zontal components of the reactions of the subgrade, and (5) the dynamic effect, expressed in terms of the inertia of the pavement and subgrade The horizontal components of the reactions of the subgrade, which are due to friction, may have a strengthening influence, especially at some distance from the edges, by causing a dome action in the pavement As to the dynamic effects, with known values of the maximum pressure developed between the tire and the pavement, the effect of the inertia of the pavement may possibly be expressed approximately in terms of an increased value of the modulus k These additional influences are suitable subjects for further analysis

REPORT ON EXPERIMENTS ON EXTENSIBILITY OF CONCRETE

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Two properties of materials are important—strength and toughness Available data are few resulting from measurements of the ability of concrete to withstand extension without the appearance of fissures These may range in magnitude (a) from those in the order of 0 0004 inch width seen only with a microscope or appearing as "water veins" or "water marks," as Feret termed them, when a skin-dried surface. breaks and capillary moisture comes from the interior through the fissures, to (b) larger fissures in the order of 0 0015-inch width, seen by the unaided eye, and (c) in the extreme to those large open cracks that occur when the elastic limit of reinforcing steel is exceeded In the class of microscopic fissures are those crazes that mar the appearance of architectural concrete or other concrete products Such crazes are not always evident to the unaided eye, but may be developed by a coating of light oil

The various fissures may be produced by load or by the action of temperature or moisture changes

The preservation of the integrity of the surface of exposed concrete is important In many cases surface cracks are the first indication of subsequent failure in concretes that have been made of defective materials, either cement or aggregate

We are increasingly required to compute expansions and contractions of structures, these movements are limited by extensibility

As has been said, the active agents may be tensions due to loads, or due to the working back and forth of the surface under temperature and moisture changes The latter express themselves most markedly when the surface of the concrete is of a richer composition than the interior, or when the surface is contracted by careless drying against a moist core Indeed, the falling off in strength of cement briquettes that have been taken from the water and then exposed to the drying air of a laboratory before testing has been explained by the presence of surface fissures arising from the sudden shrinkage of the surface of the briquettes

Such fine fissures in carelessly cured concrete exposed to the weather during summer appeared after two weeks of exposure, first on the top surface of 6 by 8 inch beams, 3 months later on the sides, and finally on the bottoms Subsequent cracks under load generally occurred at these microscopic fissures

The importance of a favorable condition of concrete surfaces and the paucity of data on extensibility and of the influence of the factors which affect the latter led the author to study what actually happens to surfaces under various conditions, and to attempt to find out the means for *increasing extensibility* The research seemed to be necessary because it was not certain that the laws of strength could be directly transferred to extensibility

The main factors to be examined were *curing* conditions and the effect of *mesh reinforcement* Up to the present time the action of reinforcement is fairly well determined However severe conditions attending poor curing have been used in this latter investigation Further studies will include various kinds of concrete cured in several manners

Prior to the research upon extensibility, a study was made of the effect of change of moisture conditions and temperature upon contraction and expansion and the warping and pulling of beams by change of condition of their surfaces Values of contraction and expansion were measured and evidence of surface checking due to difference of condition of surface [1] At that time no close survey was made of the beams to detect the first appearance of fine fissures, although they were evident in the surface of a road slab that had been warped back and forth by climatic effects

In the inquiry as to the effect of a small per cent of reinforcing in holding a concrete surface together against the agents that produce surface fissures, two series of tests were made in 1924 and 1925 on plain and reinforced concrete cured under several exposures and of various ages The tests were made on beams under the usual laboratory process in which loads progressively increased to rupture, and also on beams under repeated loads producing a fatigue action Observations were made of extensions and deflections The trained observers watched for the appearance of the first fissures, visible to the unaided eye, using a film of oil to bring out such fissures Such a film of oil will display checks in unloaded beams, and will enable the observer to watch more closely the development of fissures A coating of white wash will also serve to draw the attention of the observer to the formation of a fissure

[1] See Proc A S C E, May, 1925

that would otherwise escape nature. Later, a 100-power microscope was arranged with a three-way motion to survey the surface of the beams under the fatigue test.

The entire research is at present incomplete, and the detailed results may be reserved until the time is opportune for a full publication.

At this time the present well-defined indications of the research may be stated:

1. The gross contraction of concrete due to shrinkage depends upon curing and subsequent exposure, upon the quality and quantity of the cement and other factors to be evaluated in each case. The shrinkage of concrete may be set at 0.05 per cent generally, neat cement at from 0.10 to 0.22 per cent, and 1:2 mortar one-half of the latter.

2. The extensibility of concrete surfaces before fissures appear, depending as it does upon several factors, may be stated in ordinary cases as follows: For microscopic fissures 0.010 per cent, for fissures visible to the unaided eye, 0.018 per cent.

3. The comparison of surface conditions with respect to development of fissures in beams stored (a) inside a shed and (b) exposed to the weather is shown in Table I.

TABLE I

Average of Two Plain Beams and Two Reinforced Concrete Beams, 1:2:3 Gravel Concrete, 6 Inch by 8 Inch by 5 Feet

(Values from Curves)

Age in Days	Values in per cent of shed stored beams	
	Extension	Modulus of Rupture
7	77.5	103.0
14	84.0	104.5
21	85.5	112.0
28	87.5	117.0
60	?	119.0
135	83.0	116.0

In the series of tests of 1924 on like beams, one series was cured continuously under wet burlap and another series was exposed to a continuous draft of hot dry air. The improvement in the integrity of the surface by moist curing as shown by the deflection was 20 per cent.

FATIGUE TESTS OF PLAIN CONCRETE

4. A comparison of the effects of *progressive* and *fatigue* loading showed that the ultimate extensibility was reached at approximately the same elongation of the concrete surface, whether this elongation

resulted either from a single maximum load once applied or a smaller load applied a large number of times

5 Under fatigue a 1 2 3 concrete stretched 0 015 per cent and a 1 2 mortar stretched 0 020 per cent (Wet mortar extended 0 020 per cent under once applied load and 0 018 in fatigue, whereas in the case of dry mortar these values become 0 017 and 0 015) As in the case of wood, the dry beams have less toughness than the wet beams

EFFECT OF REINFORCEMENT

6 It might be thought that because of the prevention of shrinkage of the concrete by the rigidity of reinforcing steel, the latter would thereby actually promote surface fissures rather than diminish them, and that, therefore, the only function of reinforcing steel would be to hold together previously broken surfaces However, this is probably a question of degree of reinforcement and character of fissures It is true that the appearance of fine microscopic cracks does not seem to be postponed by mesh reinforcement, but in the case of fissures *visible to the naked eye* and which might allow climatic influences to act, the appearance of such fissures is postponed as shown in Table II

TABLE II

Increase of Extensibility of Single Mesh Reinforced Concrete Beams, 1 2 3 Gravel Concrete, 6 inches by 8 inches by 5 feet Two Beams each of Shed and Weather Storage, Plain Beams = 100, 1925 Series

(Values from Curves)

Age Days	Extensibility		Strength	
	Shed	Weather	Shed	Weather
7	147	151	120	123
14	126	149	115	111
21	114	143	114	106
28	113	141	114	103
63	126	127	111	?
135	111	100	111	100

Furthermore mesh reinforcement appears to ameliorate the conditions of the surface that arise from defective curing

The benefit of such mesh reinforcement is more evident at earlier than at later ages Beyond an age of 60 days both plain and mesh reinforced beams show approximately the same extensibility

Several series of tests on like concrete beams were completed in 1924 from which it appeared that the first crack visible to the unaided eye was postponed by mesh reinforcing, especially in the case of concrete mixed wet and cured in a current of dry air when the increased flexibility was 60 per cent at 14 days For dry mixed concrete this increase was only 2 or 3 per cent The presence of reinforcing appeared to ameliorate the surface conditions arising from wet mixed concrete At 28 days of age the plain and reinforced beams of 1924 were more equal in quality

FATIGUE TESTS ON REINFORCED BEAMS

Beams of 1 2 3 gravel concrete, plain and mesh reinforced in 0 33 per cent, in two exposures (a) shed and (b) weather, were tested in fatigue On account of limited capacity of the machine only one beam was repre-

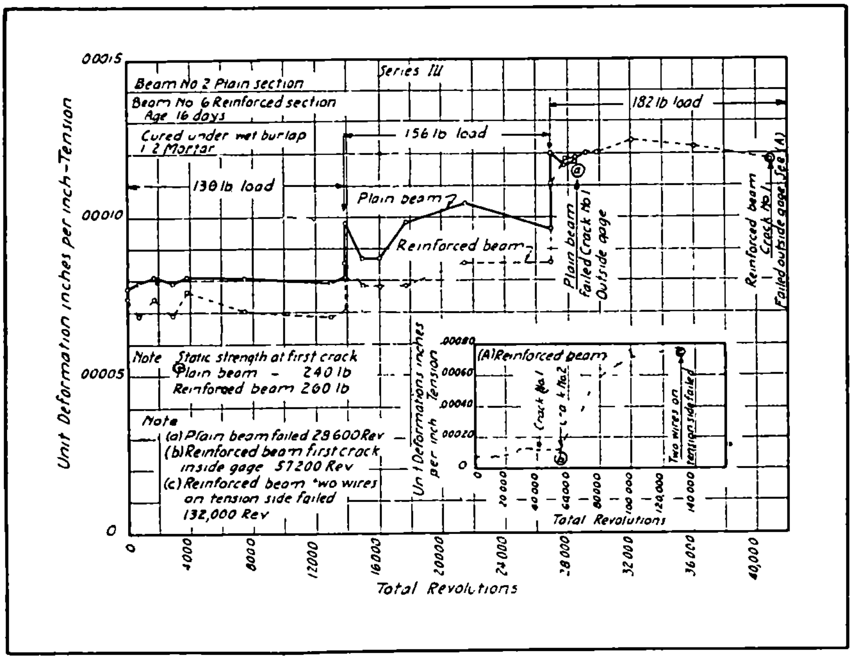

Figure 1—Typical behavior of a beam under repeated stress

sented in each condition One face of the beam was subjected to repeated tensional stress at a predetermined per cent of the modulus of rupture under the usual laboratory test The shape of the test piece, the machine and method of test are described in the Proceedings of the Fourth Annual Meeting of the Highway Research Board

The typical behavior of a beam under repeated stress is shown in Figure 1 The plain concrete beam showed microscopic fissures at 11,000 repetitions and a unit extension of 0 00011, and then failed at 38,000 repetitions with a unit extension of 0 00015 The reinforced beam showed microscopic fissures at 52,000 repetitions and the unit extension of 0.00012. Visible cracks appeared at 151,300 repetitions and at a unit extension of 0.00021. The test was stopped when large crack approximately 1/8 inch in width opened at 220,000 repetitions.

The microscopic fissures in the face of the beam and their relation to cracks visible to the naked eye were determined in the fatigue tests, and are given in Table III. It appears that these microscopic fissures or water veins, as they were termed by Feret, occur at an extension of approximately 53 per cent in reinforced concrete beams, and 67 per cent in plain concrete beams, of the extension at which eye visible cracks appear. The number of repetitions of loads is approximately 40 per cent at the time of these microscopic fissures compared to the number of repetitions at the first visible crack.

TABLE III

RELATION OF MICROSCOPIC TO EYE-VISIBLE FISSURES

1:2:3 Concrete, Gravel Aggregate, Slump 3½ inches, 2 Days Initial Curing Under Wet Burlap, Fatigue Tests, 4x4-in Section, 0.33 per cent Reinforcement

Age	Type of Beam	Storage	Microscopic Fissure		Eye-Visible Fissure	
			Unit Exten	Applic Load	Unit Exten	Applic Load
21	Reinf	Laboratory	0.00012	55,800	0.00025	149,000
21	Reinf	Weather	0.00011	65,300	0.00020	149,000
28	Reinf	Laboratory	0.00010	186,000	0.00019	214,000
28	Reinf	Weather	0.00009	75,000	0.00016	200,000
28	Reinf	Laboratory	0.00010	109,000	0.00015	214,000
28	Reinf	Weather	0.00008	88,000	0.00017	300,000
28	Plain	Laboratory	0.00011	14,600	0.00014	20,000
28	Plain	Weather	0.00010	47,000	0.00018	176,000
67	Reinf	Laboratory	0.00012	68,000	0.00021	151,000
67	Reinf	Weather	0.00010	42,000	0.00021	151,000
67	Plain	Laboratory	0.00011	11,000	0.00015	39,000
67	Plain	Weather	0.00009	39,000	0.00013	52,000
Average Values			0.00010	66,800	0.00018	151,350
in Per Cent			57.6	44.1	100	100

A plain specimen breaks immediately after the appearance of an eye visible crack, but observation with a microscope shows an earlier fissure in these plain beams which closes up on the removal of the load. Such fissure may extend 25 per cent of the depth of the beam and still close up. In case of *reinforced* beams this drawing together of the fissure extends to a *greater* degree of extension. The steel continues to draw the edges together until the elastic limit of the steel has been exceeded. Evidently steel of a high elastic limit is of advantage for this purpose.

7. The significance of minute fissures compared to those visible to the unaided eye in terms of service of concrete under load and exposure is obscure Judging by tests made in Germany to determine the durability of reinforcement in concrete beams under load in an atmosphere designed to accelerate rust producing conditions, the very fine checks which accompany an elongation of 0 010 per cent have no signficance in terms of rusting of steel From the observation of the surface of concrete roads where these checks are undoubtely present, it would not appear that they have much significance in respect to the wear of the surface of the roads Now if a mesh reinforcement will postpone the appearance of the larger eye visible fissures, then it would seem to be of substantial advantage in maintaining integrity of concrete surfaces

SUMMARY OF TENSION TESTS OF CONCRETE BRIQUETTES REINFORCED WITH STEEL FABRIC

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To all of us there has been apparent the beneficial effects from the use of a small amount of steel well distributed throughout a pavement slab Observations of actual work over a period of 10 years of pavement built with and without amounts of steel from 21 to 60 pounds per 100 square feet of slab, show definitely the advantage of the reinforced over the plain in giving better condition at less expense for maintenance The benefit observed shows a greater gain in strength in the concrete in the reinforced sections than the sectional area and the relative moduli of elasticity would indicate The first question that suggests itself is how great is this benefit and whence does it come?

An observation of the records of a large mileage of concrete pavements from construction to five years of age showed that in the minds of various observers from 20 to 30 per cent of the rupture (cracks) came in the first 28 days of the life of the pavement slab when the tensile strength of the concrete varied from zero to 250 pounds per square inch

Taking the first month as the most informative period and further limiting the study to the first 7 days when the concrete is weakest and has to resist the greatest contraction, a study of the beneficial effects of a steel fabric was conducted

In collaboration with Professor E G Hooper, of New York University, a preliminary test was conducted as follows

Test set No 1, total 24 tension specimens averaging 4⅛ by 5⅞ inches cross-section, divided equally on the basis of *time*, 3 days and 5 days, on the basis of *reinforcement* 0 1 per cent and none, and on the basis of *curing* (after removal from molds) in water to a depth of about ¾ inch and under damp sand There were then three tension specimens for each combination of time, reinforcement and curing