penditures in such areas. If the public demands by-passes around our cities, let us begin now to plan them.

The supervision of any work requires a knowledge thereof and the ability to discharge the responsibilities thus incurred. This applies to municipal units of government as well as to individuals.

SOME KNOWNS AND UNKNOWNS IN BITUMINOUS ROAD WORK

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The path of human progress is marked with many fairly successful attempts at building without much knowledge of the materials used therein. Such is the case of bituminous mixes used in road work. The practical use of these mixtures has preceded our fundamental information concerning their constituents. We have thus developed the art rather than the science of bituminous construction. Perhaps this is fortunate, so long as everything goes well. When troubles arise, however, we find ourselves poorly equipped with fundamental knowledge to get us out of difficulty.

The net result of having let our individual practices so far outrun our ability to generalize has led to this extremity —the U. S. Bureau of Roads has on file over 250 patented or proprietary bituminous mixes or processes for road building *beside* those designed by highway groups everywhere trying to dodge some of these patents. And in spite of this multiplicity, or perhaps because of it, we usually get only a startled look in response to our request for a *rational design of a bituminous mix* that will give a certain kind of road surface of *known behavior.*

BASES

Until quite recently we had developed very little conscience as to the bases which are to support our bituminous surfaces. Any old base or none has too generally been the rule. Yet it takes but casual observation to satisfy oneself that the surface course does not carry the load of traffic, but merely distributes it to the base, protecting that base from the weather while it offers a smoothing course to traffic. Poor bases have been a prolific cause for distress in bituminous pavements as in all others as well.

NOMENCLATURE

We have "muffed" some of the simplest phases of this field. Take for example our most common terms and phrases.

Maybe there is nothing in a name, but it usually breeds disrespect for the knowledge of the artisan if he disagrees too strongly with our friend Webster in the meaning of trade words or their pronounciation. My earliest recollection associated asphalt with *ashes* because the name was too commonly pronounced *ash phalt* and you even hear it today. B-i-t-u-m-e-n also has been given queer sounds, but Webster seems satisfied with bitū'men as first choice and bit'umen as second.

Of more serious consequence is the misuse or misinterpretation of the word "stability" as applied to bituminous mixes. Stability is primarily a *state* rather than a property of matter. Thus, these fixed objects, walls, chairs, desks, etc., are *stable* while the air between them is instable. That is, these materials either *are* or *are not*, stable. If they retain their shapes like solids, without being contained, they are stable. If, however, now we wish to know what loads they will withstand before deformation begins, we are measuring the *structural strength* of the mass. I believe this concept is decidedly helpful in understanding what factors contribute strength to the structure we are trying to build in mixtures of aggregate and bituminous cements.

DEFICIENCIES IN MIXTURE TESTS

It is not a little disturbing to our sense of complacency and well-being to be told that our present standard tests on the bituminous cements, the aggregates, and their combination, are of little help in properly evaluating them for use in paving construction or maintenance. A quick review of them will, however, indicate their deficiencies. Some suggestions of needed tests will be given thereafter.

Recognized Tests for Quality and Identification of Asphalts and Tars

Bitumen content (Sol. in CS_2)
Asphalatene content (Sol. in petrol naphtha)
Carbenes Content (Sol. in CCl_4)
Specific viscosity (Engler, Saybolt, Furol)
Penetration
Loss on heating
Flash and fire
Ductility
Residue at specified penetration
Specific gravity
Distillation
Water
Float test
Softening point

Tests on Aggregates Alone

Abrasion
Hardness
Toughness
Specific gravity
Absorption
Soundness—(which shouldn't be needed if our aggregates were really coated)
Stone coating test (emulsion)
Chemical analysis

Tests for Bituminous Mixes

Hubbard-Field stability
Skidmore shear
Density
Extraction for bitumen content
Occasional tests
Adhesion tension
Impact resistance
Wash test

Tests on Aggregates Included in Bituminous Mixes

None
but grading on the extracted materials

Thus we have no accepted method of predetermining or measuring the—

1. Degradation of the aggregates of a bituminous mix
2. Resistance to stripping or peeling in water or under traffic
3. Surface roughness or texture of the aggregate particles
4. Effect of their shapes, in spite of the fact that the general trend is rapidly toward specifying 100% crushed aggregate for bituminous mixes
5. Surface roughness or texture of the aggregate—bituminous mixes
6. Behavior under compaction, or the crushing and grinding effect of rolling or tamping
7. Actual optimum bitumen content of mixes
8. Characterization of the bituminous cement as to the history of its manufacture
9. Its change or rate of change when spread in films on aggregate surfaces
10. Resistance to salt solutions in stabilized bases or soil waters
11. Workability of mixes (I mean here *ability to be worked,* not that misnomer which dominates our parlance in portland cement concrete. Imagine carefully designing a mix to get it "workable" and then not working it!)
12. Picking out of aggregate particles by high-speed traffic
13. Skidivity, or skid resistance of finished mix
14. Degree of failure, relative or absolute, of any given surface
15. *Standard test* for the most important thing, namely, the structural strength or resistance to deformation under *moving wheel loads*

In attempting to present the "known and unknown" facts in the bituminous field, it would obviously be a vain effort even to list them all. Professor Petty has been very wise in his statement of my subject by making it *"Some Knowns and Unknowns."* I have perhaps omitted the ones you would have chosen had you been in my place. My list includes perhaps ten known, fairly well-accepted and understood generalities which will be discussed singly and briefly. Also, about a score of still unknown relationships concerning which information would be highly desirable will be mentioned. In neither case will these items be discussed in any order of importance, but I believe they are all of sufficient merit to be worthy of our united attention.

KNOWNS

Flexibility. It is an accepted fact that road surfaces consisting of bitumen-aggregate mixtures possess more or less flexibility, depending upon certain conditions, primarily temperature and bituminous content. This is the characteristic which has given these mixtures such versatility and widespread use. Without it, the range of adaptability would be seriously reduced. But because they possess flexibility, bituminous and bitumen-aggregate mixes are found in numerous places in the building industries, through the entire gamut of highway maintenance and construction uses from patches to pavements, and into such special uses as highly successful revetment blankets to protect banks along some of our principal water courses. This flexibility permits adjustment to external stresses without fracturing, as well as autogenous healing when rupture has occurred.

Structural Strength. Although flexible in character, bituminous mixes possess structural strength, or the resistance to deformation under load. Where the density of the mixes is high, these strength values often attain startling figures. It is believed that some of our hot-mix designs yield such high supporting strengths that we may safely reduce these in order to acquire desired properties along the lines of some other characteristic. Needless to say, it is a comforting fact to highway engineers to realize that well-designed and constructed bituminous road surfaces on proper bases can support all reasonable loads.

Temperature susceptibility is a recognized property of bituminous mixes; that is, at higher temperatures they tend toward softer consistencies, while with lower temperatures they become increasingly hard; even those bituminous cements which are less affected by temperature changes are more widely desired by the engineering fraternity. It is known also that susceptibility changes with age not only as to the extremes of the temperature range, but also in the bracket of temperatures imposed. This shift is toward the lower temperatures as the age of the road surface increases.

Light and Heat Absorption. A great deal of attention used to be given to the light reflected from various pavements or the glare in full sunlight. To that end we have learned to roughen our portland cement pavements to reduce glare from sunlight and increase the light reflected back from automobile headlights. Engineers designing our bituminous roads have been relatively slow to provide us surfaces which are sufficiently reflecting to assure safety in night driving. The public has repeatedly called for a more clearly defined surface, with prominent centerline and light-colored berms, so that the black-top roads of lower reflecting power be given the required visibility. This is certainly a just demand and one which highway engineers must meet. No black-top surface should be considered complete until it includes both well marked edges and centerline. England, with its frequent days and nights of low visibility due to fog, has gone in for fancy color contrasts between pavements and berms in which orange figures prominently. We could well afford to emulate that example in the interest of safe use of our road systems.

What has been said for light applies equally to heat, since black-top surfaces have been found to have the highest pavement temperatures recorded, because of atmospheric conditions. This in turn has a bearing on the comfort and safety of users of such roads.

Waterproofing and preservation of materials by thin bituminous coatings have been recognized from the days of early recorded history. Those of you who have seen the remarkable state of preservation of prehistoric animals, such as saber-toothed tigers, who wandered into asphaltic pools ages ago, must have been impressed with the protective effect of such material. In addition to mere waterproofing there is a defense against bacterial and fungus action which, coupled with the maintaining of a reducing condition, does wonders to combat the usual forces of decay and oxidation.

These facts, however, cannot be construed to mean that any aggregate of unsound behavior toward weathering can be used with impunity in all bituminous mixtures. Mr. Arthur R. Smith, Engineer of Tests, of the Indiana State Highway Commission, gave me some instances several years ago in which apparently well-coated, unsound aggregates showed almost as low resistance to the accelerated sodium sulfate soundness tests as the same aggregates without coating. Without having full particulars in this case, however, I am inclined to reason that perfect coating was not obtained or that during the test the drying cycle of four hours at about 220° F. was sufficient to produce exposure of some part of the aggregate pieces to permit the entrance of the disrupting solution at later immersion periods. Furthermore, the combination of these aggregates and bituminous cements may have yielded hydrophilic mixtures which permitted selective absorption of the water solution at the expense of the bituminous bond.

Discussion of this exception to the general concept of protection of mineral services by bituminous materials seems justifiable since it makes clear the fact that complete waterproofing is gained only when the entire coating of particles is accomplished and these particles have affinity for the bitumen.

Movement of Bituminous Masses. Most of you have made observations of the movement in bituminous wearing surfaces and binder courses under the compacting and displacing action of moving wheel loads. Sometimes herringbone pull cracks are visible in the traffic lanes; occasionally it can be seen that the surface has crept appreciably along its base.

Another evidence of movement is the decreasing thickness and increasing density of courses under traffic. Often an accompanying phenomenon of this compaction is an increase in the apparent richness of the mix; and even bleeding may result under some conditions.

The movement of the bituminous masses means movement of their constituents. This permits an interesting meditation as to the application of a concept from physical chemistry, namely, that of entropy. It has been demonstrated that the condition of "rundownness," or degradation of the physical and chemical world is continually increasing. This applies to materials as well as energies. It is only to be expected, then, that changes in the size and gradation of mineral aggregates imbedded in bituminous films will occur under the conditions of laying and subsequent traffic loads. As an example of the extent to which this degradation occurs, I am quoting from tests made by Mr. Lenfesty on samples of surface treatments taken by Mr. Shelburne from representative sections of work done in the late September and early October of 1936 on Indiana state roads. A comparison of the averages of the materials (No 8F and No. 11) used and the gradings after about two months in service shows the following values:

	Original Grading	After Two Months Service
Retained on ½″	35.2%	18.5%
Retained on ⅜″...............	58.0%	43.0%
Retained on 4-mesh...........	93.6%	72.5%
Retained on 8-mesh...........	98.6%	85.5%
Retained on 100-mesh..........	......	95.5%
Retained on 200-mesh..........	......	97.0%

One of the most interesting papers on the recent New Orleans program of the Association of Asphalt Paving Technologists was presented by Macnaughton on "Physical

Changes in Aggregates in Bituminous Mixtures under Compaction." His findings on dense mixtures were in general agreement with those just cited for open-textured surface treatments.

Composition of Bituminous Cements. Quoting from Spielman and Hughes' recent book, *Asphalt Roads,* we find the following definition: "*Asphaltic Bitumen.* Natural or naturally occurring bitumen or bitumen prepared from natural hydrocarbon or from derivatives of natural hydrocarbons by distillation or oxidation or cracking. Solid or viscous, containing a low percentage of volatile products; possessing characteristic agglomerating properties, and substantially soluble in carbon disulphide."

It is by no means a simple substance, but is a highly complex system of solutions and colloidal suspensions. The usually accepted components are the asphaltenes, asphaltene resins, and oily constituents. It is becoming more widely accepted that finely dispersed graphitic carbon, quite comparable to soot, is invariably a constituent of the asphaltic bitumen. The micelles possess a kernel consisting at least in part of twelve-carbon atoms, with six carbons as a benzene ring with the other six attached in place of the usual hydrogens, as demonstrated by X-ray patterns. Bitumen with high asphaltene content is usually a satisfactory road material.

Quoting again from the same author: "*Tar.* A bituminous product, viscous or liquid, resulting from the destructive distillation of carbonaceous matter." The word "tar" must always be preceded by the name of the material from which it is produced: coal, shale, peat, vegetable matter, etc. Its mode of production should also be indicated.

Aggregate Characteristics. Experience has been rather liberal in showing that aggregate characteristics which add to the structural strength of bituminous mixes are the most desirable. The keying and interlocking of angular shapes, the roughened faces of freshly fractured particles to provide larger and better bonding surfaces, the gradations which will produce the greatest strength as aggregations of particles, all these are highly desirable properties. In addition there should be the chemical and mineralogical composition which encourages wetting by bitumen in preference to water. This applies not only to coarse aggregates, but even more to the fine aggregates and fillers which exhibit such tremendous surfaces to contact. It has been generally recognized that calcareous materials, such as limestones, dolomites, and slags, regularly produce the most consistently good results, due in part at least to their mildly alkaline reactions. Where there are notable exceptions, explanation has been found in the presence of large amounts of impurities which have effectively altered the surface features. The ability of hydrated lime to add strength to a mix has been explained by its alkaline influence.

Mix Proportions. Etc. While no attempt can be made here to summarize the facts gleaned from our acquaintance with a multiplicity of mixes, these generalizations seem sufficiently substantiated to present. Each will have to be guarded by the introductory phrase. "Other things being equal":

a. The more bitumen a mix contains, the longer will be its life

b. The more aggregate a mix contains, the greater will be its structural strength

c. The strength of a mix increases with its density

d. Increases in the percentage of fine aggregate in coarse-graded mixes add strength, density, resistance to traffic dislodgment, and general increase in durability

e. The binder course gives the strength to a two-course pavement.

It has been more or less taken as a matter of fact that a definite relation does exist between the best thickness of a course and the size of the particles contained therein to obtain strength. Evidence has been presented within recent years that the thickness could not be more than about three times the average particle diameter. The widely followed practice of laying a wearing course of 1 in. or less thickness of ½ in.-¼ in. aggregate in a 1½ in. or 2 in. binder course containing aggregate of 1 in.–½ in. or larger, is therefore utilizing the best information we have.

Skidivity or Skid Resistance. It is often a good thing to have your faults flaunted by a competitor, as this sharpens the wits tremendously. The wide publicity given the slipperiness of certain bituminous pavements has caused a rather fruitful study into the factors contributing to skidding, with the result that practically all types are now made non-skid. Bitumens high in asphaltenes are advantageous in securing this effect as well as sands of an angular shape and good resistance to abrasion. In the coarse-graded mixes the matter is relatively simple with the wide range of textures possible. The result is that most of the bituminous surface types compare very favorably with rigid pavements in the resistance they give to tire skidding.

Segregation and Variation in Density. It has been shown lately that the degree of segregation occurring in bituminous mixes is of about the same order found in other surface types. Six pavement samples, two feet in diameter and two and one-half inches deep, taken adjacent to each other and equally distant from the shoulder, ranged in compacted density from

3,250 pounds to 3,840 pounds per cubic yard. All of these specimens had received identical rolling. Therefore, the difference in weight must have been due to segregation of the materials. These are perhaps startlingly high differences, but they have been confirmed repeatedly.

In the foregoing discussion of facts, I have attempted to state frankly from a technical angle, some of the known weaknesses as well as the advantages of bituminous mixes as road building materials. Nothing has been said about their vast economies, and little about the adaptabilities to many highway maintenance and construction purposes or their likely advance into newer fields. The "knowns," in which we may place confidence, will need additional study and confirmation thoroughly to establish their values to both the art and the science of bituminous mixes.

But let us now turn for a few minutes to a very brief treatment of that imposing array of "unknowns" about which we could well afford to gain information. Some of these will include a few of the deficiencies noted previously in our stock of standard or acceptable test procedures. Their repetition will confirm the importance they hold for future work.

UNKNOWNS

1. What characteristics of surfaces and bitumens control wetting; or can we secure adhesion? Nearly ten years ago Mr. Prevost Hubbard of the Asphalt Institute mentioned this surface relationship as Unknown No. 1. It is still needing an answer. As yet we still use heating, though there may be other simple means of securing adhesion of bitumens to aggregates.

2. How shall we measure and predict the changes in bitumen characteristics with time and climatic effect? A few weatherometers have been applied to the study of these changes, but the published results to date have been limited in scope and application. The extraction methods of Dow and Absen are of help, but leave something to be desired.

3. What film thickness is best for open mixes and for closed mixes to assure durability and load-carrying capacity?

4. What is the optimum temperature of application, for the bitumen's sake as well as for convenience of application?

5. To what extent is the blending of bitumens practical?

6. What effect has water in bituminous mixes? Is some water desirable or even essential?

7. How can lower temperature susceptibility be secured?

8. We should be more familiar with the actual values of cohesion and adhesion of various types of bitumens with measured areas of mineral surfaces at several temperatures and ages; i.e., how much pull in pounds per square inch is re-

quired of a cutback after four or five days? How else can we judge a surface to be ready for surfacing except by rule of thumb or personal opinion?

9. We ought to know what happens to the cement when it is heated to application temperatures, and correct at least the change to a much lower penetration, etc.

10. Do we not need characterizing tests of bitumens over a temperature range from –20 to 140° and at consistencies for laying, in addition to the usual laboratory temperatures?

11. What methods of converting hydrophilic to hydrophobic materials are practicable?

12. How can we design gradings and bitumen content for aggregate changes in gradation and size?

13. What is the resistance to moving-wheel-loads of our mixes? What we know now is only static loading; this gives us surface resistance to "hogwallowing" under parked vehicles at the curbs, but leaves us in the dark as to what moving loads our traffic lanes will carry.

14. We need a measure of roughness or openness of texture. What is too open? Can we measure it and advise before we see a job ravel?

15. We should have an apparatus for measuring the resistance to picking out or kicking out under high-speed traffic.

16. Which kind of lime is superior as an admixture, dolomitic or high calcium, hydrated or ground?

17. What about compaction, by rolling, sheep's foot, roller corrugated, tamping, vibration, etc.

18. What about using combinations of mixed aggregate, to insure roughness and overcome hydrophilic tendencies?

19. When shall a bituminous surface or the cutback or slower curing types be opened to traffic? When is it ready for carrying moving-wheel-loads? We have no beam transverse test as in portland cement concrete, but we need something badly to measure the load-bearing ability of a bituminous road at various ages.

20. What temperature or humidity ranges shall limit our field work? Evidence points strongly to the fact that surface treatments, etc., have their "light and dark of the moon" periods, but we are merely notional in this regard.

In view of these wide gaps in our present information, it seems in order to make a plea for *accurate* recording of the observations which you men make in the field. *Recorded* observations are the basis of every science. Without that help, substantial progress in any field must seriously be handicapped.

I wish to pay tribute publicly to something new in your midst. Most of you are aware that there has been instituted in this university a Highway Research Project sponsored jointly by the Indiana State Highway Commission and Purdue University. You may not know that this is unique, but it is—this rather simple matter of combining acute highway problems with the personnel, time, and facilities of a university. Of course, the research will not be limited to bituminous problems, but some of these offer a logical point of early attack because of the obvious interest Indiana has in this road type. It seems altogether likely that many valuable facts will be established and put at your disposal by this newly-formed Highway Research Project.

Russell Conwell gave his lecture "Acre of Diamonds" to hundreds of audiences who were thrilled by having the commonplace experiences, tasks, and opportunities glorified into something more than they seemed to be. I have risked copying his purpose. Hence, if this discussion has whetted your appetites for study and scientific observations of the bituminous mixes and roads of your daily experiences, then it has been more than a pleasure to appear before you today.

COMBATING FROST AND DRAINAGE PROBLEMS

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We have two distinct road problems which are connected with frost action. One is a heaving of the road surface during the winter, and the other is the softening of the supporting soil during what is commonly referred to as the spring break-up. The winters in Minnesota are as long as, if not longer and more severe than, they are in Indiana, and as a result, the frost penetrates to a greater depth. Minnesota has one advantage, however, and that is that during the winter the temperature does not vacillate around the freezing point as it does in Indiana. The road ordinarily freezes and stays frozen until spring, when the break-up occurs. The period of soft, muddy roads is probably shorter than it is in Indiana, but more severe while it lasts.

CONDITIONS ILLUSTRATED

This paper refers to Minnesota conditions, as the speaker is not familiar with the conditions in Indiana. When the conditions are such that a heave occurs, a badly cracked pavement results. It is rough and oftentimes dangerous for winter driving. The pavement never quite gets back to its original condition when the ice thaws, and it is therefore somewhat rough at best for summer driving. The slab becomes rougher with age, and eventually will crack into many small pieces, so that replacement is necessary.