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A structural design procedure for cement-treated layers in pavements

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S U M M A R Y

Cement-treated materials have been used successfully in road pavements since the thirties. In the past the research developments were mainly directed towards, and the emphasis during design was mainly placed on material properties, with very little attention being paid to thickness design. High-speed electronic computers and the appropriate programs became available during the sixties, and since then more effort has been devoted to the requirements for a successful structural layout and the behaviour of a pavement structure. This thesis, which is complementary to these studies, discusses the structural design of pavements having cement-treated layers. Some of the design requirements have been known for some time, three more have been added and finally a design procedure is proposed and verified.

Chapter 1 portrays the development of structural pavement design theory. It indicates how design procedures gradually became more extensive but also more complex. A pavement design procedure which is based on layered elastic theory fits into this development pattern and it has the potential to comply with future requirements of structural design procedures.

The requirements for a structurally well-designed cement-treated layer are summarized in Chapter 2. Some of these were obtained from a literature survey and they include the requirements that a cement-treated layer must be thick; it must be built on a proper foundation while bearing in mind the principles of a balanced design; and it must be designed to withstand the heavy vehicles expected to travel on it. In the thesis attention is paid to some of the other requirements, for example non-traffic-associated and traffic-associated cracking, fatigue behaviour, thermal stresses and the variability in the properties of field- and laboratory-prepared materials. Some other requirements which are mentioned but which will need further investigation, are the material characterization, design criteria and the general variability of construction materials.

Cracking in cement-treated materials is discussed in a somewhat original approach in Chapter 3 and it is pointed out that a clear distinction is necessary between initial, that is non-traffic-associated, and traffic-associated cracking. The occurrence of initial cracking must be accepted as a fact and very little can be done to avoid it or prevent it from occurring! Traffic-associated cracking in cement-treated layers can be

prevented by an appropriate structural analysis and design. This involves doing the analysis for an uncracked pavement and thereafter making some increase in the maximum stress to accommodate the stress increase caused by the initial, non-traffic-associated, crack.

Prismatic solid finite elements are used to calculate the extent of the increase in the tensile stress next to the initial crack (Chapter 4). The various ways of modelling the pavement, and the accuracy of each of these methods, are discussed and the use of the L-model is suggested and justified. The vertical surface deflection and the increase in horizontal tensile and vertical compressive stresses next to the crack in eight different typical structural layouts are calculated and the percentages are reported. The percentage increase in tensile stress seems to be dependent on the width of the crack and the thickness of the cement-treated material, but it does not appear to exceed 40 per cent. It is therefore suggested that the stress calculated in an uncracked pavement should be increased accordingly and this increased value should be used as the design tensile stress.

Thermal stresses in cement-treated layers have always been believed to be very important. A finite difference computer program is used to prove this for uncracked cement-treated layers in Chapter 5. It is also shown that once the layer has cracked, and all properly constructed cement-treated layers do crack, movement can take place at the crack which will prevent the development of excessive thermal stresses. The use of a thermal insulating layer is very beneficial and it seems that the thickness of the layer affects the insulating ability much more than the type of material used. It is therefore recommended that for major roads a 150 mm crusher-run layer should be used as a thermal insulator on top of the cement-treated layer.

Chapter 6 discusses the difference in properties of materials prepared in the field and in the laboratory. It is important that the same quality of material should be prepared in both cases or alternatively, that the designer should know the extent of this difference to enable him to take account of it. Samples recovered from the field indicate little variation in quality during a day's work and the section may be accepted as homogeneous with regard to the evaluated properties. The differences between work performed on different days are extremely significant, even if the sections were constructed with the same materials, by the same construction team and according to the same specifications. Thus sections constructed on different days may not be regarded as being of the same quality and as having the same properties. The variation in properties within a layer is significant and the upper half of the layer seems to have higher values than the lower half. The difference between field- and laboratory-prepared samples is significant, and the field samples generally tend to have lower values than the laboratory-prepared samples; not enough information is available to really indicate how much lower, but 30 per cent is recommended

The Heavy Vehicle Simulator (HVS) was used to correlate the predicted and actual behaviour of pavements with cement-treated layers, and ten HVS tests were performed (Chapter 7). The excellent correlations between the predicted and actual elastic moduli and predicted and actual amount of traffic-associated cracking are described for seven of these tests. The chapter also shows the progress that was made over 5 years in interpreting the results from these tests.

A pavement design procedure which is based on layered elastic theory, and the design requirements developed in this thesis, are outlined in Chapter 8. The definition of failure which is adopted and the design flow diagram with all its subdivisions, are explained. The design procedure incorporates the full spectrum of traffic wheel loading, fundamental material properties and failure criteria. Layered elastic theory is applied to calculate the stresses and strains at the various critical positions and these are compared with allowable values. Some variations in the outline, for example making allowance for mixed traffic and the use of standard designs, are discussed and explained. Finally the proposed procedure is verified by a description of the excellent agreement between the predicted and actual response and behaviour of several pavements. Five worked examples are also included.

The thesis also contains four appendices. The first of these describes a theoretical study of pumping in pavements using the prismatic solids finite element computer program. The second outlines the use of the prismatic solids finite element computer program. In the remaining two the thermal properties required in Chapter 5 are calculated.

OPSOMMING

Sementgestabiliseerde materiale word reeds sedert die dertigerjare met sukses in paaie gebruik. In die verlede het die klem tydens navorsing, ontwikkeling en ontwerp op materiaaleienskappe geval en baie min aandag is gegee aan die ontwikkeling van 'n metode om die vereiste dikte van die lae te bepaal. Sedert die hoëspoed- elektroniese rekenaars en die nodige rekenaarprogramme in die sestigerjare beskikbaar geword het, is meer aandag aan die vereistes van 'n geslaagde strukturele uitleg en die gedrag van die plaveisel gegee. Hierdie proefskrif, wat aanvullend is tot die vorige studies, bespreek die strukturele ontwerp van plaveisels met sementgestabiliseerde lae. Enkele van die ontwerpvereistes is reeds 'n geruime tyd bekend, drie word bygevoeg en bespreek en ten slotte word 'n ontwerpmetode voorgestel en geverifieer.

Die ontwikkeling van plaveiselontwerpteorie word in Hoofstuk 1 bespreek. Daar word aangetoon hoe die ontwerpmetodes geleidelik meer omvattend geword het - maar ook steeds moeiliker om te gebruik. 'n Ontwerpteorie wat gebaseer is op die teorie van gelaagde elastiese sisteme en baie goed in die ontwikkelingspatroon inpas, het die potensiaal om te voldoen aan die toekomstige vereistes van strukturele ontwerpmetodes vir plaveisels.

Die vereistes van 'n struktureel goedontwerpte sementgestabiliseerde laag word in Hoofstuk 2 bespreek. Sekere van hierdie vereistes is met behulp van 'n literatuurstudie bekom en sluit in dat 'n sementgestabiliseerde laag dik moet wees en 'n stewige fondament moet hê. Die beginsels van 'n gebalanseerde ontwerp moet in gedagte gehou word en die laag moet so ontwerp word dat dit die swaar voertuie wat op die pad verwag word, kan dra. In die proefskrif word enkele ander vereistes bespreek naamlik die moontlike voorkoming van aanvanklike barste, ook bekend as krimpingsbarste, en barste wat deur verkeerspannings veroorsaak word, die vermoeidheidslewe, die hantering van termiese spannings en die verskil tussen die eienskappe van materiale wat in die veld en materiale wat in die laboratorium voorberei is. Enkele van die ander vereistes wat genoem word, maar waarvoor verdere studie nog nodig is, is die karakterisering van die materiaal, die ontwerpkriterium en die algemene veranderlikheid van konstruksiemateriale.

Barste in sementgestabiliseerde materiale word op 'n ietwat oorspronklike manier in Hoofstuk 3 bespreek en daar word aangedui dat die verskil tussen aanvanklike barste en barste wat deur verkeerspannings veroorsaak word, baie goed verstaan moet word. Die verskyning van aanvanklike barste moet aanvaar word as 'n feit en baie min kan gedoen word om te voorkom dat die barste op die oppervlak van die pad verskyn! Barste wat deur verkeerspannings veroorsaak word kan vermy word deur 'n toepaslike analise en ontwerp te doen. Dit behels die ontleding van 'n ongebarste plaveisel en die verhoging van die berekende maksimum spanning waardeur dan voorsiening gemaak word vir die toename in spanning wat veroorsaak word deur die aanvanklike bars.

'n Eindige elemente-analise is gebruik om die toename in trekspanning langs die aanvanklike bars te bereken (Hoofstuk 4). Die verskillende maniere waarop die plaveisel gemodelleer kan word met eindige elemente en die akkuraatheid van elkeen van die metodes word bespreek. Daarna word die gebruik van die L-model aanbeveel. Die oppervlakdefleksie en die toename in horisontale trekspanning en vertikale drukspanning langs die bars in agt verskillende maar tipiese strukturele uitlegte word bereken en die persentasietoename in die maksimum horisontale trekspanning vir elke geval word gegee. Die persentasietoename in trekspanning is waarskynlik afhanklik van die wydte van die bars en die dikte van die sementgestabiliseerde lae maar skynbaar oorskry dit nie 40-persent nie. Daarom word daar voorgestel dat die berekende spanning in 'n ongebarste plaveisel dienooreenkomstig vergroot moet word en dat hierdie verhoogde waarde dan gebruik moet word as ontwerptrekspanning.

Daar is nog altyd geglo dat termiese spannings in sementgestabiliseerde lae baie belangrik is. In Hoofstuk 5 word 'n eindige verskille-rekenaarprogram gebruik om dit te bevestig ten opsigte van ongebarste sementgestabiliseerde lae. Daar word ook aangetoon dat sodra die laag gebars het, en alle goedgeboude sementgestabiliseerde lae bars, word die opbou van oormatige hoë termiese spannings voorkom, want daar kan beweging by die bars plaasvind. Dit is baie voordelig om 'n termiese isoleerlaag bo-op 'n sementgestabiliseerde laag te plaas en dit blyk dat die dikte van die laag die isoleervermoë meer beinvloed as die tipe materiaal wat in die laag gebruik word. Daarom word aanbeveel dat 'n klipslaglaag van 150 mm bo-op die sementgestabiliseerde laag van 'n hoofpad gebruik moet word.

In Hoofstuk 6 word die verskil tussen die eienskappe van materiale wat in die veld voorberei is en materiale wat in die laboratorium voorberei is, bespreek. Dit is belangrik dat die kwaliteit van die materiaal in albei gevalle dieselfde moet wees of andersins moet die ontwerper bewus wees van die grootte van die verskil sodat hy daarvoor voorsiening kan maak in die ontwerpstadium. Toetse het aangetoon dat die gedeelte van 'n laag wat op een dag gebou is, as homogeen ten opsigte van die gemete eienskappe aanvaar mag word. Die verskille in sementgestabiliseerde gedeeltes wat op verskillende dae gebou word, is uiters betekenisvol - selfs al word dieselfde materiale, dieselfde konstruksiespan en dieselfde spesifikasie in elke geval gebruik. Daarom mag daar nie aanvaar word dat gedeeltes wat op verskillende dae gebou is dieselfde kwaliteit en eienskappe sal hê nie. Selfs die variasie in eienskappe binne-in die laag is betekenisvol en dit blyk dat die boonste gedeelte van 'n laag hoër waardes het as die onderste gedeelte. Die verskil tussen veld- en laboratoriumvoorbereide monsters is betekenisvol en oor die algemeen neig die veldmonsters om laer waardes te hê as die laboratoriumvoorbereide monsters. Daar is nie duidelikheid oor hoeveel laer nie, maar 30-persent word tans aanbeveel.

Die swaarvoertuignabootser (SVN) is gebruik om die verwagte en werklike gedrag van plaveisels met sementgestabiliseerde lae te korreleer en hiervoor is tien SVN-toetse uitgevoer (Hoofstuk 7). Die uitstekende ooreenstemming, in terme van elastisiteitsmoduli en hoeveelheid verkeersbarste, word vir sewe van die toetse beskryf. Die hoofstuk toon ook die vordering aan wat gedurende die afgelope vyf jaar gemaak is met die interpretasie van die toetsresultate.

'n Plaveiselontwerpmetode wat gebaseer is op die teorie van gelaagde elastiese sisteme en die ontwerpvereistes wat in die proefskrif ontwikkel is, word in Hoofstuk 8 beskryf. Die aanvaarde definisie van swigting en die vloeidiagram vir die ontwerp asook al sy onderafdelings, word verduidelik. Die ontwerpmetode sluit die hele spektrum van wielbelastings, fundamentele materiaaleienskappe en swigtingskriteria in. Die teorie van gelaagde elastiese sisteme word gebruik om die spanning en vervormings op die verskillende kritiese posisies te bereken en daarna word hierdie waardes met die toelaatbare waardes vergelyk. Enkele variasies van die voorgestelde metode, soos byvoorbeeld om voorsiening te maak vir gemengde verkeer en die gebruik van standaardontwerpe, word bespreek en verduidelik. Ten slotte word die voorgestelde metode geverifieer met 'n beskrywing van die uitstekende ooreenstemming tussen die voorspelde en die werklike gedrag van etlike plaveisels. Vyf uitgewerkte voorbeelde word ook ingesluit.

Die proefskrif bevat 4 aanhangsels. Die eerste een beskryf 'n teoretiese studie van pompaksie in plaveisels en hiervoor is 'n spesiale eindige elemente-rekenaarprogram gebruik. Die tweede aanhangsel beskryf die gebruik van die eindige elemente-rekenaarprogram wat in Hoofstuk 4 en aanhangsel A gebruik is. In die oorblywende twee aanhangsels word die termiese eienskappe bereken waarna in Hoofstuk 5 verwys word.

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