STEEL REINFORCEMENT IN CONCRETE PAVEMENTS

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The Committee on Structural Design of Roads has given consideration to the following report and although it does not feel that the data presented warrant any definite conclusions, the indications offered are of great interest and should be further investigated. The report is published in the hope that research will be stimulated along similar lines to the end that definite conclusions may finally be drawn.

The Highway Research Board in 1925 concluded·

1 That incorporation of steel reinforcement in concrete pavements reduces the extent of tranverse and longitudinal cracking (transverse cracks, spaced not closer than about 10 feet and single longitudinal cracks in full width road slabs) more economically than increased pavement thickness, and also,

2. That increased pavement thickness reduces the extent of breakage (transverse cracks spaced closer than 10 feet, corner cracks, longitudinal cracks in half width road slabs) more economically than the incorporation of steel reinforcement

Data now available substantiate the first conclusion and explain it on the basis that steel reinforcement confines to microscopic dimensions cracks which increased slab thickness is ineffective for preventing The steel in this case merely ties cracked slabs tightly together, and thus prevents cracks from becoming visible

And the efficiency of reinforcement for this purpose depends upon its character, weight and distribution

A supplementary analysis of data previously submitted to this Committee (see references) suggests the possibility of amending the second conclusion to the effect that under certain conditions reinforcement may also economically prevent breakage in concrete pavements

In this case the reinforcement apparently increases the quality of concrete, and this performance can be explained neither by binding action nor by any existing theory on reinforced concrete

The data given in Table I, and illustrated in Figure 1, demonstrate how concrete may vary with respect to quality and how this variation is influenced by reinforcement

The author in presenting this material has taken liberties, as noted in Table I, and furthermore, he emphasizes the fact that the test slabs represented one type of aggregate and cement and that their resistances were measured by impacts. If resistances measured in terms of static loads and if variation in aggregate and type of cement would have changed appreciably the relative indications is not known It was considered that even with these qualifications, the indications furnished

by the data were of such importance as to receive the Committee's attention

TABLE I

DIGEST OF RESULTS FURNISHED BY THE ARLINGTON IMPACT TESTS

Group symbol	Type	Mix	Thickness inches	Bituminous	Subgrade	Impact causing failure pounds
A	P[1]	1 1½ 3	4	None	Drained	13,650
B	P[1]	1 1½ 3	4	2 inches	Drained	15,087
C	R[2]	1 1½ 3	4	None	Drained	11,850
D	P	1 1½ 3	4	None	Wet	[4]
E	P	1 1½ 3	4	2 inches	Wet	[4]
F	R	1.1½ 3	4	None	Wet	8,650
G	P	1 3 6	4	2 inches	Wet	2,000[3]
H	P	1 1½ 3	6	None	Drained	20,000
J	P	1 1½ 3	6	2 inches	Drained	22,225
K	R	1 1½ 3	6	None	Drained	21,560
L	P	1 1½ 3	6	None	Wet	12,825
M	P	1 1½ 3	6	2 inches	Wet	10,175
N	R	1 1½ 3	6	None	Wet	17,380
O	P	1 3 6	6	None	Drained	18,300
P	P	1 3 6	6	2 inches	Drained	18,430
Q	P	1 3 6	6	None	Wet	9,580
R	P	1 3 6	6	2, 3 and 4 inches	Wet	[5]
S	P	1 1½ 3	8	None	Drained	42,040
T	P	1 1½ 3	8	2 inches	Drained	36,800
U	P	1 1½ 3	8	None	Wet	25,900
V	P	1 1½ 3	8	2 inches	Wet	25,425
W	P	1 3 6	8	None	Wet	14,175
X	P	1 3 6	8	2 inches	Wet	13,850

[1] Plain concrete
[2] Mesh reinforced concrete
[3] Static load
[4] Broke under static load varying between 2,000 and 8,000 pounds
[5] Six out of 8 slabs tested broke under static loads varying between 2,000 and 8,000 pounds

According to Figure 1, all slabs laid on wet subgrades were less resistant than similar slabs laid on drained subgrades The extent of difference varied widely, however, being least for the reinforced rich mix slabs, and greatest for the plain lean mix sections

For instance, on the wet subgrade a rich mix reinforced thickness of 6 7 inches is required to furnish resistance to that furnished by similar slabs 6 inches thick laid on the dry subgrade In contrast to this differential of 0 7 of an inch in the rich mix reinforced slabs, a differential of 1 8 inches is required in the rich mix plain slabs, and a differential of 2 8 inches in the lean mix plain slabs

Mere difference in the support offered by the wet and dry subgrades explains why there should be a difference in the resistance of slabs laid on them, but mere difference in support does not explain why a difference should be much less in the reinforced sections and much greater in the

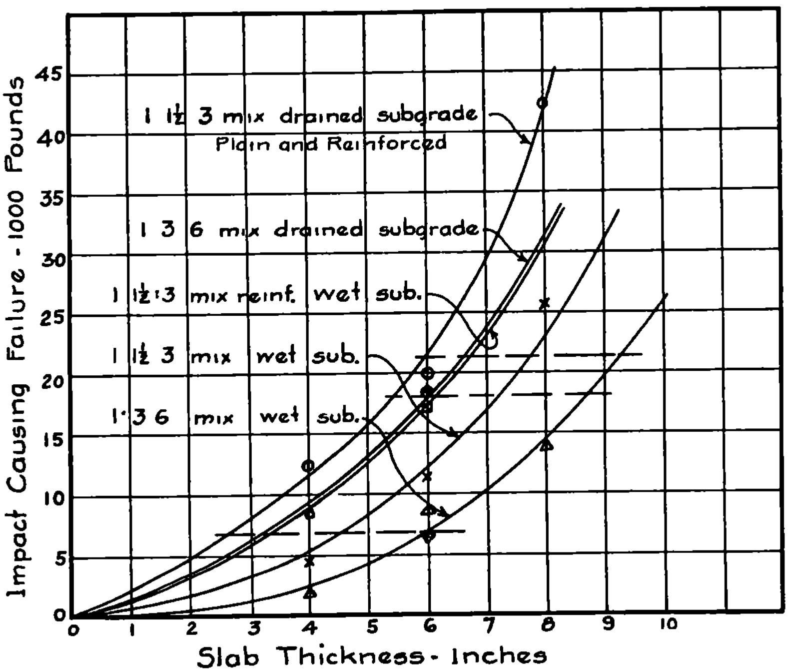

Figure 1. Relative Load Capacity of the Different Slabs

lean mix than in the rich mix sections It should be noted also in this connection that light meshes which prove highly beneficial in the slabs laid on the wet subgrade furnished no benefit whatever in the slab laid on the dry subgrade

That the benefit furnished by mesh reinforcement is due to prevention of deterioration in the quality of concrete and not to the theoretical increase in the tensile resistance in the face of the concrete subjected to tensile forces is indicated by the following

a Had the mesh merely supplied resistance to tension in the slabs, it would have been beneficial in slabs when laid on both wet

and dry subgrades, it would have been beneficial only when placed in the face of the slab receiving tension and its benefit would have been increased by increasing the amount of steel used This did not occur

b. No existing theory of reinforced concrete demonstrates how 0 2 of 1 per cent of fabric reinforcement placed in either the compressive or tensile face of slabs 6 inches thick, or in the neutral axis of slabs 4 inches thick can increase their resistance by as much as 50 per cent, nor why increasing the amount of reinforcement from 0 2 to 0 8 of 1 per cent in slabs does not increase their resistance

c. Only prevention of deterioration in the quality of concrete can explain why very light weight mesh reinforcement is beneficial only when placed in slabs whose reistance without the reinforcement is considerably less than that furnished by the slabs laid on the drained subgrade, and why the benefit should be similar for reinforcement different in weight and in placement with respect to the neutral axis or the compressive or tensile faces

The tests indicate that when properly placed and when used in a sufficient amount, reinforcement is effective for increasing also the resistance of slabs laid on dry subgrades In this case, however, a weight of 192 pounds per 100 square feet (contrasted with 22 pounds on the wet subgrade) was required to compensate for one inch difference in concrete thickness. Therefore, in this case, increasing the slab thickness seems the more economical method for increasing resistance to breakage.

It is interesting to note the variation in slab thickness indicated by these data as being required to furnish equal load capacities

According to Figure 1, slabs conforming to the following specifications satisfy the load capacity requirements equal to that furnished by a slab 6 inches thick, consisting of a 1 1½ 3 mix, not reinforced, when laid on a drained subgrade

(*a*) 6 inches thick, reinforced, 1 1½ 3 mix, dry subgrade
(*b*) 6 7 inches thick, plain, 1 3 6 mix, dry subgrade
(*c*) 6 7 inches thick, reinforced, 1 1½ 3 mix, wet subgrade
(*d*) 7 7 inches thick, plain, 1 1½ 3 mix, wet subgrade
(*e*) 9 3 inches thick, plain, 1 3 6 mix, wet subgrade

Slabs conforming to the following specifications satisfy the load capacity equal to that furnished by slabs 6 inches thick, consisting of 1 3 6 mix, when laid on a drained subgrade

(*a*) 5 3 inches thick, plain, 1 1½ 3 mix, dry subgrade
(*b*) 5 3 inches thick, reinforced, 1 1½ 3 mix, dry subgrade
(*c*) 6 0 inches thick, reinforced, 1 1½ 3 mix, wet subgrade
(*d*) 7 2 inches thick, plain, 1 1½ 3 mix, wet subgrade
(*e*) 8 8 inches thick, plain, 1 3 6 mix, wet subgrade

The indications just discussed are submitted to the committee merely because they suggest the possibility of wide differentials in pavement thicknesses, due entirely to subgrade and mix variables and therefore should receive attention

REFERENCES

Teller, L W, 1924, Impact Tests on Pavement Slabs, (Original Report).
Smith, E B, and Teller, L W, 1925, U S Bureau of Public Roads
Impact Tests, Summary of Report, Highway Research Board, Fifth Annual Proceedings, Part II, page 124
Hogentogler, C A, 1925, Discussion of same tests, Highway Research Board, Proceedings Fifth Annual Meeting, Part II, pages 16, 69 and 82

DISCUSSION

ON

STEEL REINFORCEMENT IN CONCRETE PAVEMENTS

MR F. R McMILLAN, *Portland Cement Association* In the discussion which Mr Hogentogler presented on that part of the report referring to the difference between slabs on wet and dry subgrades, with and without reinforcement, he left the impression that the quality of the concrete in some unexplained way is changed by the addition of a small percentage of reinforcement It would seem that this whole problem can be fully explained by recognition of the simple fact that when an unrestrained piece of concrete is kept moist, there is a swelling effect which induces tensile stresses in embedded reinforcement, and when allowed to dry out, the shrinkage induces compression in the reinforcement On the wet subgrade, therefore, the concrete swells and there is an initial tension in the steel and compression in the concrete For symmetrical reinforcement top and bottom this results in a greatly reduced tendency to cracking for as a load is imposed, the initial compression in the concrete must first be reduced by the tensile stresses that are developed before actual tension can exist As the load is increased, the initial compression in the concrete finally reduces to zero and subsequent increase in the load creates a tension that finally causes cracking of the concrete

As opposed to this, on the dry subgrade there is an initial tension in the concrete induced by the inability of the steel to accommodate itself to the shrinking mass This initial tension in the concrete is balanced by the compressive stress in the steel In this case, as the load goes on, the tension developed is added to the initial tension already in the

concrete so that cracking under load develops at a much lower load than is required to crack the slab on the wet subgrade

The foregoing explanation still applies for road slabs with steel on only one side, though with some modifications With steel in the top, a wet slab tends to warp concave upwards with the entire surface held together by the tension developed in the reinforcement from the swelling—a condition unfavorable to the formation of cracks On the other hand the dry slab warps convex upward owing to the compression in the steel induced by the shrinking This warping together with the drag on the subgrade and the initial compressive stress in the steel, all combine with the effect of wheel loads to cause early and frequent cracking

With steel in the bottom, a wet slab tends to warp convex upward while the dry slab would warp concave upward Since the steel is in the bottom the dry slab would show the greatest tendency to crack

In some tests carried out by Mr A Knauss under the writer's direction at the University of Minnesota, 1916–1917, it was found that the load necessary to produce initial cracking in a beam tested wet was four to six times as much as when the beam was tested dry In these tests the steel was on one side only with the load applied in the usual manner This large increase in capacity for the wet beams indicates that these purely mechanical effects due to shrinking and swelling with embedded reinforcement can completely explain the phenomena which were observed by the Committe

MR C A HOGENTOGLER (*Author's closure*) Professor McMillan's suggestions partially explain the behavior of the Arlington test slabs The writer believes in addition, however, that the steel reinforcement offered resistance to expansion and contraction and thereby changed the characteristics of the concrete during the setting period thus causing the non-reinforced slabs, after resting upon the wet subgrade for a period of time, to be less resistant to impacts than the reinforced concrete subjected to similar conditions of moisture

Had the concrete in both plain and reinforced slabs on the dry subgrade been the same in character and had the reinforcement served only to produce initial tension in them, the non-reinforced slabs would have been more resistant to impacts than the reinforced slabs This according to the data is not consistently true Instead there seemed to be but little difference between the strengths of the plain and the reinforced sections laid on the well drained subgrades

In this respect the Arlington Test results agreed with those furnished by tests performed on beams subjected to high shrinkage due to improper curing at Purdue University In reporting upon these tests in the Proceedings of the Fifth Annual Meeting of the Highway Research Board, Dr. Hatt states: "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 "

Likewise producing only initial compression in the concrete does not explain the very appreciable benefit furnished by the reinforcement to the slabs laid on the wet subgrade In this case, it will be noted, a slab 6 inches thick and reinforced with a very light mesh, furnished resistance equal to that of a non-reinforced slab of similar mix, about 7 inches thick

Using a simple beam for the sake of illustration we find that one 12 inches wide and 6 inches thick must possess 270 pounds per square inch in tension in order to resist bending equally with a similar beam 7 inches thick having but 200 pounds per square inch tensile resistance Thus the steel in the beam 6 inches thick would have to produce initial compression in the concrete equal to at least 70 pounds per square inch And even under extreme conditions it is difficult to see how the steel can furnish more than 40 pounds per square inch

Furthermore, expansion of the concrete in amount sufficient to fully distend the very light weight fabric would of necessity cause greater initial compression in slabs reinforced with heavier meshes That this did not occur is disclosed by the fact that the resistance of the slabs to impacts did not increase consistently with increase in weight of reinforcement Therefore distension or compression in the concrete without change in its character does not furnish a satisfactory explanation

There are two effects of the reinforcement that may possibly cause a change in the character of the concrete, to account for the differences in behavior between plain and reinforced slabs, noted in the Arlington tests

1 If reinforcement restrains the concrete (subjected to moisture) from expanding during the setting period, the concrete must of necessity set under pressure and consequently become stronger than if no pressure existed

2 Reinforcement may prevent deterioration in concrete by eliminating some of the detrimental fissures and other openings through which water may enter the concrete

According to the Concrete Primer prepared by Professor McMillan "The greatest deterioration in exposed concrete comes from the penetration of moisture to the interior of the mass Disintegration can be both chemical and physical, chemically, the action proceeds by the dissolving out of essential ingredients of the hardened cement paste, physically, by the action of frost on the entrained water or through the deposition near the surface of dissolved salts as the water is brought to the surface and evaporated "

Also according to Professor Stephen Taber, porous material such as pottery, brick, cement, etc , even when saturated may resist repeated freezing and thawing without suffering distress When, however, these materials contain fine cracks or similar openings they are apt to disintegrate when repeatedly frozen and thawed

Therefore, when concrete slabs contain fine cracks or fissures which permit water to enter the slab by capillarity and to either evaporate from its top (concrete pavements) or to remain in and saturate the concrete (bases covered with impervious tops) disintegration due entirely to chemical changes can be expected to occur at a rate dependent upon the amount of water furnished by the subgrade, the character and number of fissures in the concrete and possibly other factors now unknown

It is possible also that the water furnished by some subgrades may contain in solution chemicals capable of causing greater detriment to the concrete than water furnished by other subgrades Alkali soils, for instance, furnish moisture which is extremely detrimental to concrete

Finally the presence of frost action serves to accelerate the rate of disintegration produced only by chemical agencies

Therefore if the presence of reinforcing steel tends to eliminate cracks and fissures or to reduce them to such size that the amount of water entering the concrete is much less than in plain concrete, the disintegration of the concrete must be greatly reduced The writer's observations on the Arlington Tests, the Virginia Demonstration Road, a highway near Pensacola, Florida, Wood Street, West Union, West Virginia, the road between Washington D C and Alexandria and others, furnishes corroborative evidence that such is the case

More thorough investigation of the factors affecting strength and durability of concrete discussed by Professor McMillan and the writer should be well worth while

METHODS FOR CONSTRUCTING SMOOTH RIDING BITUMINOUS SURFACES

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Principal among the requirements for safe and easy operation of automobiles and trucks is a riding surface of regular contour To obtain and retain a regular contour the surfacing must be built regular at the time of construction on a base which is free from irregularities All base materials are not suitable for bituminous surfaces, and the selec-