LABORATORY EVALUATION OF RHEOLOGICAL BEHAVIOR OF AN ASPHALT CONCRETE CONTAINING AN SBR ELASTOMER

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The subject of this paper is the influence of synthetic rubber [an elastomer styrene-butadiene rubber (SBR)] on the rheological behavior of asphalt concrete. The viscoelastic functions of a wearing course asphalt concrete with and without rubber have been evaluated with unconfined tensile creep tests and tensile-compressive stress dynamic tests at various frequencies and temperatures. The tests were carried out with an electrohydraulic system. The results obtained in the creep tests were perfectly comparable to those obtained in the dynamic tests, confirming the validity of the linear viscoelastic approach. The addition of rubber to concrete increases stiffness at high temperatures, long stress times (in creep tests), and low frequencies (in dynamic tests). Moreover, a general improvement in the elastic characteristics is found when phase angle between stress and deformation is reduced. Rubber contribution to asphalt concrete has also been evaluated in terms of fatigue behavior in a series of tests carried out in the laboratory under different loads.

•DURING recent years the increase in heavy traffic on Italian highways has necessitated research into the rheological behavior of pavement materials, with particular reference to the wearing course, both for the construction of new highways and the reinforcement of existing ones. It seemed indispensable to direct the research toward the improvement of asphalt concretes considering the effects of both aggregates and asphalt cement. The Italian National Hydrocarbons Authority (ENI) research laboratories, responsible for the study of petroleum products, directed their work toward the improvement of the elastic properties of asphalt concrete. The contribution of latex of SBR elastomers toward improving the elasticity, deformation resistance, and fatigue life of asphalt concrete was investigated.

EXPERIMENTAL EQUIPMENT AND TEST METHODS

Research was carried out with an electrohydraulic system on specimens of wearing course asphalt concrete, which were subjected to static and dynamic tests at temperatures of 32 F (0 C) and 68 F (20 C) (1).

Static tests under unconfined axial tensile stress were carried out to define creep compliance for times from 10^{-1} to 10^{3} sec. Stress was 1.5 bar at 32 F (0 C) and 0.3 bar at 68 F (20 C). Dynamic tests under tensile and compressive stress (a short period of tensile stress followed by one of compression) on specimens of the same kind to evaluate the complex modulus at frequencies of 0.03, 0.3, 3, and 30 Hz at the same temperatures were carried out. Stress levels were selected to remain in the field of linear viscoelasticity.

The last investigation was the definition of fatigue behavior of the concrete under examination. Tests were carried out only at 68 F (20 C) by applying to the specimens a sinusoidal axial stress (tensile amplitude equal to compressive) at a frequency of 10 Hz.

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The experimental equipment included a MTS servo-controlled electrohydraulic testing machine by which dynamic stress functions were imposed and which could be programmed to different frequencies (Fig. 1). The specimens were lodged in a thermostatic cell with an accuracy of ±1 F (±0.5 C); the temperature was checked by 2 thermoresistors, one free in the environment and the other immersed in a reference specimen. Axial strains were measured by 2 strain gauges cemented at the middle of the specimen on diametrically opposed sides and inserted in a Wheatstone bridge circuit, which included 2 strain gauges belonging to the unstressed reference specimen used to compensate for temperature effects. A carrier frequency amplifier and a photographic galvanometer recorder were used for strain output measurement. The phase angle between stress and strain was directly measured by a frequency response analyzer.

COMPOSITION AND PREPARATION OF TEST SPECIMENS

Figure 2 shows the gradations of aggregates and the volume characteristics of the concrete mix used.

The experimental tests were carried out on cylindrical specimens (ϕ = 6 cm; h = 12 cm) compacted into molds of the required bulk density by applying at the same time the necessary load at 2 ends of the cylindrical molds by 2 opposed and free plungers.

The concrete was obtained from totally crushed stones composed according to specifications for the building of national highways from an 80-100 penetration grade asphalt produced by the Italian National Petroleum Agency (AGIP) and optimized in concentration by the Marshall method (ASTM D 1559-71). Both pure asphalt and that with 5 percent SBR latex (produced by ANIC of the ENI Group) added in dry weight were used for the production of concrete. This was carried out with mechanical mixers under strict temperature checks. The preparation of the specimens was carried out with systems that guaranteed the best uniformity of the bulk densities and the best repeatability.

For fatigue-test specimens, the same concrete was used, but the specimens were planned differently, because the creation of a weaker section where failure could occur was necessary. They were therefore produced in the shape and size shown in Figure 3 by using the above-mentioned methods. The concrete was compacted into molds that consisted of 2 specular parts firmly bound together that were easily separable after compaction.

Before testing, all the specimens were left for 3 weeks at room temperature to allow a suitable weathering of the concrete. They were then capped with steel caps as shown in Figure 4.

CREEP AND DYNAMIC TESTS

In Figure 5 the experimental creep compliance function is shown at 68 F (20 C) for concretes with and without rubber. The creep compliance reported on double log scale as shown in Figure 6 can be represented by the function

$$J(t) = J_e + J_v t^{\alpha} \qquad (1)$$

which fits the experimental data well for times up to 10^3 sec at 32 F (0 C) and up to 30 sec at 68 F (20 C) (2). J_e and α are practically temperature independent. J_e is the elastic component of the creep compliance ($1/J_e$ represents the upper limit of the absolute value of the complex modulus at low temperatures); its value was determined experimentally during the tests at 0 C. The values of J_e, α, and J_v obtained at 20 C are as follows:

Specimen	J_e	J_v	α
Concrete with rubber	5.5×10^{-6} bar^{-1}	7.8×10^{-5} bar$^{-1} \times$ sec$^{-\alpha}$	0.32
Concrete without rubber	5.0×10^{-6} bar^{-1}	12.7×10^{-5} bar$^{-1} \times$ sec$^{-\alpha}$	0.37

Concrete with rubber shows less tendency to strain during prolonged stress periods. Its resistance to permanent strain can therefore be seen.

Figure 1. General view of the experimental apparatus.

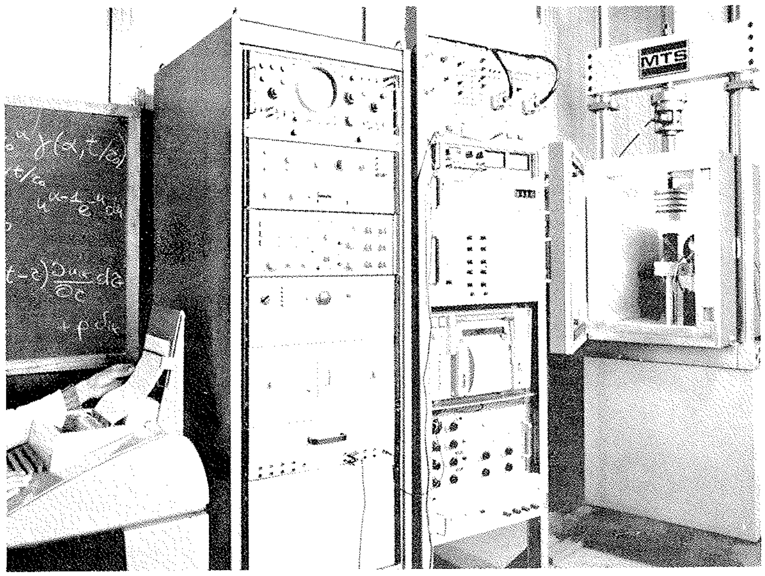


Figure 2. Asphalt concrete characteristics.

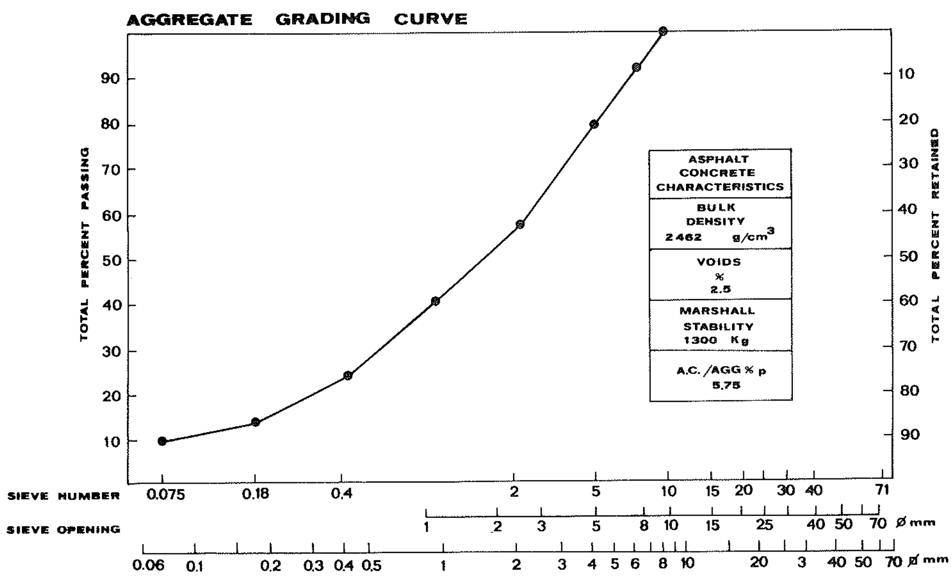


Figure 3. Dimensional view of specimen used in fatigue tests.

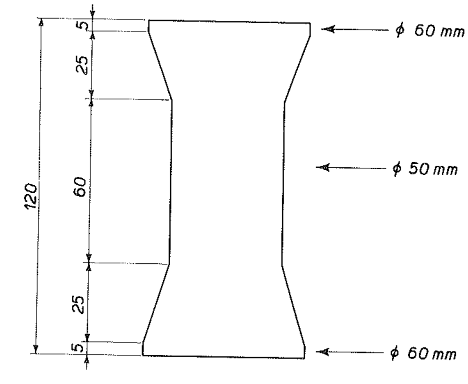


Figure 4. View of specimen used in creep and dynamic tests.

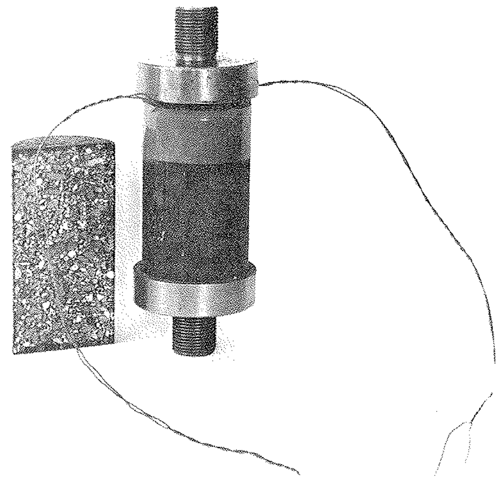


Figure 5. Creep compliance, experimental values at 20 C.

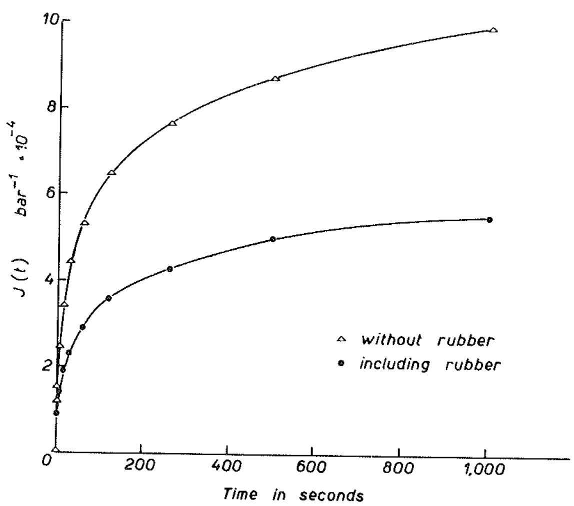


Figure 6. Creep compliance, experimental values at 0 and 20 C.

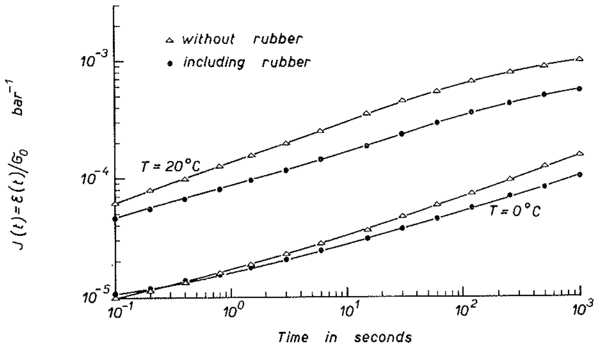


Figure 7. Absolute value of complex modulus, calculated from creep compliance.

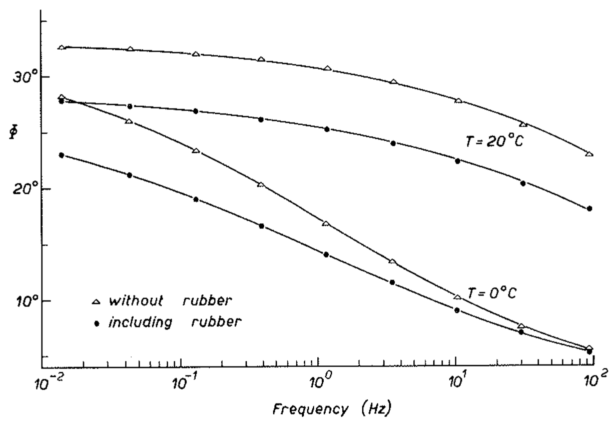
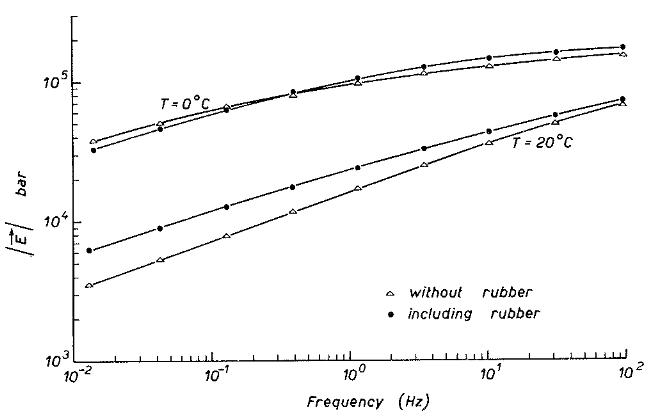


Figure 8. Phase angle between stress and strain, calculated from creep compliance.



Based on the linear viscoelastic theory, an analytical expression of complex modulus from Eq. 1 can be obtained (3). The relationships of phase angle and absolute value of the complex modulus to the frequency calculated by creep compliance are shown in Figures 7 and 8 respectively. These values can be correlated to those measured directly with dynamic tensile-compressive tests at the same temperatures and in a frequency range from 3×10^{-2} to 30 Hz.

The experimental values of E and ϕ are shown in Figures 9 and 10. The good correlation confirms the validity of the phenomenological approach.

In terms of stiffness, rubber proved to be essential with increase of temperature and reduction of frequency in dynamic testing.

FATIGUE TESTS—GENERAL CONSIDERATIONS

The fatigue behavior of the asphalt concrete was the subject of various laboratory studies with stress or strain imposed, which often produced contradictory results (4, 5). Analysis of the fatigue phenomena of asphalt concrete under real traffic conditions shows that fatigue behavior with strain imposed is correlated to the phenomena to which the intermediate layers of flexible pavement were subjected because these layers have to follow the subbase strains. Otherwise, wearing course fatigue behavior is better representable in the laboratory through stress tests (6). It was decided to carry out dynamic tensile-compressive tests with constant stress amplitude until failure without intermediate rest periods.

This program justified the need both to observe the behavior of an asphalt wearing course and to evaluate the rubber contribution.

RESULTS

As is well-known, fatigue behavior studies in asphalt concrete are made difficult by considerable data dispersion. The statistical interpretation of these phenomena was done by the law of normal distribution of the failure cycle logarithm. In our case, the standard deviation of this distribution varied from a minimum of $\pm$ log 1.3 to a maximum of $\pm$ log 1.7 (15 specimens were used for each type of concrete and level of stress applied).

The axial strain versus time encountered during a fatigue test is shown in Figure 11. The specimen failure was observed to occur generally when the strain became twice the initial one. In the case of a concrete with rubber added, a failure strain was observed at about 3 times the initial value.

This behavior is consistent with the best ductility characteristics of asphalt cement at 68 F (20 C). The curve of the failure cycle numbers is shown in Figure 12 (mean values of log N) with respect to the stress applied, $\pm\sigma_o$ (tensile stress is indicated by +, and compressive stress by -). The experimental data were correlated with the function

$$\log N = \alpha \log \sigma_o + \beta \qquad (2)$$

where the α and β values were calculated with a linear regression. As shown in Figure 12, the elastomer contribution is clear, especially for the lowest values of applied stress. Compared with nonrubberized concrete, there was an increase in life from 2 to 5 times in the stress range considered.

The failure cycles and the initial strain values are given in Table 1 together with correlation results and strain standard deviations. The α value varied from -4.5 for the concrete without rubber to -6.0 for the concrete with rubber. This is in accordance with the fact that the angular factor α is generally greater (in absolute value) for stiffer concretes (2).

In Figure 13 failure cycles are shown with the mean values of initial strains obtained at 3 stress levels where ϵ_o represents the peak amplitude of the dynamic strain. The behavior of log N with respect to log ϵ_o can be represented in this case by a relation analogous to Eq. 2

Figure 9. Absolute value of complex modulus, experimental values.

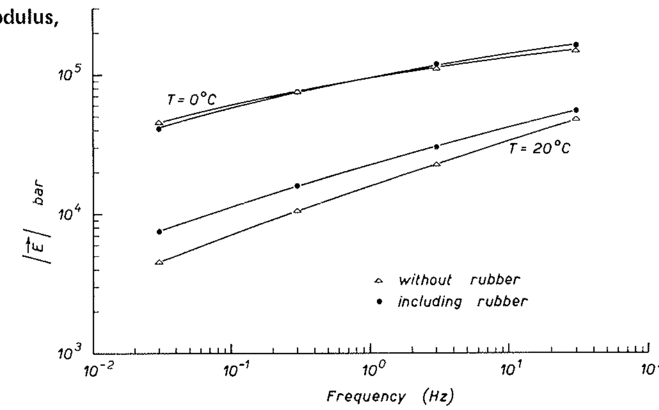


Figure 10. Phase angle between stress and strain, experimental values.

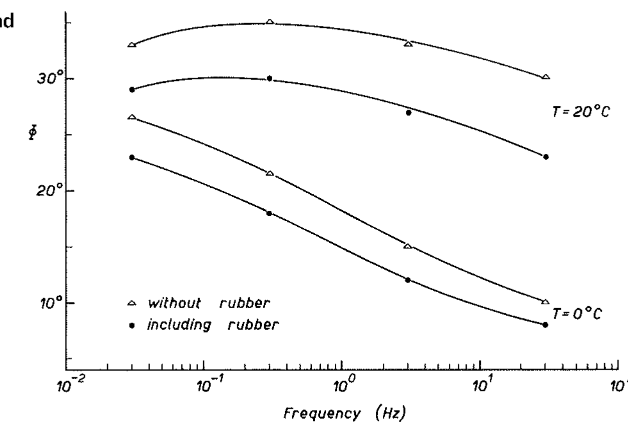


Figure 11. Axial strain versus time during a fatigue test.

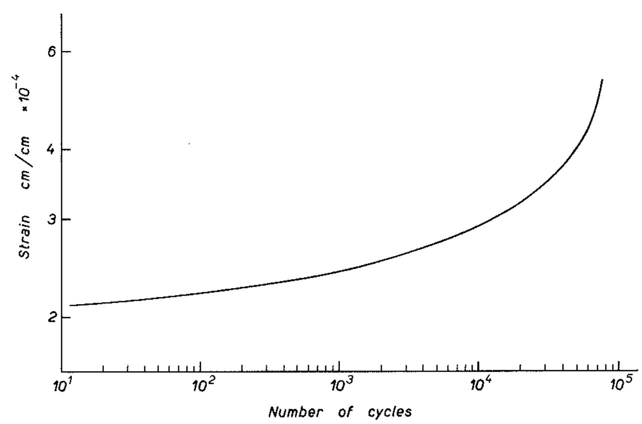


Figure 12. Tension compression fatigue test, failure cycle number versus stress applied.

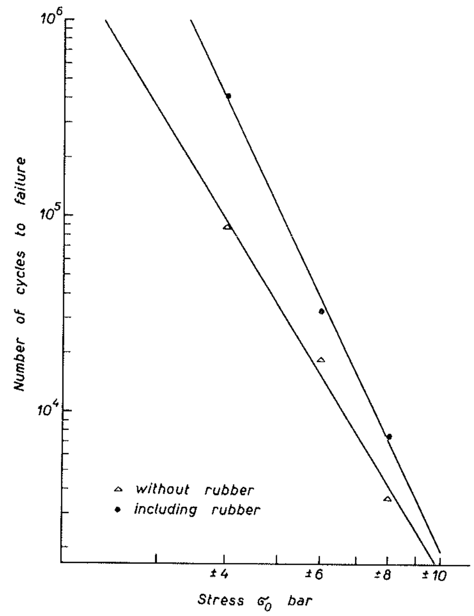
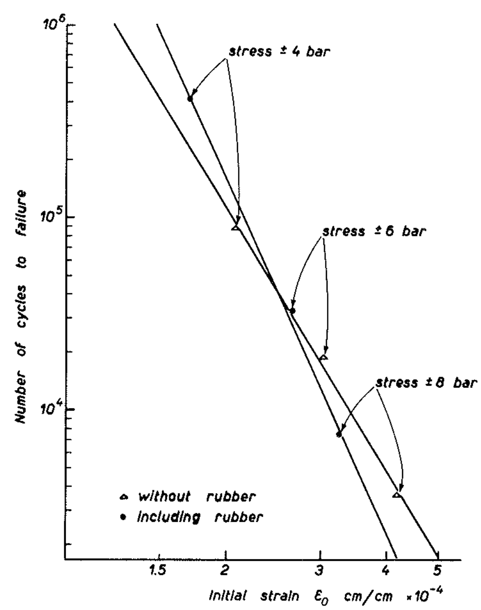


Table 1. Results of fatigue tests of sinusoidal stress of constant amplitude.

Stress, σ_0 (bar)	Number of Cycles to Failure	Initial Strain, $\epsilon_0 \times 10^6$	$\text{Log N} = \alpha \log \sigma_0 + \beta$	$\text{Log N} = \alpha \log \epsilon_0 + \gamma$
Without Rubber				
±8	3,650	418 ± 22	α = -4.5	α = -4.5
±6	18,700	304 ± 16	β = 7.7	γ = -11.8
±4	88,000	208 ± 12		
With Rubber				
±8	7,500	324 ± 16	α = -5.8	α = -6.1
±6	32,500	264 ± 14	β = 9.1	γ = -17.5
±4	410,000	170 ± 10		

Figure 13. Tension compression fatigue test, failure cycle number versus initial strain.



$$\log N = \alpha \log \epsilon_o + y \qquad (3)$$

The best fatigue behavior observed in the rubberized concrete seemed to be a consequence of its greater stiffness. The curves in Figure 13 (log N versus log ϵ_o) show in fact that the initial strain is the parameter that principally affects the number of failure cycles; the 2 curves differentiate in their slope, intersecting at $\epsilon_o \approx 2.5$ cm/cm $\times 10^{-4}$. This may partially explain the apparent contradiction between the results obtained in the fatigue tests with applied strain and stress. For the latter, a better behavior for the stiffer concrete was found particularly in a limited field of values of applied stress; in the constant strain tests, a longer life for those with a lower modulus was generally noted.

For the high initial strains, the faster the fatigue process, the higher the modulus of the material was according to the hypothesis that the length of cracks appearing in material increases in time proportionally to σ^4.

CONCLUSIONS

The laboratory tests showed the validity of employing a latex of SBR because of the mechanical characteristics observed, in terms of both deformation resistance and fatigue behavior.

This improved performance is assuming particular importance in Italy because of the continuous increase of heavy traffic and loads over 10 tons/axle.

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REFERENCES

1. Verga, C., Battiato, G., and La Bella, C. Laboratory Evaluation of Rheological Behaviour of Wearing Course, Binder and Base Asphalt Concrete. Autostrade, Rome, Italy, Sept. 1972.
2. Verga, C., Battiato, G., La Bella, C., and Ronca, G. Viscoelastic Analysis of the Deformation Behaviour for Flexible Pavements Models. Acts of the 2nd Meeting of Italian Society of Rheology, Siena, Italy, May 1973.
3. Ferry, J. Viscoelastic Properties of Polymers, 2nd Ed. John Wiley and Sons, Inc., New York, 1970.
4. Pell, P. S. Fatigue of Asphalt Pavement Mixes. 2nd Internat. Conf. on Structural Design, Univ. of Michigan, Aug. 1967.
5. Kennel, M. Etude de la résistance à la fatigue des bétons bitumineux. Révue général des routes et aerodromes, Paris, Jan. 1973.
6. Doan, M. Contribution à l'étude du comportement à la fatigue des bétons bitumineux. Faculté des Sciences de Paris, Thèse de Docteur-Ingénieur, Paris, May 1970.