Heavy duty laminated reinforced concrete pavements

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A technique has been developed for laminating reinforced concrete with bitumen to give the high load carrying capacity of concrete while maintaining the long term flexibility of bituminous pavement. This may prove an economic method of reconstructing existing roads to carry heavier axle loads without significantly increasing thickness of construction, as compared to conventional methods. The paving may also be appropriate for factory floors and runways. The paper discusses progress in design, testing, and construction methods.

INTRODUCTION

1. The development of heavier vehicles depends on pavement strength and depth. The weight and economy of heavy vehicles (and aircraft) are currently restricted by the need to limit axle loads (and tyre pressures) to current pavement design values.

2 The vehicle weight may be increased by extra standard axles or the same number of heavier axles requiring a higher tyre contact pressure, or an increase in the size or number of tyres (the contact area).

3. Any increase in axle weights on current pavements would result in a disproportionate loss of working life. A doubling of axle loads could typically cause sixteen times as much damage.

4. Increasing the number of axles reduces the pavement life in direct proportion (unless the axles are closely spaced,which is more damaging). However longer vehicles and extra non productive vehicle weight may be necessary. The tandem undercarriages carried by large aircraft are an example of this. There are other mechanical (and comfort) limitations for road vehicles.

Modifications to pavement design

5. Increasing the axle weight by raising the tyre contact pressure, or the contact area (number and size of tyres), can easily be achieved mechanically.

6. Increasing the contact area requires an extra thickness of existing strength pavement.

7. Increasing the contact pressure requires an extra strength of pavement but not necessarily a much greater thickness.

8. This paper is concerned with the last alternative of increasing the strength of pavement, enabling a more durable pavement also capable of higher wheel and axle loads.

Current Pavement Design

9. Current techniques may be approximately classified as either 'flexible' (bituminous) or 'rigid' (concrete), with many intermediates.

10. The strength of flexible (bituminous) pavement is more or less at the limit of design, and only minor improvements in allowable contact pressure can be expected. Major increases in vehicle weight on flexible pavement can probably only be achieved by more axles or by extra contact area (larger tyres or more wheels) requiring an extra depth of flexible construction.

11. The current strength of rigid (concrete) pavement could be increased by thickening the concrete. However a majority of the stress in concrete pavement is internally generated by volume changes in the concrete and in the soil below, rather than by traffic.

12. Increases in slab thickness result in disproportionate increases in internal stresses, requiring either frequent movement joints or some design changes.

Concrete pavement

13 Concrete slabs are loaded by traffic, by internal volume changes caused by both temperature and moisture changes within the concrete, and by self weight combined with uneven ground support.

14 The loads due to traffic are mainly shear forces as there is relatively little bending deflection in the slab or ground below (the angular deflection is typically 1 / 1000). These shear stresses reduce directly with increased slab thickness.

15 The stresses due to concrete volume changes are mainly due to the temperature fluctuations which cause the slab to expand and contract horizontally creating high tensile stresses. Differential temperature changes between the top and bottom of the slab cause the slab to buckle up or down. Similar though less severe stresses occur due to changes in concrete moisture content. These stresses increase directly with slab thickness or in the differential case increase with the square of slab thickness.

16. The stresses due to self weight combined with uneven support are slightly more complex.

The self weight increases directly with thickness. The uneveness (the distance between points of ground support) depends on the stiffness of the slab which is a function of the cube of the thickness.
17. The combined effect of increasing the slab thickness is that traffic stresses reduce in direct proportion, but the internal stresses increase at a significantly higher rate, so that extra thickness becomes non-productive unless joints are provided at more frequent intervals. This is common practice for airfields which generally have thicker slabs than roads.

PROPOSED LAMINATED CONCRETE PAVEMENT

18 To reduce the internal stresses while maintaining the benefits of a thicker concrete pavement it is proposed to laminate the concrete with thin (1 - 3mm) layers of bitumen between 100 to 150mm layers of concrete. Because of the viscosity of the bitumen the resulting laminate acts a whole when suddenly loaded by traffic, and as individual thin flexible laminae when slowly internally stressed by thermally induced volume changes in the concrete, or loss of support from the soil below.

Experimental details.

19 Work commenced in 1968 when it was found that 0.5 to 0.8m thick factory slabs on a poor subgrade failed under a combination of exceptionally high moving plant loads and uneven soil support. Progressive increases in slab thickness had proved unsuccessful and an alternative floor design was required.
20. Initial experiments were on laminated beams subjected to bending, and direct shear tests on various bitumens to determine effects such as temperature, bitumen thickness, rate of strain etc. Work progressed slowly because of the difficulty in simulating a soil subgrade and the complex interrelationship of the variables. For example the beam stiffness varies along its length because the rate of strain and hence shear resistance of the bitumen laminae varies along the length. The stiffness is also dependent on the rate of application of load.
21. More recently Hassani (ref 1) has constructed a model Winkler type subgrade of rubber pads. The subgrade stiffness can be varied by altering the thickness of pads, usually 1, 3, or 9 pads, at each support.
22. A typical slab 6 x 3m consisting of 2 x 100mm thick concrete laminae and 1.5mm bitumen has been tested at full scale on the model subgrade using a 3 pad thick support. Thin 6m long x 150mm wide x 200mm deep transverse cross sections of the slab have also been tested as beams and the results compared with equivalent solid beams on the same model subgrade.
23. The slab was tested at traffic rates of loading by quickly lowering a 50 kN weight on to a plate on the slab and deflections taken at 0.04 s intervals. For long term measurements the load was left in place for periods up to 24 hours. Similar methods were used for the solid and laminated beam models.

Results

24. The deflected profiles of the slab and comparative profiles for beams are shown in Fig 1 to Fig 4, taken from Hassani (ref 1).

Traffic Loading

25 Experiments on the beams have confirmed that under rapid traffic loading the laminated beams are only slightly less stiff than the solid equivalent beams. Experiments on the laminated slab show that stiffness reduces appreciably with time of loading as predicted. A comparable solid slab has not yet been constructed but the initial stiffness is expected to be similar for both the solid and laminated slabs as is the case for the beams.

Self weight loading combined with uneven support

26 The long term loadings on the beam and slab, and artificially induced subsidence under the beams, show that the beam stiffness reduces with time, the rate depending on the type and bitumen thickness. As the ground below subsides the slab behaves as a series of independent laminae, with considerably more flexibility. The tendency to deform with ground subsidence maximises points of contact and minimises unsupported areas.

Stresses due to thermal changes.

27 The horizontal change in length of a conventional slab in response to temperature changes is normally resisted by ground friction and sufficient tensile steel reinforcement is added to transfer the tensile stress. Tensile cracks are initiated in the concrete but then prevented from opening by the reinforcement.
28 In the new pavement the thermal motion of each concrete lamina is resisted by the bitumen below which acts as a slip layer with time. The bitumen resistance depends on the rate of strain, a function of bitumen thickness and rate of thermal movement. The design thickness of bitumen laminae may eventually be governed by the rate of heating.
29. The tensile stresses due to thermal motion can be no greater than for a conventional slab if the lowest lamina sits on the subgrade and generates the same frictional resistance to motion as a conventional slab. The slip in the bitumen laminae has the effect of allowing some extra longitudinal motion which dissipates the stress developed, particularly in the upper laminae.
30. Where there is a thermal gradient through the slab the bitumen allows differential horizontal strain reducing buckling.
31. The above discussion applies mainly to hourly changes in temperature. Much of the stress in the concrete and bitumen dissipates during daily changes in temperature and length and the effects of seasonal changes are negligible, except for the lowest lamination, which retains frictional contact with the soil.
32. Whether to place a bitumen slip layer below the bottom lamina depends on the site

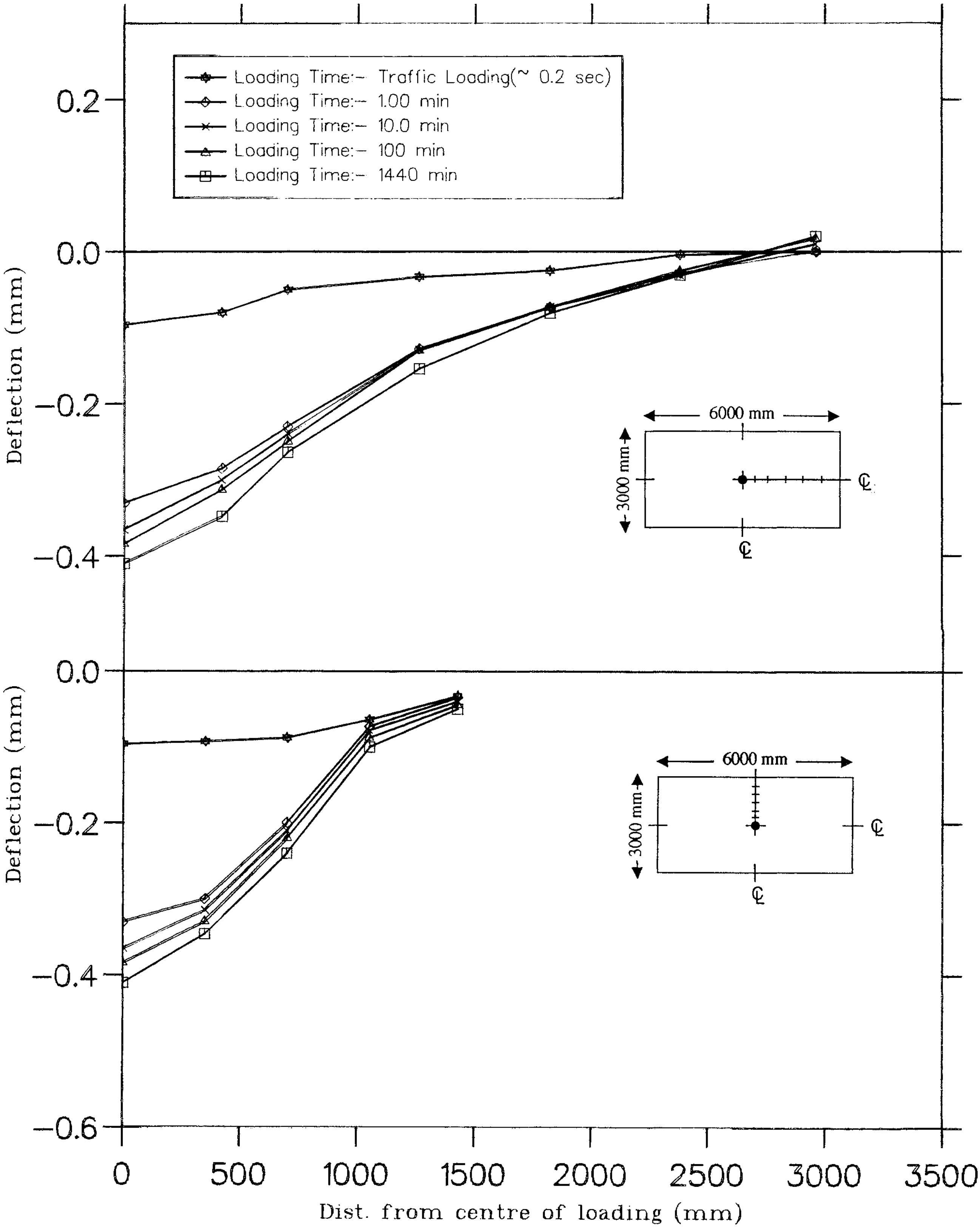

Fig 1 & 2 Deflected profile of laminated RC slab on an elastic subgrade with varying duration of 50 kN load. (Half section shown)

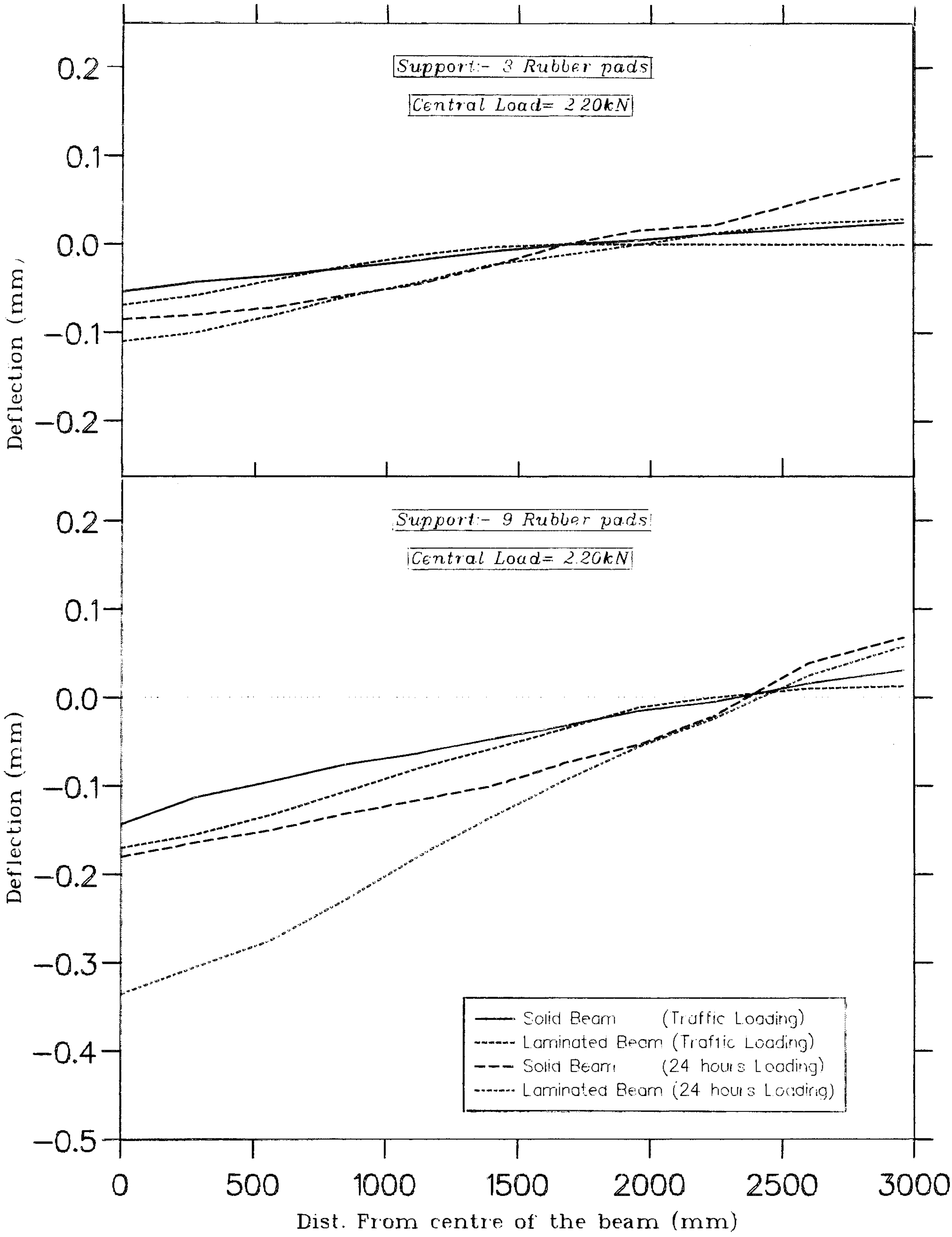

Fig 3 & 4 Deflected profiles of laminated and solid RC beams on an elastic subgrade with varying duration of load and subgrade stiffness. (Half section shown)

conditions. If rapid changes in temperature and length are expected right through the slab then the short term bitumen shear strength may be greater than the base frictional resistance in which case the bitumen could be omitted from the base.
33 Joint spacing will depend on the amount of reinforcement used and the amount of base friction generated within each successive layer. Since joints will be staggered, load transfer devices such as dowel bars may well be unnecessary, particularly in the lower layers. Joint design is currently being investigated. 34 It may be feasible to construct an upper layer of continuously reinforced concrete (CRCP) without joints, over lower layers of mass concrete, where the number of joints is immaterial. CRCP is conventionally used over a bituminous sliplayer in Belgium.

Mechanism of stress distribution

35 The deflection of pavement under traffic load is typically 1mm or less. If this value is much exceeded then the pavement is usually considered to have failed, as ruts will form almost immediately. The 1mm deflection is insufficient to generate large bending stresses. Also the concrete is cracked as a result of unavoidable thermal movements, and although the cracks are kept closed by reinforcement, the resistance to bending is quite small.
36 Consequently it seems that bending provides only a small proportion of the resistance to traffic load and the majority appears to be due to the shear strength of the concrete, possibly with some membrane or arching effects.

The effect of lamination on shear distribution

37 Immediately on loading by traffic the shear stress in the bitumen laminae is typically about 100 to 200 kN/m^2. This is considerably less than the immediate shear strength of the bitumen although with time the strength declines due to viscous effects. The average and maximum shear stresses in the concrete remain the same although redistributed.

The effect of lamination on bending stress distribution.

38 The immediate loading by traffic produces a small bending stress in the slab which is governed by the deflection allowed by the soil subgrade below.
39 The beam experiments indicate the immediate bending stiffness in the laminated structure is slightly less than the solid structure, and this difference is probably due to the small extra strain necessary to generate shear resistance in the bitumen laminae. Increasing the thickness of bitumen would probably reduce the immediate bending stiffness.

MATERIALS AND CONSTRUCTION DETAILS

40 Experiments have been carried out with conventional reinforced concrete and fibre reinforced concrete slabs and beams up to 3 laminae thick. The individual reinforced concrete laminae are limited to about 100mm minimum thickness although this could be reduced to about 75mm using epoxy coated steel or stainless steel. The fibre reinforced concrete can be laid to almost any thickness down to about 10 mm.
41 A range of bitumens have been tried. The one used for the experiments shown was a Shell penetration grade bitumen with 13 pen at 25°C and a softening point (R&B) of 70°C. The bitumen was placed by preparing 0.5 m^2 sheets of 1.5mm thickness which were then torched onto the concrete.
42 The feasibility of a wide range of similar techniques is being considered, such as the use of precast slabs, and other materials, for the laminates.

Aggregates

43 Granites have a low thermal conductivity but a high coefficient of expansion. Limestones have a higher conductivity but a lower expansion. Granite may be preferable since the slower rate of expansion will minimise the stress developed by the bitumen.

Steep Gradients.

44 On steep gradients the lack of long term frictional resistance will allow the downslope movement of laminations. If appropriate it will be necessary to provide a key midway between the movement joints to prevent long term translation.

Curing

45 The relatively thin slab and the impermeable surface created by the bitumen allow differential shrinkage, and a full coat of curing compound is required to prevent curling as the concrete cures.

Rideability

46 If the pavement is used, as proposed, in areas of subsidence, or on poor subgrades then although the pavement will remain serviceable after deflection, the rideability may not be acceptable. The provision of a thin high strength bituminous regulating surface, reinstated as necessary, seems the most efficient solution.

SUMMARY

47 The principle of laminated concrete pavement has been examined and tested using beams and a full scale slab on a rubber pad subgrade. The behaviour was as expected. The trial slab behaved satisfactorily under a typical 50 kN wheel load.
48 The next stages intended are field experiments on sites such as lorry parks, short term haul roads or factory floors etc. to determine the behaviour of a series of interconnected laminated slabs with staggered joints, prior to constructing trial roads. Sites and finance for such experiments are now being actively sought.
49 Laboratory trials continue with varying subgrade stiffness's and materials

CONCLUSIONS

50 Subject to successful field trials laminated concrete offers an economic and practical alternative to both current flexible (black top) and rigid (concrete) methods of construction, with the possibility of a more durable pavement capable of much higher axle loads, without overstressing the materials below.

51 The new construction could be placed directly over existing black top or concrete construction in many instances.

52 The most suitable sites are probably factory or warehouse floors with high axle loads from fork lift trucks, roads to carry heavy vehicles with minimum maintenance, major airfields (where reducing the weight of the undercarriage could have cost implications for large aircraft) and roads or pavements on subsiding or poor subgrades or reclaimed land.

REFERENCES

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