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Experimental and Field Investigation of the Influence of Relative Rigidity on the Problem of Reflection Cracking

ABD EL HALIM OMAR ABD EL HALIM

ABSTRACT

Because of the state of the economy, it is no longer viable to reconstruct a roadway that has been left to deteriorate with time. One of the most commonly used methods to keep pavements in service is to construct a new asphalt layer over the existing structure. However, it has been found that this new asphalt overlay does not serve its intended purpose as, in most cases, cracks soon appear. It is believed that these cracks are caused by a combination of different factors. However, a serious deficiency in present analytical approaches dealing with the observed cracks is the assumption that the new asphalt overlay is structurally sound. A new approach in investigating the important parameters that govern the structural behavior of the asphalt overlay at the time of construction has indicated that surface cracks can be induced, which results in the destruction of the structural integrity of the newly constructed overlay. Based on the results of this analysis, two experimental models were developed. The first model is a simple composite beam designed to verify the assumptions of the new approach. The second model is directed to the phenomenon of surface cracks. The new theoretical approach is presented in this paper and the developed experimental models are described. Finally, it provides a model of a new compactor that has been developed to prevent construction cracks so that new pavement can be described as "sound."

The problem of asphalt overlay cracking has been known for many years. Asphalt overlays are often used to correct a cracked, old surface and, consequently, to restore the riding quality of the road surface. However, field observations and research work have indicated that cracks will develop on the new pavement surface in a relatively short time (1-3). Thus, the desired riding quality has not been achieved and the considerable investment is wasted. Therefore, if a reliable method and an economic technique could be devised to minimize or delay the occurrence of the observed cracks, it would certainly be a valuable approach to pavement designers and engineers.

A comprehensive research program was started in 1983 at Carleton University and its main objective was to examine overlay pavement structures at the time of construction. It was felt that the conditions and method of compaction of asphalt overlays were responsible for a large portion of the cracks observed later on the surface of the pavement.

Results of the analytical phase of the research have indicated that present compaction equipment will induce cracks on the surface of the new added layer. To verify the analytical findings, field data were gathered and analyzed. It was concluded from the collected observations that the analytical approach is, in fact, a reliable theoretical tool. Subsequently, a laboratory investigation was carried out to verify the general assumptions and findings of the analytical approach and to simulate observed

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field cracking. Finally, the results of both the analytical and experimental investigations were used to develop a new machine to compact the asphalt layer. The results of using the new compactor have demonstrated a substantial reduction in crack occurrence.

The analytical approach and results, some of the reported field observations, the experimental programs, and their findings are presented in this paper.

ANALYTICAL INVESTIGATION

Background

Present pavement design methods and theories are based on the assumption that newly constructed pavements are structurally sound (1,4,5). As a result of this assumption, the basic research on the mechanisms that govern the behavior of pavement structures is focused on pavements under traffic conditions (6-8). Pavements under construction conditions have not been seriously investigated (1).

A review of the problem of pavement cracking has revealed the following weaknesses in present mechanisms (9,10):

1. The lack of a unique definition of the problem of pavement cracking. For example, is it crack initiation or propagation?
2. The nonexistence of a reliable solution. The problem of reflection cracking has been recognized since 1932 (2). In spite of intensive research work carried out on this particular subject, however, more than 50 years later, there still is neither a reliable field solution nor a theoretical model that could present or explain the occurrence of cracks (1,2,4,11-14).
3. The most serious deficiency found in the present approaches is that they do not consider the construction conditions in their analysis.

Based on the preceding shortcomings, the first step in the development of current investigation was to analyze the pavement structures at the time of construction. In the following sections, the term "pavement system" is used to describe different situations of time period, pavement structure, and the loading device. Figure 1 is an illustration of the concept of pavement system.

Principle of Relative Rigidity

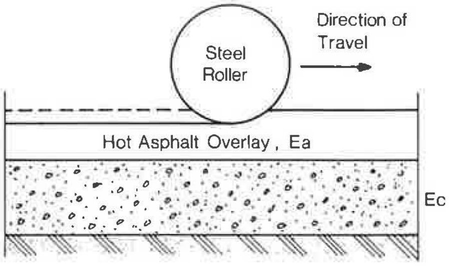
The principle of relative rigidity has been known and applied for many years in soil mechanics (15). The influence of relative rigidity on the load transfer characteristics can be understood by the problem of a plate resting on an elastic soil mass. The plate is considered to exert a uniform load distribution at the contact surface. Figure 2 shows the stress and deflection distributions imposed on the soil by two different plates under the same load. The differences in the distributions between the two loading conditions are governed by the relative rigidity between the plate and the soil mass. A dominant relative rigidity parameter, RR, is defined as follows (15):

$$RR = (E_p/E_s)\ (t/a)^3 \qquad (1)$$

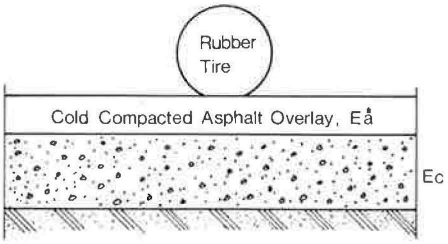
where

RR = relative rigidity,
E_p = elastic modulus of the plate,
E_s = elastic modulus of the soil mass,
t = thickness of the plate, and
a = radius of the circular contact area.

For pavement systems, the transfer of stresses between the loading device and the various components of the multiphase elastic material or the multicomponent elastic structure is strongly influenced by RR. For example, in the case of a soft asphalt layer on top of a rigid concrete layer, at the time of construction, the pavement system is both a multiphase and multicomponent elastic structure. On the other hand, a pavement system under traffic conditions may only behave as a multicomponent.



a) Construction conditions, $\frac{Ea}{Ec} < 1$



b) In-service conditions, $\frac{E\overset{*}{a}}{Ec} \geq 1$

FIGURE 1 Components of pavement systems.

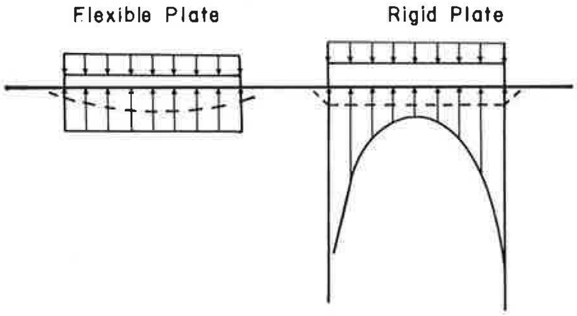


FIGURE 2 Influence of relative rigidity on stress and deflection distributions.

The foregoing discussion has shown that the concept of relative rigidity can also be used to analyze and to compare different pavement systems. Based on this premise, the developed analytical approach includes (a) a pavement system as a reference for comparison; (b) a comparison criterion that reflects the influence of the RR on the pavement systems; and (c) a failure criterion to describe failure for different pavement systems. (These components or features are discussed in the following sections.)

Reference for Comparison

To use the concept of relative rigidity in investigating different pavement systems, a standard system has to be established as a reference. In this analysis, the standard system was considered as the "zero load" system, which means that a pavement system can be described by its geometry. Because there is zero applied load, the material properties of the system are not in an active state. The geometry of this system consists of multiparallel surfaces. Of interest are the top and bottom surfaces of the uppermost layer, that is, the asphalt overlay.

Comparison Criterion

The pavement system at construction time is governed by RR, which differs from the parameter that governs pavement systems opened to traffic. The ratios given in Equation 1 differ between the two systems as follows:

1. Although the ratio of ($E_{asphalt}/E_{concrete}$) for the construction conditions is considerably less than 1, it is close to or larger than 1 if the system is opened to traffic.
2. The ratio ($E_{steel}/E_{asphalt}$) for the first system (construction conditions) is obviously much larger than the ratio of ($E_{rubber\ tire}/E_{asphalt}$) for the systems that are opened to traffic.
3. As a result of items 1 and 2, the relative geometry component, (t/a), in Equation 1, would be governed by the steel compactor at the top interface and by rigid concrete layer at the bottom interface of the construction pavement system. On the other hand, for the traffic pavement systems, the top interface is governed by the asphalt layer (stiffer than the inflated tires) and the bottom interface by the rigid concrete layer.
4. The ratio (t/a) will result in two different geometrics for the two systems.

This analysis has led to the establishment of a comparison criterion, which describes the influence of the RR, on the relative behavior of the two interfaces of the overlay. The developed comparison criterion--the coefficient of stability, H--has the following characteristics:

1. It has the ability to describe the response to any changes in the values of the ratios given by Equation 1;
2. It reflects the characteristics of the interface conditions that are governed by the RR; and
3. It is applicable to both elastic as well as inelastic conditions.

The details of this analysis were given elsewhere (9,10,16). Therefore, a brief summary of its application follows.

Application of Coefficient of Stability, "H"

The mathematical modeling of the recommended criterion is given by the following equation (10,16):

$$H_i = (r_1/r_2) \qquad (2)$$

where

H_i = coefficient of stability of a pavement system;
r_1 = radius of curvature of the top interface, and
r_2 = radius of curvature of the bottom interface.

To appreciate the importance of H, it is important to observe that (a) the term "stability," as used in this research, is different from its conventional definition--in the context of relative rigidity, it is defined as the change in the value of H between the reference system and the loaded system; and (b) the value of H is a ratio that describes the actual physical condition of a given pavement system. Figure 3 is an illustration of the developed H. To apply this criterion in the case of a multilayer structure (such as pavements), the following technique is adopted.

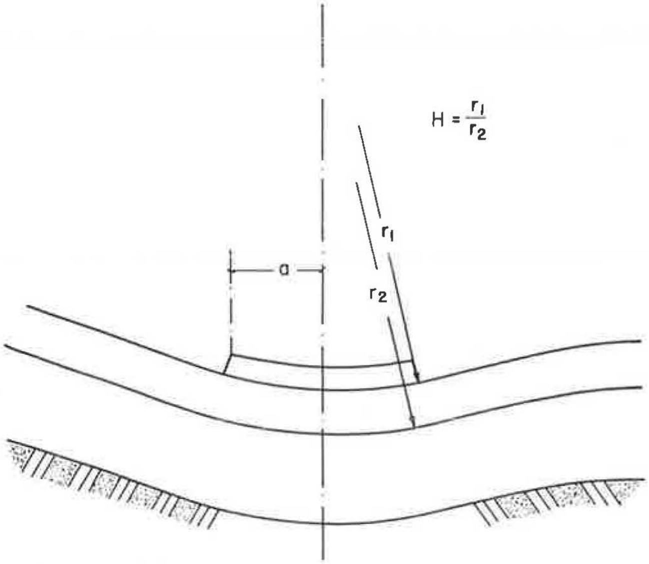


FIGURE 3 Details of the coefficient of stability, H.

First, the reference system is presented by the structure just before any external load is applied to the plate. This initial condition can be described using H as follows:

$$H_I = (r_1/r_2)_I$$

Obviously, the values of r_1 and r_2 for the unloaded pavement are large compared to the actual thickness of the top layer. Thus,

$$H_I = r_1/r_2 = r_1/r_1 + t = 1/(1 + t/r_1)$$

and, for the geometry of the multiparallel structure,

$$t/r_1 \rightarrow 0 \text{ as } r_1 \text{ and } r_2 \rightarrow \infty$$

Thus, $H_I = 1$. (3)

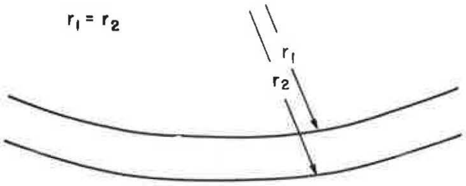
Because there is no load or stress applied on this system, the structure can be described as stable. As a result, the initial stability coefficient, H_I, is unity.

When an external force is applied on the plate, stresses, strains, and deflections will result. Subsequently, one should expect either of two possible conditions to develop. The first is that H would remain the same (i.e., $H_N = H_I = 1$). This condition cannot take place unless the total change in the absolute value of each radius of curvature is the same. If this is the case, no relative deformation or cracking should take place either in the structure or in the plate (i.e., in the system). Thus, the value of H for the new conditions would remain the same and, therefore, $H_N = 1$.

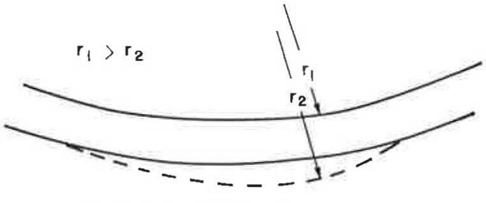
Because the new conditions yielded the same H value for the initial conditions, it can be concluded that there is no change in the stability conditions between the two systems. It should be noted that both systems are sound and that for the critical conditions of the loaded system to be determined, the conventional stress-strength analytical techniques must be applied.

The second possible condition is that, as a result of applying an external force, cracks or deformation may develop at either interface. At the outset of crack initiation, the changes in the radii of curvatures at both interfaces are not the same, resulting in $H_N \neq 1$.

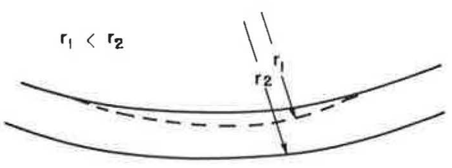
Similar to the previous case, the new value of H should be compared to the initial value of H of the reference system. Because the new value is clearly different from the initial value ($H_I = 1$), a different stability condition will result. In fact, any condition in which $H \neq 1$ will indicate an unstable condition or incipient failure of the pavement system. Any value of H that is different from unity ($H > 1$ or $H < 1$) will also indicate where failure or crack initiation will occur. For $H = 1$, the system is stable and no cracking of the system is expected; for $H \neq 1$, the system is in incipient failure--that is, crack initiation or deformation will occur; for $H > 1$, failure is taking place at the bottom interface of the top layer of the pavement system; and for $H < 1$, failure is initiated at the top interface. Figure 4 shows these conditions.



a. Case of Sound Structure ; H = 1



b. Case of Failure at Bottom; H > 1



c. Case of Failure at Top; H < 1

FIGURE 4 The developed comparison criterion.

Failure Criterion

The third step of developing this approach was to define a criterion to describe the failure of pavement systems at construction time. The developed criterion defines failure as follows:

Construction process of new pavements is similar to the industrial production process. Therefore, the end product of the construction process must have the following characteristics (a) uniformally compacted layer(s), (b) an even, smooth surface, and (c) a crack-free surface. Accordingly, any produced pavement structure that does not meet all of the conditions given under a, b, and c is considered to have failed.

Results of the Analysis

Analysis of the results obtained from the multilayer computer program, BISAR, has shown the following:

1. For pavements simulating in-service conditions (i.e., $E_1/E_2 \geq 1$) and that is loaded with rubber tires, the calculated value of H was equal to unity. This indicates a stable pavement system.
2. For pavements having H values equal to unity, their behavior is independent of the value of RR. Therefore, based on strength concepts, analytical methods must be applied to determine their critical stresses and strains.
3. For pavements under construction conditions for which $E_1/E_2 < 1$, the calculated value of H is always less than unity. This indicates an unstable pavement system.
4. Because the value of H is less than 1 for pavements under construction conditions, the critical interface is at the top surface of the new overlay as explained before (see Figure 5).
5. The relative rigidity of construction systems and their coefficient of stability are independent of the value of the applied stresses (as shown in Figure 6). This conclusion is in agreement with results reported by others (17).

The parameter remaining to be investigated is the effect of curvature of the applied rigid load on the pavement system, that is, if the rigid plate is replaced by a steel roller during the construction condition. As shown in Figure 5, these pavements are in unstable conditions as indicated by their coefficients of stability being less than unity.

By replacing the plate whose initial radius of curvature is infinite with a rigid cylinder roller having a radius R_r, the value of r_1 will be close to the value of the radius of the imposed new geometry, R_r. Correspondingly, the value of H will decrease significantly. However, it should be remembered that for both loading conditions (i.e., plate and roller), the pavement system is in a state of failure. Figure 7 shows the results of this comparison.

Failure of Rolled Overlays

The analytical results have shown that for a soft layer underlain by a rigid base, the pavement system is unstable or in a state of incipient failure for a rigid plate loading. The pavement system becomes even less stable if the plate is replaced by a roller. The term "unstable" needs a further explanation. It has been mentioned earlier that the initial conditions for a given pavement system (before any loading) are described by the stability coefficient H being unity. Figure 5 has shown that H decreases as the value of RR decreases. Thus for $H_I = 1$,

$$RR_I = (E_1/E_2)_I \, (t/a)_I^3 \tag{4}$$

and when $H_N < 1$, then $RR_N < RR_I$. However, for RR_N to be less than RR_I, either $(E_1/E_2)_N < (E_1/E_2)_I$, and $(t/a)_N < (t/a)_I$, or both.

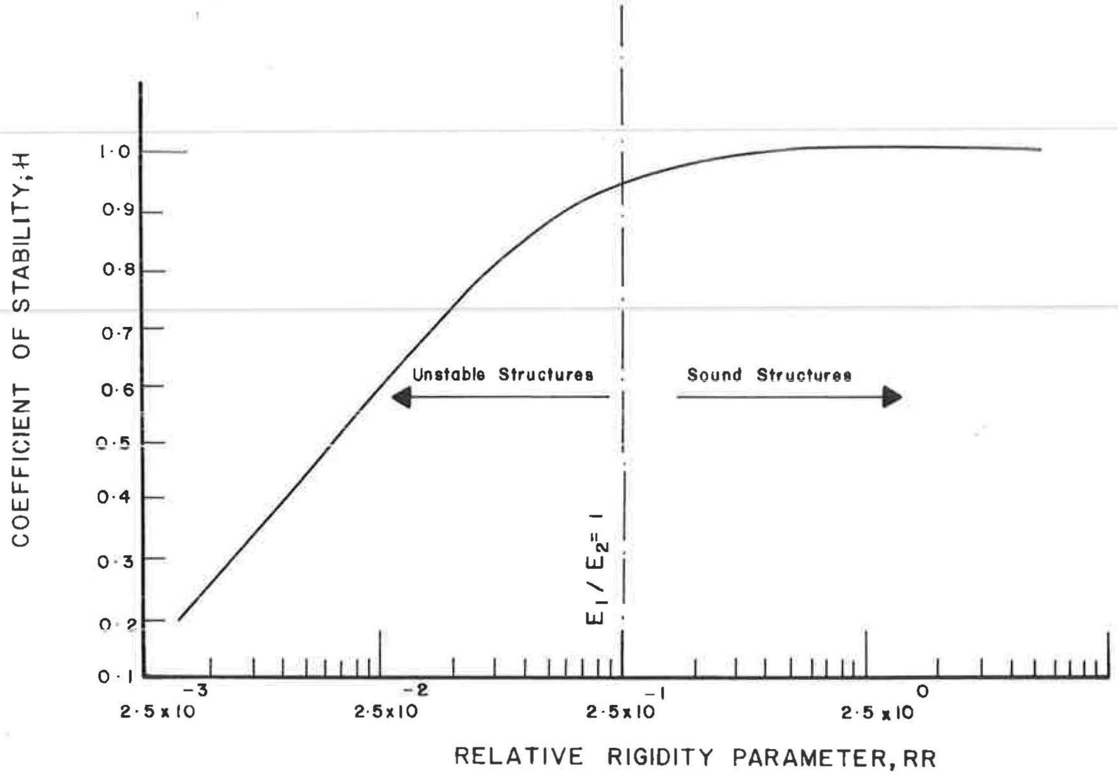


FIGURE 5 Computed relationship between relative rigidity parameter, RR, and coefficient of stability, H.

The first condition cannot be obtained unless $E_{1N} < E_{1I}$, or $E_{2N} > E_{2I}$. The value of E_2 represents the elastic modulus of the existing concrete layer and, therefore, its value is unlikely to increase as a result of compaction. Thus, E_{2I} will remain the same during the compaction process (i.e., $E_{2I} = E_{2N}$). Consequently, the only other possibility is that the value of E_{1I} of the asphalt layer is decreased. A reduction in the modulus of the new asphalt layer from E_{1I} to E_{1N} cannot occur unless cracks are developed. These cracks will develop regardless of the value of the applied stresses because the hot asphalt mix does not possess any tensile or bending strength.

The condition of a reduction in the ratio of (t/a) cannot occur without a reduction in the thickness of the new asphalt layer or an increase in the contact area between the loading device and the asphalt material. Therefore, the reduction in the thickness, t, is the result of compaction, which stands to reason. However, if the reduction in t is

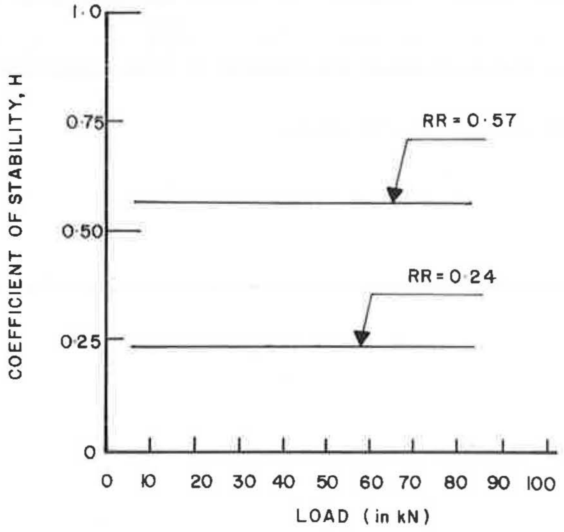


FIGURE 6 Computed relationship among the applied load, coefficient of stability, and relative rigidity.

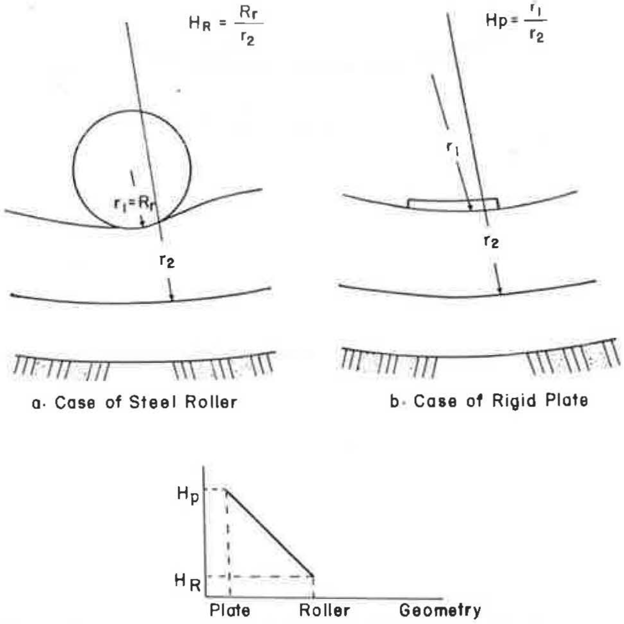


FIGURE 7 Effect of replacing the steel plate by steel roller.

the result of compaction, there cannot be any decrease in the value of H as a result of increasing r_1. Thus, the reduction in H_I accompanied with a reduction in t cannot mathematically correct unless the reduction in the thickness is accompanied by deformation or separation in the asphalt layer. The decrease in the stability coefficient must therefore be the result of the increase of radius, a, of the area of contact. Because the loading device (steel roller) is rigid compared to the soft asphalt layer and in order to have an increase in the area of contact, the steel roller must punch through the softer asphalt overlay. Obviously, the resulting layer thickness will, in this case, be less than the initial value. The area of contact will increase and, consequently, cracks will develop in the vicinity of the roller. This conclusion is further supported by the fact that the asphalt lacks any tensile, bending, or shear strength when it is in the compaction state. Therefore, the term "unstable" is a state of failure in which the rolled pavement surface will be either cracked or deformed, or both.

FIELD OBSERVATIONS

The results of the analysis have indicated that surface cracks and surface discontinuities perpendicular to the direction of rolling will occur when a new overlay is constructed. In order to confirm the aforementioned analytical finding, inspection of field projects were undertaken. This was carried out in the fall of 1984 in and around Ottawa.

Typical photographs from six different projects are shown in Figures 8 and 9. A number of features were observed in all the photographs, regardless of the project location and the asphalt mix used. In all pavements, the development of hairline cracks perpendicular to the direction of rolling were observed after the first pass of the steel compactor. These cracks remained visible even after the multi-rubber rollers were used. This is in contrast to the common belief that these cracks will reweld as a result of the kneading action of the rubber tires. The second observation is related to the spacing between the observed cracks. For larger rollers, the spacing between cracks developed under relatively smaller rollers. This observation can also be made when asphalt sidewalks are compacted. The type of compactors used in this operation is usually much smaller than that used for roads. The third observation was that the finished surface of the asphalt pavement was definitely uneven. These observations supported the results of the presented analysis.

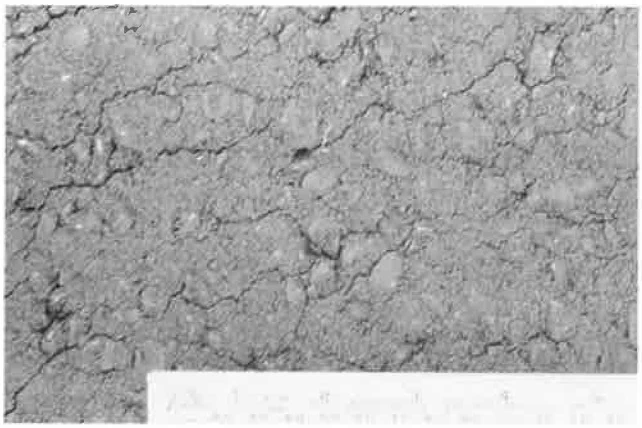


FIGURE 8 Construction cracks on a street pavement.

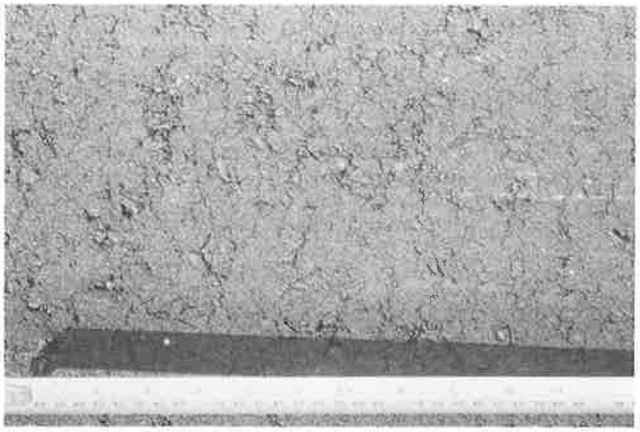


FIGURE 9 Construction cracks on a paved sidewalk.

As a next step, an experimental program was initiated to verify the general assumptions of the mechanistic approach to simulate the observed field cracks and to recommend a solution for the problem of crack initiation in pavements.

EXPERIMENTAL INVESTIGATION

An experimental program was carried out to investigate the occurrence of construction cracks. The main objectives of this investigation were (a) to verify the general assumptions and major findings of the analytical approach, (b) to simulate the cracks observed in the field, and (c) to develop a new compactor that will minimize cracking. The following sections discuss how each of these objectives was achieved.

The analysis has shown that the moduli ratios and the geometry (radius) of the loading device are the most important variables. Based on these considerations, a simple physical model was constructed to simulate the various types of a pavement structure as follows:

- Polyurethane foam was chosen to represent the soft asphalt overlay,
- Wooden beams represented the rigid underlying concrete layer,
- Steel plates were used to simulate the loading conditions used in the theoretical analysis, and
- Steel rollers were employed to simulate field compaction and to show the effect of the change of the loading device radius on the pavement system.

The pavement structure was then represented by a composite beam, made of foam and wood, 1000 mm long and 160 mm wide, although the thickness of the beam varied according to the feature to be illustrated. The interface between the foam layer and the wood was fully bonded to represent rough interface conditions.

Clearly, when the beam is loaded with the soft layer at the top, the modulus ratio is less than 1, and when the beam is turned upside down, the modulus ratio will be greater than 1. Thus, the conditions explained earlier in the analytical model can be investigated. A mesh of perpendicular lines 12.5 mm by 12.5 mm, was drawn on the front face of the beam in order to observe the deformations.

The results of this investigation are shown in Figures 10 to 15. As shown in Figures 10 and 11, the initial values for H for both systems (soft layer underlain by rigid layer and vice versa), are indeed equal to unity as was assumed in the analytical investigation. The value of H remained unchanged for a system having $E_1/E_2 > 1$, in spite of an applied load of 300 N (30 kg) as can be seen in Figure 12. This phenomenon was considered as experimental verification of the first assumption in the theoretical analysis. Figure 13 shows a crack at the bottom of the beam. The radius of curvature at the top interface, r_1, is obviously greater than the radius of curvature at the cracked interface, r_2, and, as a result, the calculated value of H is greater than 1. This is also in agreement with analysis discussed earlier.

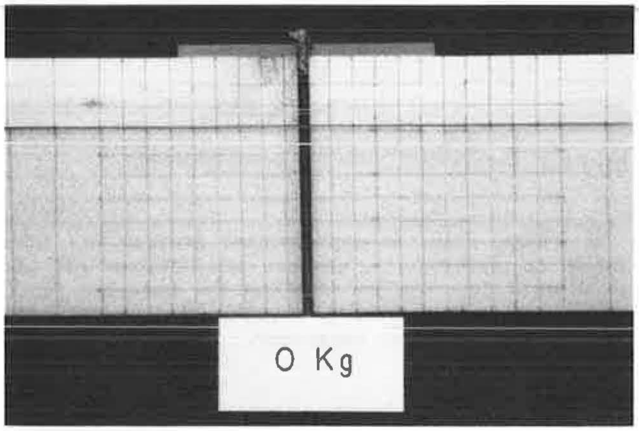


FIGURE 10 Reference system, $E_1/E_2 > 1$ and H = 1.

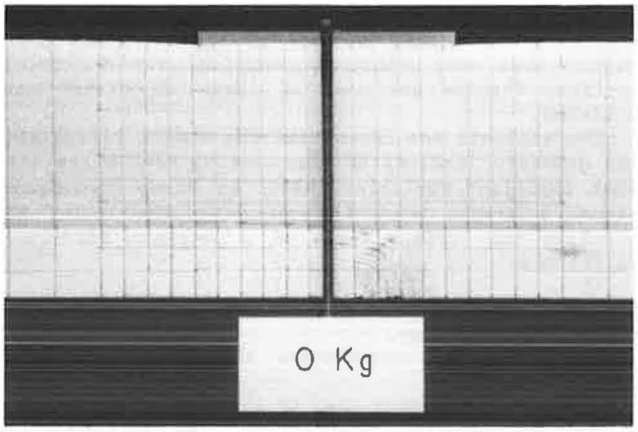


FIGURE 11 Reference system, $E_1/E_2 < 1$ and H = 1.

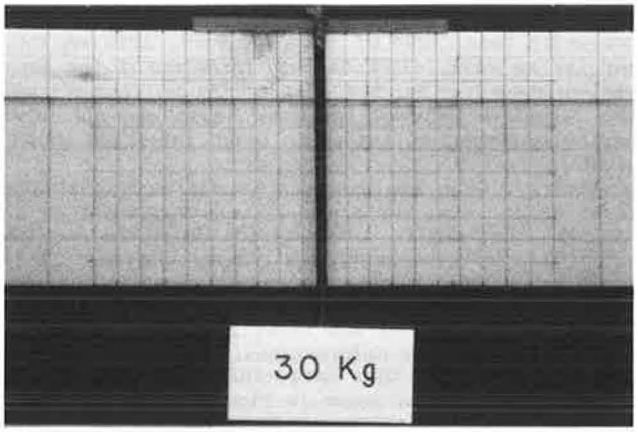


FIGURE 12 Case of loaded sound system, $E_1/E_2 > 1$ and H = 1.

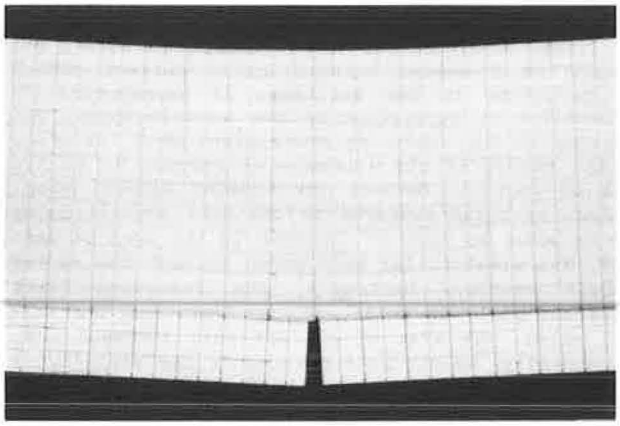


FIGURE 13 Case of failure at the bottom, H > 1.

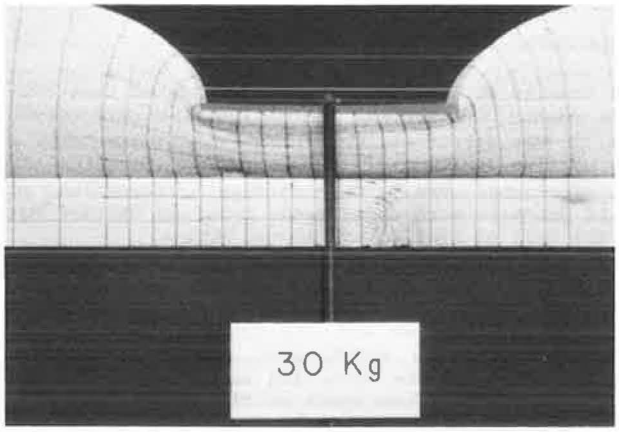


FIGURE 14 Case of failure at top of loaded system, $E_1/E_2 < 1$ and H < 1.

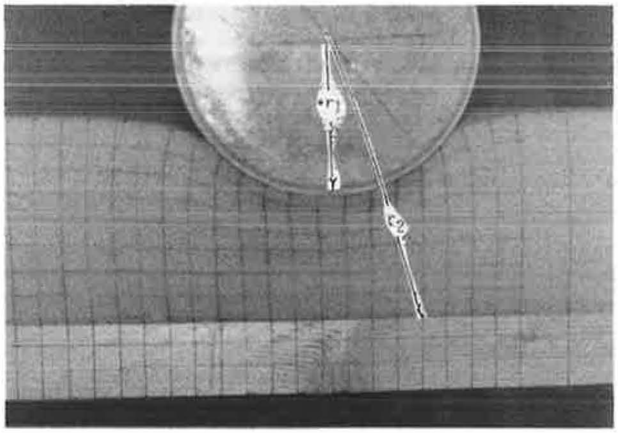


FIGURE 15 Effect of replacing the loading geometry on the value of r_1.

The remaining assumption deals with the value of H when $E_1/E_2 < 1$. As can be seen in Figure 14, the value of H is less than 1 for $E_1/E_2 < 1$. It can also be seen that the deformed interface occurs at the top, which is in agreement with the analytical results. Clearly, because of the high stretching properties of the foam, cracks do not develop. In contrast, however, for new asphalt overlays, cracks can develop as was observed in the field. The effect of using a steel roller instead of a steel plate for load application can be observed in Figure 15. Comparing the photograph shown in Figure 15 to the one shown in Figure 14, it is obvious that the value of H in Figure 15 is smaller.

The results obtained from the use of this simple model have confirmed the general assumptions and findings of the theoretical analysis. The next phase in the investigation was to verify these findings by observations on specimens of pavement systems constructed in the laboratory.

Simulation of Construction Cracking

The results of the analytical and experimental investigation have shown that the observed cracks in the field are due to the relative stiffness of the base and the compacted material as well as the high rigidity of the compactor. In the laboratory investigation, the field construction procedure was simulated to observe the occurrence of cracks.

Six types of asphalt mixes were prepared at the proper temperature (about 150°C), and wooden forms were used to construct the asphalt slabs. The bottom of each form was made of 5-mm-thick wooden boards so that the modulus ratio between the asphalt and the underlying layer would be less than 1. A total of 24 asphalt slabs were constructed.

Test Results

FIGURE 16 Simulated construction cracks.

The test results showed that cracks developed behind the roller in all of the constructed asphalt slabs. These cracks were similar to the ones observed in the field. The type of mix and percentage of asphalt content seemed to have some influence on the width of the crack, but not on the frequency and distribution of the cracks. The roller size of the compactors had a significant influence on the number of cracks observed. It was concluded that an increase of the radius of the roller resulted in a wider spacing of cracks. This conclusion is in agreement with the field observations and also agrees with findings reported by others (18). Figures 16 and 17 show two of the asphalt slabs tested in the laboratory. As shown in Figure 16, cracks are perpendicular to the direction of rolling. This is similar to the field observations. Also, as can be noted in Figure 17, the effect of the roller on the surface deformation is similar to the results obtained in Figure 15. The results of the laboratory tests have confirmed the findings of the analysis presented early in this paper. Newly constructed overlay pavements are not structurally sound.

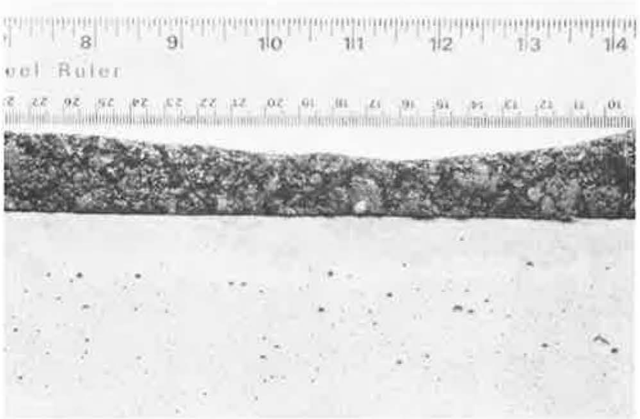


FIGURE 17 Deformed asphalt surface as a result of steel roller.

Comparison Between the Foam-Wood and Asphalt-Concrete Models

The modeling of the pavement structure by a composite beam of foam on top of wood was then compared with a composite beam made of hot asphalt mix on top of Portland Cement Concrete (PCC).

The objective of this test was to demonstrate the importance of understanding the difference between system and component analysis. As was discussed in the theoretical investigation, the important parameter under investigation is the value of the modular ratio (i.e., Ea/Ec versus Unity). Although neither the foam nor the wood behaves like asphalt when compared to concrete, the resulted modular ratio of this model (which is smaller than unity) is of interest. For all systems whose modular ratio is less than 1, it was shown that the most critical interface is the one at the top.

Typical results obtained from this test are shown in Figures 18 to 20. Figure 18 shows a composite

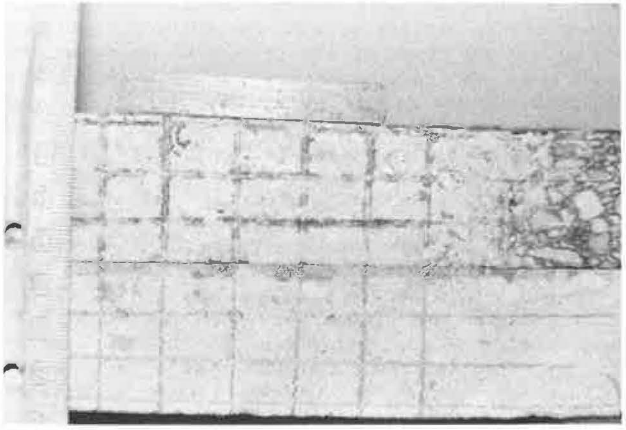


FIGURE 18 Reference system of the asphalt/concrete model ($E_1/E_2 < 1$ and $H = 1$).

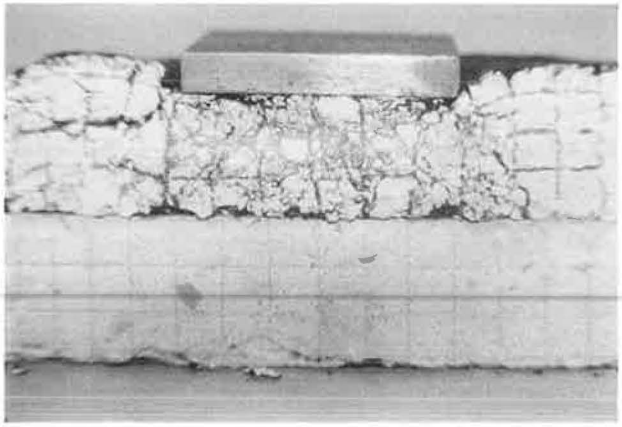


FIGURE 19 Loaded asphalt/concrete model, failure at top.

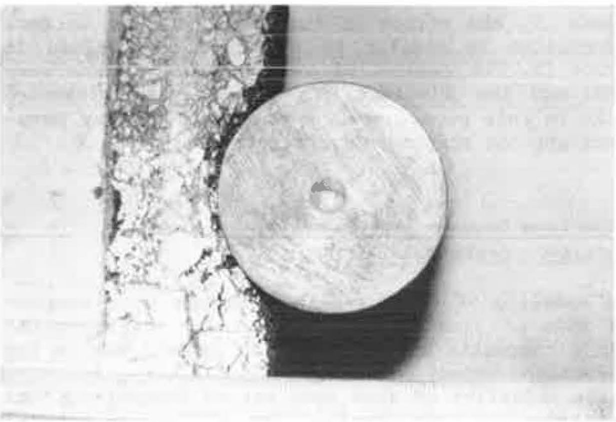


FIGURE 20 Effect of the steel roller on the asphalt surface.

beam made of asphalt concrete on top of PCC with a grid drawn on the face of the model. This is similar to the model shown in Figure 11. The beam was then heated in an oven to warm the asphalt mix to simulate actual field conditions. Clearly when the top layer is hot, the modular ratio is less than unity. The next step was to apply load on the beam using a steel plate and roller. Figure 19 illustrates the results of applying the load on top of a steel plate. As shown in this figure, cracks developed on the top of the asphalt surface in addition to higher bending in the lines of the draw grid close to the loaded area. The results obtained in this figure are similar to Figure 14. As for the effect of changing the geometry of the loaded device, Figure 20 shows the results of using a steel roller instead of steel plate. As shown in this figure, the radius of curvature at the roller/asphalt interface is smaller than the one observed in Figure 20. Also, the results observed in these two figures agree with the results obtained from Figures 14 and 15.

The results of this comparison have shown (a) the validity of the use of the foam-wood model to investigate the pavement system, and (b) that the advantages of using the foam-wood model over the asphalt-concrete one cannot be ignored. These advantages include flexibility, durability, and the scale with which the results can be obtained.

Development of Solution

The results of the analytical investigation have shown that mismatch of the rigidities of the components of the pavement system, as well as the geometry of the steel roller, will contribute to the initiation of construction cracks. Hveen noted that, "if more of our compaction rollers had six-foot wheels, many of our asphalt-compaction troubles would disappear" (19). Increasing the radius of the roller will not result in any significant change in the applied stresses on the asphalt material. The only beneficial result of using a larger roller is the increase in the spacing between the cracks. Therefore, increasing the radius will not eliminate construction cracks.

The results of the analytical and experimental investigations presented herein have shown that the problem of crack initiation is governed by the following parameters:

1. The modulus ratio between the new overlay material and the existing rigid layer (i.e., the pavement structure);
2. The modulus ratio between the steel and the new overlay material; and
3. The relative geometry between the top and bottom interface (i.e., the steel roller and flat surface of the rigid layer).

To eliminate cracking, these three parameters have to be controlled.

Relative Rigidity of the Pavement System

The main objectives of the developed solution are to (a) produce pavement that is free of construction cracks and surface deformation, and (b) keep the advantages of the existing rigid layer (i.e., its structural strength). To meet these objectives, the presented analysis led to the following basic findings (a) the moduli ratio between the steel and the asphalt has to be reduced, and (b) the radius of the compactor has to be infinitely larger (in fact, the top interface has to be parallel to the bottom one).

To achieve these basic requirements, a new compactor termed "Asphalt Multi-Integrated Roller," AMIR (protected by a patent application) has been built in the laboratory. It consists of two steel rollers with a rubber belt that integrates both rollers into one. Figure 21 is a photograph of the new compactor.

FIGURE 21 The developed new compactor (AMIR).

In this roller, the modulus ratio between the rubber belt and the asphalt is close to unity. In contrast, the ratio for a steel roller is significantly larger than unity. Furthermore, the integration of the two steel rollers with the belt has resulted in a flat surface that is parallel to the bottom interface. Thus, both the stiffness and geometry requirements of the RR have been met.

The new compactor was used to compact asphalt samples similar to the slabs previously discussed. The results of using the AMIR compactor proved the validity of the mechanistic approach. As shown in Figure 22 no cracks developed and the resulting pavement has a smooth even surface (i.e., a sound structure).

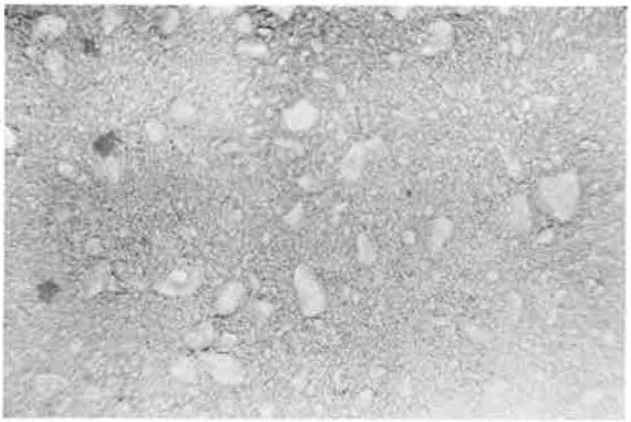


FIGURE 22 Compacted asphalt samples using the new compactor.

CONCLUSIONS

This paper presents a novel and comprehensive investigation of the pavement system at time of construction. It also presents two simple physical models that can be used to visually demonstrate the problems associated with certain pavement systems. The results of this research can be summarized as follows:

1. The problem was identified and a new mechanistic approach was developed to analyze it.
2. The indication that surface cracks and deformations are likely to occur at the surface of the new overlay.
3. The results of the analytical investigations were supported by field observations and laboratory tests.
4. The assumption of pavement soundness is questionable.
5. A novel compactor that has been shown to be effective in producing crack-free pavements was developed.

Finally, with more research being conducted to evaluate the mechanical and physical properties of asphalt samples obtained by the new compactor, a large-scale model for field trials would help to assess and confirm the results and findings of this research.

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The Development and Implementation of the Australian Accelerated Loading Facility Program

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ABSTRACT

The Accelerated Loading Facility (ALF) is a transportable, linear test facility with unidirectional loading and pavement measurement data-logging instrumentation systems. The first pavement trial was conducted on a heavy-duty flexible pavement in New South Wales from July 1984 to April 1985. The second trial is now in progress on a typical rural arterial flexible pavement with a chip seal at Benalla, Victoria. A research strategy is being developed to ensure that ALF trials contribute to broad research objectives and that the ALF program is integrated with other components of pavement research, including long-term monitoring.

The Accelerated Loading Facility (ALF) is a relocatable facility that applies controlled, full-scale wheel loads to sections of real pavement. ALF is now engaged in a program of testing and research, in cooperation with the National Association of Australian State Road Authorities (NAASRA). Contained in this paper is an outline of factors leading to the building of the ALF; its design, construction, and instrumentation; the first year of operation; and early results.

FACTORS LEADING TO THE ALF TESTING PROGRAM

The early Australian Road Research Board (ARRB) research on materials and layers demonstrated the complexity of material response and that a form of rolling-wheel test was needed. This led to the construction of a quarter-scale test track that produced useful results but that also exposed the limitations of small-scale testing. The NAASRA Economics of Road Vehicle Limits Study (1) contains a review of the costs and benefits of heavy vehicles that predicts the impacts, costs, and benefits of increased axle loads and different configurations. These predictions, although of vital importance, were based on limited local and overseas experience with heavier vehicles, greater traffic, thicker pavements, and stronger materials. The late 1960s and 1970s saw the construction of many kilometers of high-standard highway in Australia to carry heavy traffic volumes. The pavement designs and construction standards used were developed from previous experience of unbound bases with thin bituminous surfacings. Under some conditions, the performance of these new pavements was disappointing.

In 1979, the Principal Technical Committee (PTC) of NAASRA formed a working group to review pavement research needs and to recommend means for implementing the necessary research. The working-group review identified and strengthened the need for research into pavement materials and structural response to traffic loads, and recommended that these be studied at full scale with the maximum legal load (at least) being applied by a moving wheel to a pavement constructed of typical materials to normal dimensions

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