\mathrm{s}} \tag{7}$$

Subject to

$$h \geqslant 150 \text{ mm} \tag{8}$$

$$0 \leqslant \text{fatigue factor} \leqslant 100 \tag{9}$$

$$0 \leqslant \text{erosion factor} \leqslant 100 \tag{10}$$

$$\text{Type of sub-base} \geqslant \text{min recommended sub-base} \tag{11}$$

$$A_{\mathrm{s}} \geqslant A_{\mathrm{s\,min}} \tag{12}$$

where $C_{\mathrm{p}}$ is the cost of building the pavement per square metre, $C_{\mathrm{c}}$ is the cost of a cubic metre of concrete, $h$ is the thickness of the base, $C_{\mathrm{LMC}}$ is the cost of a cubic metre of lean mixed concrete, $h_{\mathrm{LMC}}$ is the thickness of the lean mixed concrete layer, $C_{\mathrm{bound}}$ is the cost of a cubic metre of bound material, $h_{\mathrm{bound}}$ is the thickness of the bound material, $C_{\mathrm{s}}$ is the cost of one cubic metre of reinforcement and $A_{\mathrm{s}}$ is the area of reinforcement in a square metre of the base. The "Type of sub-base" variable is the type of sub-base that the designer can choose. AUSTROADS recommends these types: 100, 125 and 150 mm of bound material and 100, 125 and 150 mm of lean mix concrete (LMC). "min recommended sub-base" is the least sub-base type to satisfy Fig. 9.1 of AUSTROADS.

The design parameters that are input to the problem are type of pavement, location of the pavement, whether shoulders exist, daily commercial traffic, the growth rate, design life, sub-grade CBR, strength of concrete, and strength of steel. The cost of concrete, LMC, and bound material, all expressed per cubic metre are also input. Based on these input parameters the optimisation process obtains the optimum solution, which includes the best type and thickness of sub-base (sub-base type), the thickness of the base and the amount of reinforcement. In this study, the design variables are restricted to the sub-base type and the thickness of base. As the amount of reinforcement changes linearly with the base thickness, i.e. the lower the base thickness the lower the reinforcement, the cost of reinforcement was not considered in this study.

## 5. Genetic algorithm

A new evolving branch of optimisation is the genetic algorithm (GA) that is based on nature's theory of evolution, survival of the fittest. GA's have been developed by Holland [16] as reported by Goldberg [17]. The GA is an iterative process that involves reproduction, crossover and mutation. Briefly, the steps involved in GA are

1. Represent all the variables in the optimisation problem in binary form. Hence all variables will be represented by a string of bits. All the variables will be in

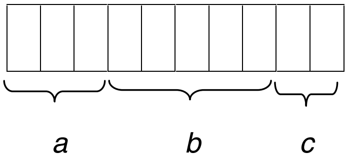

Fig. 1. A binary representation of three variables.

one block. For example, if we have three variables, $a$, $b$, and $c$ ; where $a$ can have any value between 0 and 6, $b$ can have any value between 0 and 32 and $c$ can have any value between 0 and 4, then the following string will represent all three variables. In other words, one binary number of length 10 can represent all the three variables (see Fig. 1).

2. Randomly select two binary numbers of 10 bits length parents. Those two numbers need to satisfy all the constraints.
3. Perform what is called crossover on the two selected numbers. Crossover between two variables is a simple process where the bits of the two variables, after a randomly chosen point of crossover, interchange values with the corresponding bits in the other variable. For example, if we have the two variables shown in Fig. 2(a), crossover will yield the variables shown in Fig. 2(b). In this example, bits 5 to 10 exchange values with corresponding bits in the other number.
4. Perform mutation on the new offsprings. Mutation is simply to change the value in a randomly chosen bit from 0 to 1 or from 1 to 0, as shown in Fig. 3.

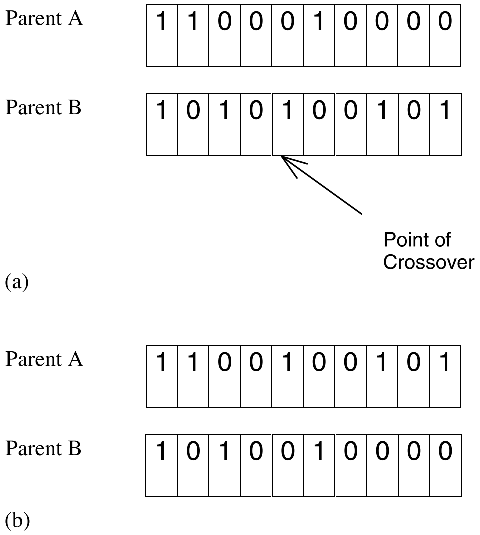

Fig. 2. Crossover: (a) before crossover and (b) after crossover.

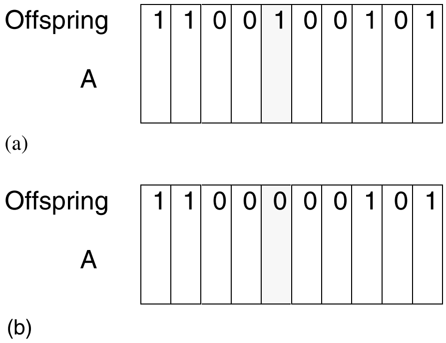

Fig. 3. Mutation: (a) before mutation and (b) after mutation.

If at any stage of mutation any of the variables violate the problem constraints, then such variables will be discarded and a new number is chosen randomly. Repeat steps 3 through to 4 for the pre-defined maximum number of generations. The best solution will be achieved at the end of the iterations.

In the last few years, GA has been successfully used to achieve the optimal design of structures. To list a few, Hadi and Arfiadi [18] used GA to calculate the optimum design of the absorber for multi-degree of freedom structures subjected to earthquake loading. Chen and Chen [19] used GA for topology optimisation for structures and proposed improving the efficiency of simple genetic algorithm (SGA) by employing the elitest strategy, multi-point crossover, identification of passive design variables, gradual increase of penalty parameter, and bit-wise local search. Coello et al. [20] presented an optimisation model for the design of rectangular reinforced concrete beams subject to a specified set of constraints. They used GA to achieve the optimum solution. Hadi [21] presented a problem formulation for the optimum design of continuous T beams and applied GA to calculate their optimum design.

In the current study for the optimum design of rigid pavements, a string was chosen to represent the type of sub-base and base thickness, those being the design variables that their optimum value is sought. The string has a length of 8 bits, 5 for the base thickness and 3 for sub-base type. The range of base thickness was limited to 150–350 mm, with increments of 10 mm. Thus, there are 21 possible outcomes of the base thickness, 1 being 150 mm, 5 being 190 mm and 20 being 340 mm. The 5 sub-base types represent the recommended sub-base types by AUSTROADS [4]. A computer program was written in Matlab comprising two modules, one for the analysis of the rigid pavement and the second to compute the optimum solution. All input design parameters are input to the program and the program seeks to find the optimum value of the design variables (base thickness and sub-base type), which are represented by the

8-bit string. Both modules are interconnected, as such the values of variables pass to either module during the GA process. Fitness of the design variables represents the value of the inverse of the objective function. The inverse was chosen as GA maximises the fitness and our problem is to minimise the cost. The GA operations of generating offsprings by selection, crossover and mutation is repeated a few hundred times in order to achieve the fittest (optimum) offspring (design).

## 6. Examples

In this paper, a number of pavements were designed and compared with the corresponding optimum solutions presented by Hadi [15]. Table 1 summarises the pavements' design parameters and Table 2 summarises the results of both methods. Each of the GA runs was repeated four times and the number of generations were limited to 400. In each case, the same solution was achieved. Table 2 shows that the results of both methods are of comparable magnitude. The advantage of GAs is making use of the discrete nature of the GA and applying it to the discrete nature of the rigid pavement design.

## 7. Conclusions

Optimisation of rigid pavements yields pavements that are safe as well as economical. With advances of computing capabilities available to practising engineers, it is herein proposed to include the cost of building the pavement as an explicit design criterion. This will produce pavements that are safe and economical. The current work is based on optimising the initial cost of pavement construction. As the maintenance cost of pavements is an important factor, this needs to be included in future development.

As mentioned above, optimisation of the structural design of pavements has been applied in a number of computer programs. But so far it has not been included in design guides, such as AUSTROADS (1992). This may be due to the fact that the design of rigid pavements used to be empirical and due to lack of computing power. Nowadays, most pavement design methods have some degree of determinism and there is a continuous upgrade of the design methods in order to make them more mechanistic. This is coupled with the availability of computer power of which design engineers can take advantage fairly easily.

Based on these facts, it appears that the time is ripe to develop equations for the optimum design of rigid

Table 1
Design examples

| Pavement number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Locality | Rural | Rural | Rural | Rural | Urban | Urban | Urban | Urban |
| Shoulders | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Dowelled | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| CBR | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| LSF | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| CVAG | $1 \times 10^8$ | $3 \times 10^8$ | $5 \times 10^8$ | $1 \times 10^9$ | $1 \times 10^8$ | $3 \times 10^8$ | $5 \times 10^8$ | $1 \times 10^9$ |

Table 2
Results of optimisation

| Pavement number | GA | | | | Optimisation [15] | | | |
|---|---|---|---|---|---|---|---|---|
| | $H_{\text{Bound}}$ (mm) | $h_{\text{LMC}}$ (mm) | $h_{\text{base}}$ (mm) | Cost ($\$/\text{m}^3$) | $h_{\text{Bound}}$ (mm) | $h_{\text{LMC}}$ (mm) | $h_{\text{base}}$ (mm) | Cost ($\$/\text{m}^3$) |
| 1 | 0 | 125 | 210 | 41.9 | 0 | 125 | 200 | 40.5 |
| 2 | 0 | 125 | 220 | 43.3 | 0 | 125 | 210 | 41.9 |
| 3 | 0 | 125 | 220 | 43.3 | 0 | 125 | 210 | 41.9 |
| 4 | 0 | 150 | 220 | 45.8 | 0 | 150 | 220 | 45.8 |
| 5 | 0 | 125 | 190 | 39.1 | 0 | 125 | 190 | 39.1 |
| 6 | 0 | 125 | 200 | 40.5 | 0 | 125 | 200 | 40.5 |
| 7 | 0 | 125 | 200 | 40.5 | 0 | 125 | 200 | 40.5 |
| 8 | 0 | 150 | 200 | 43.0 | 0 | 150 | 210 | 44.4 |

pavements and apply these equations to obtain the optimum design of rigid pavements. In this paper, the GA was easily adopted to the problem of rigid pavement design. The discrete nature of GA was utilised in solving the discrete rigid pavement design.

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