Coordination of Concrete Paving Operations By a Trial Area Specification

P. SMITH, *Senior Materials Engineer (Concrete),*
Materials and Research Section, Ontario Department of Highways, Toronto

This paper introduces the idea of regarding the start of laying concrete pavement on a new contract as a trial during which the contractor's organization, crew and equipment must be brought into working coordination with the design concrete mix so as to achieve the specified concrete and riding quality for the pavement. A systematic method is described which should ensure that the paving operation as a whole reaches its final and most satisfactory form as quickly as possible. A specification for this, as used with great success in Ontario, calls for a trial pavement area 1,000 ft long to be laid ahead of the main paving. This trial area affords an opportunity for any necessary changes in the organization of the job, for any adjustments to the equipment or alterations in the design mix proportions to suit working conditions, and for the training of inexperienced men.

To check the quality of the pavement as quickly as possible, accelerated tests are under development to establish the strength and compaction of the concrete within a few hours. In addition, the riding quality of the pavement is measured. If the results of these tests are satisfactory and the trial area was successful, the contractor is allowed to proceed and the trial area becomes part of the pavement. If not, the contractor is held until necessary corrections are made; any slabs in the trial area not meeting the specification are removed and replaced at the contractor's expense. The background, contractual and practical advantages, together with the results achieved by such a trial area specification, are discussed.

• THE HIGHWAY engineer engaged in concrete paving is in many ways a fortunate man who should be able to derive a lot of satisfaction from his part in an operation which can produce many miles of high quality, durable and good riding pavement each year. When running smoothly, these operations appear to the passing motorist to be both impressive and easy. Nevertheless, this ease is only achieved as a result of much hard work by the many people engaged in the planning, design and construction of the road. Of all the work which goes into building a concrete highway, it is the common experience of the highway engineer that the first few days of actual construction on a new contract often seem to be the hardest and most difficult. Indeed, on occasions things become so difficult that he may begin to doubt his fortune; he may even begin to wish he were elsewhere.

If things are to go wrong they will surely do so at the beginning: the contractor may be green, the inspectors inexperienced, the equipment new and unfamiliar, and the concrete mix untried. Even when an experienced contractor starts up there may be unexpected troubles: a new concrete mix is in use, equipment which has been standing over the winter may need repair or adjustment. Often only one factor in the organization of the job—the equipment, the men, or the quality of concrete—needs to be wrong for it to have a considerable, and often magnified, effect on many other parts of the operation in turn. This is even more apparent with an inexperienced contractor. Given a green crew with new equipment (especially if the supervision is also inexperienced or disorganized), a whole set of interrelated things can go awry. The job as a whole becomes disjointed, one correction at a time must be made, and each correction naturally leads to another so that by a series of fits and starts, trials and errors, things are got underway.

Unfortunately, some jobs tend to remain in this trial and error stage throughout; others, however, shake down rapidly. What is it that decides which it is to be—a smooth, easy job or a rough tough one? The answer to this question should provide the answer to an even more important one. Is it going to be a good riding, high quality pavement or not?

The answer is compounded from many things. The construction experience and skill of the contractor and his men is one factor. The supervisory ability and knowledge of the engineers and inspectors representing the highway authority is another. The use of first-rate materials suitably proportioned to make a workable concrete of the specified quality, is a third. The proper handling of this concrete by the right equipment which is in good order and correct adjustment is a fourth. There are others, but the deciding one may well be that each person, each part of the operation and each thing has to work in unison with the others. By some means, each of the items that go into making the pavement must in themselves be as perfect as those on the job can make them through the exercise of their pride and skill, and each must be coordinated with the other.

The manner in which this will be done is dictated by the specification which governs construction and sets the atmosphere for the job. Often, this specification reads as though it had been written 50 years ago, in phrases of foreclosing doom for the "thou shalt not" school of specification writers, by their lawyers. The approach is negative; what is wrong is forbidden, what is right is never mentioned. Now, since at different times in many different places concrete paving contracts have had a troubled life, especially at the start, it might well be asked if there is not a more constructive and positive attitude which, if taken by the highway authority, would lead to better results.

Maybe the time is ripe for a new approach; ripe for a new school of specification writers and engineers to be founded. Perhaps it might be called the "togetherness" school, whose objective would be to produce a specification that not only would convince both the contractor and the highway authority's supervisory staff of the need for the highest quality in concrete pavement, but which also would offer them an up-to-date, realistic and practical chance to achieve this together. At the same time, the "togetherness" school might well dedicate itself to the proposition that within the limits imposed by the fact that circumstances must be similar, specifications also should be similar. This would be a great boon to a contractor who may work on federal, provincial (state), or municipal jobs, and who often finds that minor differences in their specifications or in local interpretation cause major construction difficulties, which are often solely due to his men having become used to performing a particular operation in a certain way, or are due to a particular piece of equipment being acceptable to one authority but not to another. In this respect, before new specifications are promulgated the highway authority and the local contractors' organization should talk them over together. Each should be prepared to carefully consider and offer constructive criticism of the other's viewpoint.

Many highway engineers have thought and talked about what is needed in design, specifications and practice, to produce a concrete pavement of the quality, durability, riding quality and safety which the traveling public has a right to expect. A few have described new ways of doing things, but often the incentive for any real change has been lacking. In Ontario all the difficulties described had been experienced, plus some special ones of the area. A few years ago there was a realization that unless the standard of concrete pavement design and construction was vastly improved, concrete would fall completely out of favor. This realization was the incentive needed to institute a review of the whole question of concrete pavement, and to produce an answer which, although not wholly new, is to some extent novel, and which gave the "new approach" considered to be necessary.

Concrete paving in Ontario is an old art; pavements laid in the 1920's and 1930's are still giving excellent service, although often they have been resurfaced as part of realignment or improvement schemes. However, the war years were followed by a severe cement shortage and little concrete paving was laid. When concrete paving restarted in earnest in 1955, there was thus a dearth of up-to-date experience amongst both contractors and highway department personnel. The results were open to improvement; something had to be done.

Over the last three years, concrete pavement has, however, regained a widely accepted place in highway construction due to five major things, as follows:

1. The redesign of pavements from unreinforced concrete slabs 20 ft long to a reinforced pavement with load transfer devices at each 70 ft joint spacing.
2. The experience gained by the contractors and the introduction, encouraged by the Department, of new techniques and equipment, in particular the use of long wheel based final finishing machines with screeds which operate to a large measure independently of the form grade.
3. The maintenance of equipment and concrete mix in adjustment and balance within a properly organized operation.
4. The use of a firm yet realistic, up-to-date, and somewhat novel specification which while including the conventional methods, allows for reasonable alternatives provided the same high standard of the end product in concrete quality and ride is achieved. This is a great boon to initiative and incentive.
5. The enlightenment of Department supervisory staff so that by now they have a good knowledge of what is needed to make a good concrete pavement. When armed with suitable control tests for the quality of the concrete and the ride of the pavement, and fortified by their technical competence, they are prepared to fully enforce the specification.

This paper is concerned with the methods which have been developed to correlate the last four items, in particular by means of a trial area, so that a systematic approach is induced both in the mind and in actual practice towards solving the problems attendant in producing high quality concrete paving.

The trial area is the focal point around which the other ideas revolve. There is always a danger of things in specifications remaining unread and empty words unless substance can be given to them. The laying of a trial area 1,000 ft long ahead of the main paving gives meaning to the words and develops the correct approach, attitude, equipment and technique; it also allows for adjustment of equipment and concrete mix as needed before much real harm is done.

BACKGROUND FOR TRIAL AREA SPECIFICATIONS

The idea of a trial area is not new: engineers have called in the past for trial slabs to be laid ahead of the main paving. This has in particular been popular in England. Kidd (*1*) reported on the Oxton By-Pass extension, as follows:

Trial Slab

Eighteen days before work started on the concrete carriageway proper, a length of about 200 ft was laid to try out the plant and methods to be used. It was finished 3 in. below running level and will be surfaced with a bituminous carpet to match the existing flexible pavement at the south end of the scheme. Cores were cut to determine the degree of compaction obtained and the location and degree of bond of the reinforcement. The trial resulted in the introduction of several improvements and familiarized the contractor's staff with the relatively novel constructional techniques being used.

Both the Ministry of Transport "Specification for Road and Bridge Works" (2nd Edition 1957), which governs most road work in England, and the Air Ministry Directorate General of Works "General Specification No. 201, Paved Areas for Aircraft — Concrete" (March 1958), which covers most airfield work, call for possible trial slabs.

Quoting the former:

Trial Mixes and Trial Slabs

1025. The Contractor shall make trial mixes using the aggregates proposed for the work to ensure that the concrete is sufficiently workable and that segregation of the mix during transportation and placing does not occur. The composition of the trial mixes shall comply with the requirements of the specification in all respects.

Where included in the Bill of Quantities the Contractor shall construct a trial slab of the same thickness as that to be laid in the works, to the full width of the finishing machine, and at least one slab long. The slab shall be constructed with the approved mix to be used in the works, and in a position as shown on the Drawings or directed by the Engineer. Construction of the trial slab shall be commenced sufficiently in advance of the main construction to enable cores to be cut from the trial slab. Six cores shall be cut therefrom and shall be tested at 7 days, to ensure that the mix as designed and the equipment proposed to be used are both suitable to achieve a fully compacted concrete.

Quoting the latter:

Trial Bays

805. The first bays of the approved concrete mix which are laid by each spreading and compacting unit, whether self-propelled or hand manipulated, are to be regarded as the trial bays, and are to include jointing (see clause 609).

At least four cores are to be cut in order to prove the degree of compaction.

These cores are to be cut when the concrete is not less than 7 days old during the months of April to October inclusive, and not less than 14 days old during the months of November to March inclusive.

Should any of the cores show honeycombing in the concrete, the trial bays are to be cut out and further use of the spreading and compacting unit will not be permitted until further trials have shown that modifications can be made which will result in sufficient compaction being obtained.

What in effect is being called for in England is a very limited trial largely designed to check the efficiency of compaction units on the type of dry mix which until recently was almost universally used.

If trial slabs are confined to a small area (often they have been surreptitiously laid on a piece of waste ground behind the batch plant), they have little value other than as a nuisance because little is learned from them other than that the concrete can be got out of the mixer and will compact. The larger problems of organization, equipment operation, skill of the crew, and properties of the concrete are still put off until that fatal first day of full-scale paving.

To help overcome the inexperience, it was thought that a trial area might be an answer, if it were extended from simply dealing with concrete mix and compaction problems to encompass a full-scale run of the operation as a whole. This would give a chance to set right any starting difficulties such as had been experienced. One thousand lineal feet was selected as the minimum length of pavement that would provide a real trial (anything shorter and the trial would be over before it really began) to demonstrate the mettle of the contractor to produce a concrete pavement of the required quality.

REQUIRED QUALITY OF PAVEMENT

Inasmuch as getting the desired end result is the reason for having a specification, it is first best to state what it was hoped to achieve above and beyond a mere piece of pavement constructed to the details, lines, grades and cross-sections shown on the plans.

Concrete Quality

The specification requirements for concrete quality may be summarized as follows:

(a) *Cement Factor* shall be between 481 lb and 612 lb per cu yd. Cement is supplied by the Department.

(b) *Flexural Strength* shall be at least 550 psi at 10 days.

(c) *Compressive Strength* shall be at least (that is, at least 95 percent of the specimens tested shall reach) 3,500 psi at 28 days.

(d) *Admixtures and Air Entrainment.* The air content specified is between 4 and 6 percent (1½ in. nominal maximum size of coarse aggregate is used). This may be achieved with either interground cement or an approved air-entraining agent, supplied by the Department. Water-reducing retarding admixtures have been tried on an experimental basis, with such particular objects in mind as improving the finishing characteristics in hot weather, but are not yet in general use.

(e) *Consistency.* When the mix is designed in the laboratory it is proportioned to give concrete of the required properties, placing and finishing characteristics. This mix, which is known as the designated mix, may however be subject to adjustment during the construction of the trial area specified in order to suit it to the equipment in use.

Thereafter, in practice, the water content is to be kept by the contractor to the minimum thus established to yield concrete of adequate workability and finishing characteristics considered necessary by the engineer, taking into account ambient conditions, pavement grades, crossfalls, etc. The slump test made in accordance with ASTM C143-58 shall be used as a guide to workability and to control the consistency of the concrete, especially from batch to batch. The engineer will determine the specific slump required in light of the above considerations and the fact that maximum slump shall not exceed 2½ in.

(f) *Aggregates* are supplied by the contractor and are covered by a typical specification as to quality and grading (except as noted later when the concrete mix design is discussed). Normal maximum size is 1½ in.

Surface Defects, Accuracy, and Riding Quality

The specifications covering surface defects, accuracy, and riding quality are as follows:

The intent of this specification is that the Contractor shall produce a pavement which not only meets the specified concrete quality requirements, but also gives the best possible riding surface. The Contractor shall, within the scope and limitations of the specification, select equipment, method of use and workmanship with this end in view.

The finished surface level of the pavement is to conform to the levels, grades and contours indicated on the plans.

The surface is to be free from open texturing, plucked aggregate and local projections.

Except across the crown or drainage gutters, the surface is to be such that when tested with a 10-foot long straight edge placed anywhere in any direction on the surface there shall not be a gap greater than ⅛ in. between the bottom of the straight edge and the surface of the pavement anywhere below the straight edge.

No variation will be permitted across anv joint in the pavement.

The surface shall be checked, as described above, immediately after the final working with the scraping straight edge and before burlap dragging.

The surface shall again be checked at the end of the curing period in the same manner and to the same tolerance.

Areas that do not meet the required surface accuracy shall be clearly marked out and the Contractor shall, at his own expense, as required by the Engineer:

(i) Grind down any areas higher than ⅛ in. but not higher than ⅜ in. above the correct surface.

(ii) Correct any areas lower than ⅛ in. but not lower than ⅜ in. below the correct surface, by grinding down the adjacent high areas.

(iii) When the deviation exceeds ⅜ in. from the correct surface, the pavement slab shall be broken out and replaced for a length, width and depth which will allow the formation of a new slab of the required quality in no way inferior to the adjacent undisturbed slab.

The grinding shall be carried out by an approved machine of a type and capacity suitable for the total area of grinding involved until the surface meets the specified requirements.

If the surface or slab edge is damaged in any way by construction traffic or construction machines or operations, or if the pavement shows signs of distress or scaling prior to the final acceptance of the pavement, it shall be cut out and replaced by the Contractor at his own expense.

Clauses are also included to cover protection against rain damage and detailed instructions for the repair of such damage if it occurs.

It may be of interest to recall that when the requirements for surface accuracy were being drawn up, the following was drafted:

At the completion of the concreting operations and after joint sealing, the overall riding quality of the pavement shall be determined by D.H.O. Materials and Research Section using a roughometer equivalent to that developed by the U. S. Bureau of Public Roads. The integrated roughness index for each ¼-mile section of each lane shall not exceed 100 in. per mile. Where it lies between 100 and 125 in. per mile, 2 percent shall be deducted from the unit price for that area of pavement. Between 125 and 150 in. per mile, the deduction shall be 5 percent, and above 150 in. per mile the Contractor shall cut out and renew the area in question at his expense. Correspondingly, if the Contractor achieves a roughness between 75 and 100 in. per mile the Department will pay a bonus of 2 percent; between 50 and 75 in. per mile, the bonus shall be 5 percent, and if less than 50 in. per mile, the bonus shall be 10 percent of the unit price for the concrete item considered over each ¼-mile section of each lane. Widening and acceleration and deceleration lanes are not included in this consideration.

This was done because it was realized that technically such requirements as "shall not exceed ⅛ in. in 10 ft" were not a valid measure of how the pavement would ride and a good riding quality was regarded as supremely important.

This idea had to be abandoned, however, for two reasons, the first being the need to obtain fully reproduceable results with the roughometer, and the second being a legal opinion that any such "bonus and penalty" clause could not be made to stick if it were challenged at law in Canada.

Therefore, a straight measurement was reverted to, but with the addition of a preamble about "best possible riding surface." Perhaps others might like to toy with ideas for providing the contractor with a reward, and thus an incentive to provide a good ride. Currently the contractor is simply shown a copy of the roughness profile for his job so he can compare it with others, the Department indicating where improvements are needed and why.

The meat of the matter as it concerns the actual construction operation is in the preamble (the first specification paragraph) under "Surface Defects, Accuracy and Riding Quality." To this end, the following is provided for.

CONSTRUCTION AND EQUIPMENT

For construction methods and equipment there are two alternatives, as follows:

1. A conventional specification.
2. A specification of alternative methods and equipment.

One of the objects of a specification is to give that information which cannot readily be shown pictorially on the drawings which the contractor reasonably needs in order to produce the desired result. A specification usually is either a prescriptive specification that gives a play-by-play description of the materials to be used and the manner of using them, which if followed to the letter, should give the required result, or it is an end-product specification which while describing what the job is to be like when finished, leaves the method by which it is to be achieved to the imagination of the contractor. Both have their merit. It seems safe to assume that the State Highway Department of Utopia, when formed, will use an end-product specification. At present, however, it is usually felt that to keep the contractor on the right road, the highway authority must specify, at least in part, the means to the end. This is, in a way, probably most vital when it comes to inspection of construction practice. If an inspector, upon seeing something he knows to be wrong, has not a specification clause to which to refer the contractor, he has lost. It is of little use waving under the contractor's nose a copy of the *HRB Proceedings* for 1902, which condemned the practice, as the contractor will justifiably claim that *HRB Proceedings* are not (fortunately or unfortunately) part of the contract documents.

But with the rapid advances made in concrete paving technique of late, it is both punitive and stupid to deny the use of new things to the contractor if they will do the job just as well, simply because the conventional specification does not cater for them. Because it is impossible within a specification to cover all contingencies, even if an annual revision is made, the Ontario Department of Highways has specified the following:

> Should the Contractor contemplate using any method of construction not directly as specified by this Section, he shall outline the equipment and method of working in writing to the Chief Engineer and produce satisfactory evidence that the concrete pavement or base will meet the requirements in spirit and intent of this specification. This shall be done at least two weeks before tenders are closed and the acceptance or otherwise shall be advised to the Bidder at least one week before the tenders close. The use of ready-mixed concrete will not be acceptable for the construction of concrete pavement but is generally acceptable in concrete base construction.

The reasons for the exclusion of ready-mixed concrete are as follows:

1. Experience in concrete base and large structures has indicated that to give the same consistent quality of concrete as can be obtained by a first-rate site batching and mixing

arrangement, a ready-mix plant would require to be close to the work and have automatic batching and moisture control with premixing.

2. Extensive tests in conjunction with a manufacturer of ready-mix trucks have failed as yet to produce a truck capable of rapidly discharging low-slump concrete with satisfactory uniformity throughout the batch.

3. Control of concrete quality is laregly off-site, which coupled with breakdown in delivery schedules, has a detrimental effect on the quality of the whole job. Further, it would be necessary to restrict the ready-mix plant just to producing concrete for the one paving job to the exclusion of its normal business if it did not have separate aggregate bins, cement silos, etc.

This is not, however, to say that these infirmities will always prevail in Ontario and when developments in the ready-mix industry warrant a reconsideration this should be given.

The consideration of alternatives is also included in the section of the specification covering equipment, as well as in that dealing with construction under the same terms for approval.

PREPARATORY WORK

The contractor, having now successfully bid and taken up his contract either to construct the pavement conventionally or with alternatives accepted by the Department, proceeds with the preliminary work of establishing himself on site, setting up his concrete batching and other equipment, and getting a sufficient area of granular subgrade ready to allow him to lay forms and start paving.

This preparatory period usually takes at least a month and during this time the selection of aggregates, the design of the mix, the checking of equipment, and the establishment of a working relationship between contractor and Department takes place.

Materials and Concrete Mix Design

As soon as possible, the contractor must select sources of the coarse and fine aggregates. Preliminary samples are then taken and tested as to quality by the Materials and Research Section of the Department, which accepts or rejects them. As soon as material is found which is qualitatively acceptable, the contractor must process aggregates to grading. The processed graded material is then sampled and concrete mix designs are made in the laboratory.

To stress the importance attached to the selection of the mix, the following is specified:

> The concrete mix and proportions to be used will be designated by the Materials and Research Section, D.H.O., who will design the mix to be used, based on samples of the approved aggregates, to meet the requirements outlined in this section; trial mixes will be made in the laboratory. When a satisfactory mix is achieved and before the commencement of the main concreting operations, the Contractor shall be required to run this mix through as a full-scale trial mix to establish adjustments to water content, air content, etc., dictated by the type and size of mixer in use.
>
> If the Materials and Research Section is unable to obtain a satisfactory design mix, which meets the requirements of this Section, from the aggregates the Contractor proposes to use, this shall be cause for rejection of the aggregates even though the quality requirements are met.
>
> To this end, the Contractor shall cause to be available, processed material of each aggregate to the required gradings for sampling at the earliest possible time since quality testing and mix design will require a minimum of three weeks before a final decision on the suitability of the materials can be given.

(The paragraph allowing rejection of materials which will not give a satisfactory mix was included after experiences with certain aggregates, which despite meeting the normal quality requirements were weak and broke through the stone at less than the design compressive or flexural strength.)

The Goldbeck (*2*) method of mix design is used. The two sizes of coarse aggregate used are combined in the proportions which give the maximum unit weight within the limits of a grading curve. These proportions are used in each of a number of trial mixes made with various cement factors. The most economical mix yielding the specified concrete quality is adopted. Additional mixes are then made to establish the strength characteristics at early ages by accelerated curing.

The full data on the quality tests of the aggregates, the gradings used in the mix designs, as well as the details of each mix and the results of 7-day cylinder tests, 10-day beam tests, and accelerated strength tests, are then given to the engineer who will be in charge of the concrete quality at the start of the paving. Where possible, this engineer should witness one of the final trial mixes in the laboratory.

Checking of Equipment

Although it remains the contractor's sole responsibility to provide suitable equipment in good condition and satisfactory working order, the highway engineer and his inspectors must be familiar with the equipment, its working caprices, and its adjustments. During the time prior to laying concrete they have a chance as the contractor sets up the equipment on site to familiarize themselves with any types they do not know and to check over each piece.

This time should not be spent in just standing around watching the contractor's mechanic trying to make a new screed from an old iron bed frame, but rather in examining and checking the equipment. The two greatest aids in this are a copy of the equipment manufacturer's manual for the particular machine and a nylon fishing line, which is much easier to use than the piano wire usually recommended for checking screed settings.

Harwood (*3*) has covered the adjustment and checking of equipment. At this stage all that can be done is to make certain that worn and damaged parts are replaced and that the equipment is set to suit average operating conditions. The trial area prior to the main paving is intended to allow for working adjustments.

The Department feels strongly that the supplier of any piece of equipment has a continuing responsibility throughout its operating life for it remaining in a satisfactory working condition. Further, it is felt that if major equipment difficulties arise, they are the best people to seek and provide a solution. Often the contractor's mechanics, although first-rate men at keeping things going, do not have the detailed knowledge to deal with major problems. Rather than only call on the equipment supplier when a major breakdown occurs and spare parts are needed, they should be brought in as needed to give advice on the everyday operation and use of the equipment. Such consultation is of great value to the supplier, because when he comes to design or construct a new model or to try to sell an existing type to another contractor, he will know precisely how the present equipment has performed and stood up to the job.

Inasmuch as contractors often are reluctant to bring in the outside expert or to appreciate the need for prechecking of equipment, the following is specified:

> The Contractor shall supply all equipment. Listed in this section is the minimum amount of equipment required for the placing of concrete pavement and it shall be on the site, available for inspection, testing and approval before paving operations are started. Where at any time, the Engineer is not satisfied with the condition of a particular piece of equipment, the Contractor shall upon request, immediately arrange

for a representative of the manufacturer or their agents to inspect and report to the Engineer upon the equipment and make such repairs or modifications as are necessary to bring the equipment into proper working order. All equipment, tools and machinery shall be maintained in a satisfactory working condition. Unavailability of any specified piece of equipment, its imperfect working or breakdown shall be sufficient cause for the Engineer to instruct the suspension of the affected operations until the equipment is available or is working properly.

Organization

The best equipment in the world will not put together even the best of materials to give a good pavement unless there are men who know what they are doing and there is a first-rate organization on both the contractor's and supervisor's side. So often the two sides remain poles apart waiting to catch each other out, whereas if they got together, the need to try to catch each other out would never arise.

The contractor must have at least a leavening of experienced men, especially key equipment operators. The Highway Department must have engineers and inspectors who know what they are talking about if they are to command the contractor's respect.

So as to gain the confidence of each other and avoid mistakes simply due to misunderstandings about the part each has to play, a meeting is arranged at which the contractor's superintendents and foremen are introduced to the Department's engineers and inspectors. At this meeting, the function and authority of each is explained, chains of command are established, the manner in which instructions will be given and the course of action in case of dispute are made clear, technical and working problems are discussed, and the trial area is explained. The high quality of work required is strongly emphasized and the tests and inspection that will indicate satisfaction are set forth.

By now it should become quite clear to the contractor that not only does the Department mean business when it says that a high quality pavement is going to be built on this contract, but it should also be clear to the contractor that he will have a large measure of help from the Department in achieving this.

READINESS TO START

Inspection and Full-Scale Trial Mix

Assuming that the equipment has been checked and appears to be in good order, the design mix has been made available to the site, the cement silo is full, the stockpiles are spilling over, several thousand feet of forms are set on a good grade, and the whole organization is ready and eager to go, on the day before the start the engineer and his inspectors should make a thorough check in company with the contractor's superintendent, starting at the form grader and working back to the batch plant seeking for overlooked points. For example, has the water gage on the mixer been calibrated? Is the 10-ft straight edge really straight?

At the batch plant the scales should bet set to the batch weights (corrected for moisture). Then a trial run should be made with a few batches to check the batching arrangements. These trial batches should then be put through the mixer to check on its timing cycle and mixing efficiency. A determination can be made at the same time of the water requirement and air-entraining agent requirement of a full-size mix. After mixing, the concrete can be dumped clear of the pavement or into ancillary work. A full set of quality control tests is made and if any adjustments to the design mix have been indicated they are made and a set of specimens for accelerated strength testing made so that by the start next day the engineer will have some idea of the effect of the changes.

Accelerated Testing

Strength Testing.—One of the great handicaps faced by a person called upon to adjust a concrete mix in the field is the lack of quick information as to what effect a change (for example, in sand content to deal with a finishing problem or water content dictated by the mixer) will have on the strength and other properties of the concrete. Although the basic principles are understood and the theoretical effects of such changes are known, the engineer is often left in the position of only being able to make an educated guess as to how far he can go; 7, 10, or 28 days is a long time to wait to know if he was right. Attempts have been made in the past to develop accelerated tests indicative of later concrete quality (or quality of component parts). Rapid curing by boiling or steam-curing cylinders is one method described by Patch (*4*), King (*5*), and Akroyd and Smith-Gander (*6*). Physical separation is another such method (*7*); centrifuging (*8*), a third; optical examination (*9, 10*), a fourth; ultrasonic testing (soniscope), a fifth; early flexural testing of beams (*11*), a sixth; and there are others.

The author was engaged on some of the tests reported by Stewart and Bates (*11*) and, at the time, formed the opinion that accelerated testing was an elusive subject. He has since modified his opinion provided the tests are on concrete made from one specific set of materials and trends, not specific prognostications, are sought.

Of the possible methods, that of rapid curing appears to have most promise because the required equipment can readily be set up in a field laboratory. The other tests are either indirect in the results they provide or require equipment and skills not usually available on a paving contract.

For rapid curing, a set of cylinders is made in the usual manner and immediately taken to the field laboratory and placed in a tank of hot water when 6 hr old. The temperature of the electrically heated tank is thermostatically controlled. Laboratory experiments made to develop the technique have shown that optimum curing conditions are provided by placing the cylinders in water at a temperature of 190 F. The water temperature is then raised to the boiling point as rapidly as possible, and this temperature is maintained for the rest of the curing period.

At the end of a 17-hr curing period the cylinders are removed from the tank and tested in compression; it has been found best to try to make cylinders with true ends so as to avoid the need for capping prior to testing.

When the design mix was made in the laboratory, similar rapidly cured specimens were made and tested and their strength development recorded. Therefore, because the 7-day (and maybe 28-day) cylinder and 10-day beam strengths are available by the start of the job and the corresponding accelerated strengths are known, the engineer in the field is able to make a worthwhile comparison of the results of the mix actually in use with the design mix within 24 hr.

Concrete Compaction

Up to the present the degree of compaction achieved in the concrete has been checked by taking cores from the concrete after 24 hr, examining these visually for voids, and measuring the density. The development of such equipment as nuclear density aparatus for checking the compaction of subgrades offers promise that the same technique might be used on plastic concrete. Experiments to this end are being carried out.

Surface Accuracy and Riding Quality

The wet surface profilometer developed and used by Kirkham (*12*) in England offers a means of measuring the surface accuracy and the effect of adjustments in equipment or mix changes while the concrete is still plastic. However, after study, it has not been found necessary to introduce the use of such equipment as a standard device to check the quality of every paving job. The equipment is somewhat cumbersome and the use of the newer types of long wheel base final finishing machines appears to give a most acceptable riding quality to the pavement in most circumstances. Checking of surface accuracy while the concrete is still plastic is therefore confined to the use of a straight edge and string line. This in particular is done thoroughly at any construction or expansion joints (contraction joints are all sawn) or in areas where superelevations or steep grades introduce special problems. There is need of work to establish the best methods of concreting, as well as the cohesive qualities required in the concrete itself for use on grades over 3 percent or on superelevation. An example is shown in Figure 1.

TRIAL AREA

The time has now come to prove out the operation, the equipment, the mix, and the men, by laying a trial area 1,000 ft long. This trial area is definitely to be regarded as a trial laid ahead of the start of the main paving and will be included as part of the pavement only if satisfactory.

The specification reads as follows:

In order to prove out the Contractor's proposed method of working before the main concreting starts, the Contractor shall be required to lay at least 1,000 lineal feet of paving as a trial area. This area shall be used to bring the batching, mixing, placing, finishing and curing operations and

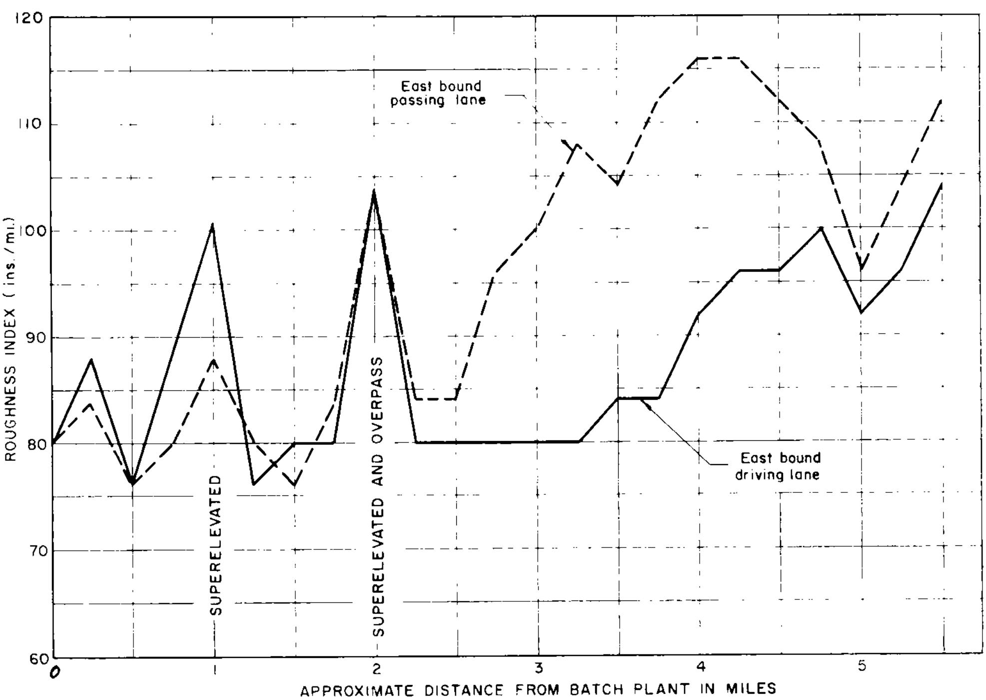

Figure 1. Effect of frequent stops and starts caused by a shortage of batch trucks on the riding quality of concrete pavement.

equipment into full and satisfactory adjustment.

Before concreting continues, adjustments in both equipment and working technique, which in the opinion of the Engineer are needed to produce a pavement of the required standards of soundness, durability, finish and riding quality, shall be made.

After 24 hours, the forms shall be removed and the edge of the slab examined for voids, honeycombing or other defects. Cores shall be taken to assess the compaction of the concrete achieved and for compression strength testing at 7 and 28 days.

The Contractor shall remove the burlap curing next day, as required by the Engineer, over any or all of the surface of the concrete laid during the first 2 days' concreting operations, in order to allow testing of the surface accuracy, and shall replace the burlap when testing is completed.

Should the trial area be defective in any respect of the specification, it shall be removed and replaced by the Contractor, at his expense, otherwise it shall remain as part of the pavement.

Function of the Coordinating Engineer

In order to get the full value from the trial area, it is necessary for the Department to have a senior engineer present who is experienced in concrete paving and who has been through all this before. He should have visited the site beforehand to be acquainted with the lay of the land and the people concerned. He should be armed with the full details and results of laboratory trial mixes and should witness the full-scale trial mixes on the day before the start. It is his job to guide and advise the Department's supervisory staff, who will remain with the job throughout, on how to achieve a good pavement. It is his job at the beginning, side by side with the contractor's superintendent, to coordinate the whole operation. It will be largely on his advice that the Department's engineer regularly in charge of the work will instigate changes or instruct the contractor on needed corrections before the work proceeds beyond the trial area.

This coordinating engineer may face many problems before the day is out. These problems will broadly resolve themselves into the following questions:

1. Is the pavement being correctly constructed to the details shown on the plans and specifications?

2. Is the laboratory design mix suited to the equipment to be used for batching and mixing (checked the previous day), placing, compacting and finishing? If not, what is to be changed, the mix or the equipment? Obviously the latter if any change, which had to be made in the mix due to inadequate or unsatisfactory equipment, would cause the concrete quality to fall below specification. Often, however, a change in mix proportions (for example, the sand content) will yield a satisfactory pavement without recourse to condemning equipment.

If the concrete is hard to finish, even the most enlightened contractor will first try to blame the mix. The unthinking cry will be raised for more sand or more water, irrespective of what is actually wrong. A wise engineer will have anticipated this by discussing the characteristics of the mix ahead of time with the contractor. In particular he should have explained any difficulties found during the laboratory or full-scale trial mixes. Most contractors are happy and satisfied that the materials meet the specification, few realize that within the specification limits there are "good" and "bad" materials. A contractor will often burden himself with a material problem that has a time consuming and costly effect on his operation. An example would be if he chose to use a very coarse sand or small stone containing lots of flat pieces (such particles will pluck out under the screeds and make a concrete that is difficult to finish).

The greatest importance must be attached to achieving uniformity in concrete from batch to batch. Is this consistently happening?

3. Is the equipment in proper working adjustment and mechanical order? Even when thoroughly checked ahead of time, certain defects only show up under use. These fall into two classes:

(a) Corrections to defective equipment that can only be made during a shutdown. If such show up, should the operation be immediately stopped and the work bulkheaded, or can the equipment continue working to the end of the trial area before it is stripped down? The decision, of course, depends on the magnitude and nature of what is wrong.
(b) Running adjustments (for example, to screed settings, which have to be made as the equipment is working).

4. Once one piece of equipment is adjusted, the next piece in turn in the train will undoubtedly need adjustment too.

5. Do the contractor's men know what they are doing? Are competent workmen being employed? Do the machine operators fully understand the workings and potentials of their equipment?

6. Is the contractor's organization organized? For example, is there always a batch truck at the mixer?

7. Are the Department's inspectors inspecting? Or are they bunched together like bananas?

8. Are quality control tests being made and is the quality of concrete and pavement, as far as can be seen, up to par?

9. What would happen if a sudden rainstorm broke? Would everyone run for cover without caring what happened to the concrete?

10. There are many others, all forming part of the question: Is it going to be a good job or not?

Laying the Trial Area

The coordinating engineer, having assured himself that all is ready and well on the grade, should go to the batch plant with the contractor's superintendent. A quick check should be made that batch weights are correct and that adjustments for moisture have been made. The first trucks are then batched, a close watch being kept for anything wrong. Unless there are serious troubles which prevent accurate batching, a note is simply made of any improvements needed and the last truck is followed out to the grade. Supervision of the batching operation is then left for the next few hours to the batch plant inspector, who will await instructions for any changes in the mix batch weights.

When reinforcing mesh is incorporated in the pavement the contractor usually elects to use two mixers and two spreaders to place the concrete in two lifts. Therefore, the operation starts by charging the first mixer. If the first batches of concrete, as usually happens, appear to be too wet, they should be dumped. As soon as a good batch appears, this is placed between the forms and at once tested for slump and air content. If these are grossly in error, an immediate adjustment should be made to the water gage or dispenser; but if they are close, the adjustment should be delayed until the effect of the placing equipment on the concrete is seen. The mixer driver and spreader operator should be shown the importance of correctly placing and running out each batch.

As the reinforcing mesh is laid, a check should be made that the correct overlap is allowed between sheets and at dowel bar assemblies and that any curled wires are tied down. It is best to lay the steel with the transverse wires down, as they dig into the concrete and avoid the sheets creeping as the top layer of concrete is spread.

A check on the depth at which the steel is laid should be made before and after the top lift of concrete is placed, and the strike-off of the first spreader should be adjusted if needed. The tendency is always for the steel to move downward during compaction and finishing, except for the occasional curled wire, which tends to break through the surface and foul a screed.

As far as possible, the engineer and the superintendent should remain close to the start of the pavement and watch each operation as it starts and each piece of equipment as it moves onto the concrete. When the top layer of concrete is ready to be placed, any mix adjustments found necessary on the first mixer should first be set on the second. Thereafter, it is as well to concentrate quality control tests on the top lift of concrete to avoid dissipating the efforts of the inspector with the air meter and slump cone. This inspector should report the result of each test as he makes it to the engineer, as well as recording it in his diary. When the second spreader moves onto the pavement, its strike-off and vibrators should be closely watched because the performance and settings of the following units are governed by how the concrete is left by the spreader. The tendency is always for the transverse finisher and final finisher to move too close to the spreader and not allow the concrete time to settle after compaction. Therefore, their stationing should be closely controlled until the operators realize they can do a better job by staying apart. Adjustments to each screed in turn will undoubtedly be needed to leave the correct amount of concrete for the next stage of the finishing operation. The operators, if green, should be encouraged to try the different combinations of screed and forward speeds which their machines permit so that they begin to understand the effects of each on the concrete. If the concrete itself appears totally unsuited to the finishing machines at each and every screed and forward speed or screed cant, changes in the mix must now be made. Such changes will most probably be to improve workability.

Although it has been shown (*12*) that every operation affects the final surface profile of the concrete and its riding quality, for all practical purposes the correct operation of a long wheel base final finishing machine on concrete of suitable consistency determines the ride of the pavement. Therefore, although other equipment should not be neglected, this should receive prime attention. If the surface of the concrete after this machine has passed shows tearing, plucked aggregate, depressions, or standing waves, it is cause for great concern and immediate adjustments to the screeds, finishing plates or mix are needed. It should not be necessary to use hand finishing other than a light lute and edging behind this machine. The need to use heavy hand floats, especially ones with short blades, indicates that changes at or ahead of the final finishing machine are needed; the use of such tools will only build bumps back into the pavement. A straight edge should be in constant use behind the finishers.

Experience shows that final finishing machines, even more so than the other laying equipment, must be operated at a steady rate without frequent stops and starts due to catching up with the machine ahead. The detrimental effect of such stops and starts is indicated in Figure 1, which shows the deterioration in riding quality with distance from the batch plant on a recent contract where the contractor used the same number of batch trucks irrespective of haul. It is such potential developments as this (or say inability to set forms fast enough to keep ahead of the concreting) for which the coordinating engineer should be looking in assessing the contractor's organization of the job.

By this stage of the trial, it is assumed that each piece of equipment and operation right through to applying the curing at the correct time, is either working, how be it a little shakily, or a major trouble has occurred which has halted the job. The coordinating engineer and the inspectors have now still 300 or 400 ft left in which to see that any needed running adjustments are made and to decide how things are shaping up.

As the 1,000-ft mark is approached, a decision must be made either to allow the contractor to proceed or to halt him while changes are made. Certainly if all is running smoothly, no point is served by stopping. But if the operation appears shaky or even one piece of equipment is not functioning properly, it is probably best to stop and take stock of the situation. All the factors must be weighed by the coordinating engineer, who then has to advise for either continuating or for stopping. The contractor's superintendent must be given a clear-cut decision.

Assuming that a halt is called, the reasons for stopping must be shown and explained; the faults found should be listed to the contractor, who is advised that a restart can only be made when all these are corrected to the satisfaction of the engineer.

If any area of pavement is so bad as to have defects in it which would definitely make it unacceptable, (for example, this has occurred due to a complete breakdown of mixer water gage on a contract where only one mixer was used, within the first 100 ft) the defective area should be removed at once while the concrete is still green. Otherwise, it should remain until cores are taken and the surface accuracy is measured next day.

If sawn contraction joints are to be cut that night, the engineer should return to witness the first cuts. It is surprising how many saws will not start or how many crooked cuts are made at night.

Critical Examination

Next morning an inspection of the pavement laid should be made. Cores should be taken, either at random or at specific locations where concrete compaction difficulties were experienced, as the engineer feels it necessary, to determine the compaction of the concrete (density, voids, honeycombing, or segregation) and the depth of concrete or steel. The use of a rolling straight edge (hi-lo indicator) or profilometer provides the needed check of the surface accuracy. Although the profilometer may be of great assistance in a detailed examination of the pavement surface to correlate the surface accuracy with adjustments made to the equipment or changes in the mix, the hi-lo indicator quickly picks up any spots outside the specified tolerances; these spots can then be checked with a straight edge and a decision given on grinding down or removal in accordance with the specification.

Assuming that all is well with the surface of the pavement, that the cores indicate satisfactory compaction, that accelerated tests on concrete representative of any mix changes show them to be satisfactory compared with the design mix, and that any alterations to the equipment have been made, the contractor is at liberty to proceed. And it is hoped that the job as a whole is better for its experience of going through a formal trial area, and what is more important, will remain better.

BENEFITS OF A TRIAL AREA SPECIFICATION

What has been achieved by a trial area and the type of specification described? Has it simply been a nuisance that impeded the contractor or has it served a useful purpose?

After operating under this specification for two or three years, the impression is that:

1. A trial area provides an unhurried, ordered start for concrete paving contracts during which equipment is adjusted, the concrete mix is set, and the organization on both sides is tested out on the one day of the job when production is not the god.

2. The specification itself, with its alternatives, is a reasonable one likely to provide a climate conducive to good work and the building of a first-rate pavement in a modern way. Yet it has teeth to it (for example, removal of grossly defective areas, grinding down of surface irregularities), which causes a poor contractor to realize that unless he does a good job there is a heavy price to pay for undertaking a venture for which he was neither experienced nor equipped, and which even causes a good contractor to treat things with greater respect.

3. When things are most likely to go wrong at the beginning, expert advice is available that has had special experience in dealing with similar problems before and can leave the job properly set up for the average project engineer and inspectors to run.

4. Contractual recognition is given, by including a trial area in the specification, of the difficulties which arise at the start of a job; delays or defects are no grounds for a claim while the coordination of mix to equipment or supervision to operation is taking place.

5. An atmosphere is created at every level between Department and contractor by taking each other into their confidence, which gives the best approach and attitude to the job, not only before the start but also throughout the life of the contract. The "teething" troubles are got over as quickly and rationally as possible in the trial area so that from thereon unnecessary quibbles, delays and defects are avoided.

6. The main quality of a pavement type by which it wins or loses the acceptance of the traveling public is that of how well it rides. Figure 2 illustrates the improvement in riding quality achieved over three construction seasons by the same contractor while laying 32 consecutive miles of 4-lane concrete pavement. In this case the mean roughness index has improved from 113 in. per mile to 64 in. per mile and the standard deviation of the roughness index has decreased from 15 in. per mile to 7.5 in. per mile. Similar improvements towards a more uniform smooth riding pavement have been general.

These benefits are surely worthwhile having.

CONCLUSION

The precepts for the successful design, specification, construction and inspection of concrete paving under modern conditions have been well-established in recent years, as follows:

Design—A.C.I. Committee 325 (1958) (*13*)

Specification—A.C.I. Committee 617 (1958) (*13*)

Construction—R. L. Peyton (1957) (*14*)

Inspection—P.C.A. (1959) (*15*)

This paper has endeavored to show a positive way in which one highway department has taken these criteria and by the use of a "trial area" specification has endeavored to give them a coordinated practical form.

Although it must be admitted that in Ontario there was the special reason of seeking for a solution to inexperience when the trial idea was originally introduced, it has been found to serve such a useful purpose that it would not now be willingly given up. That this view can also be shared by contractors may be

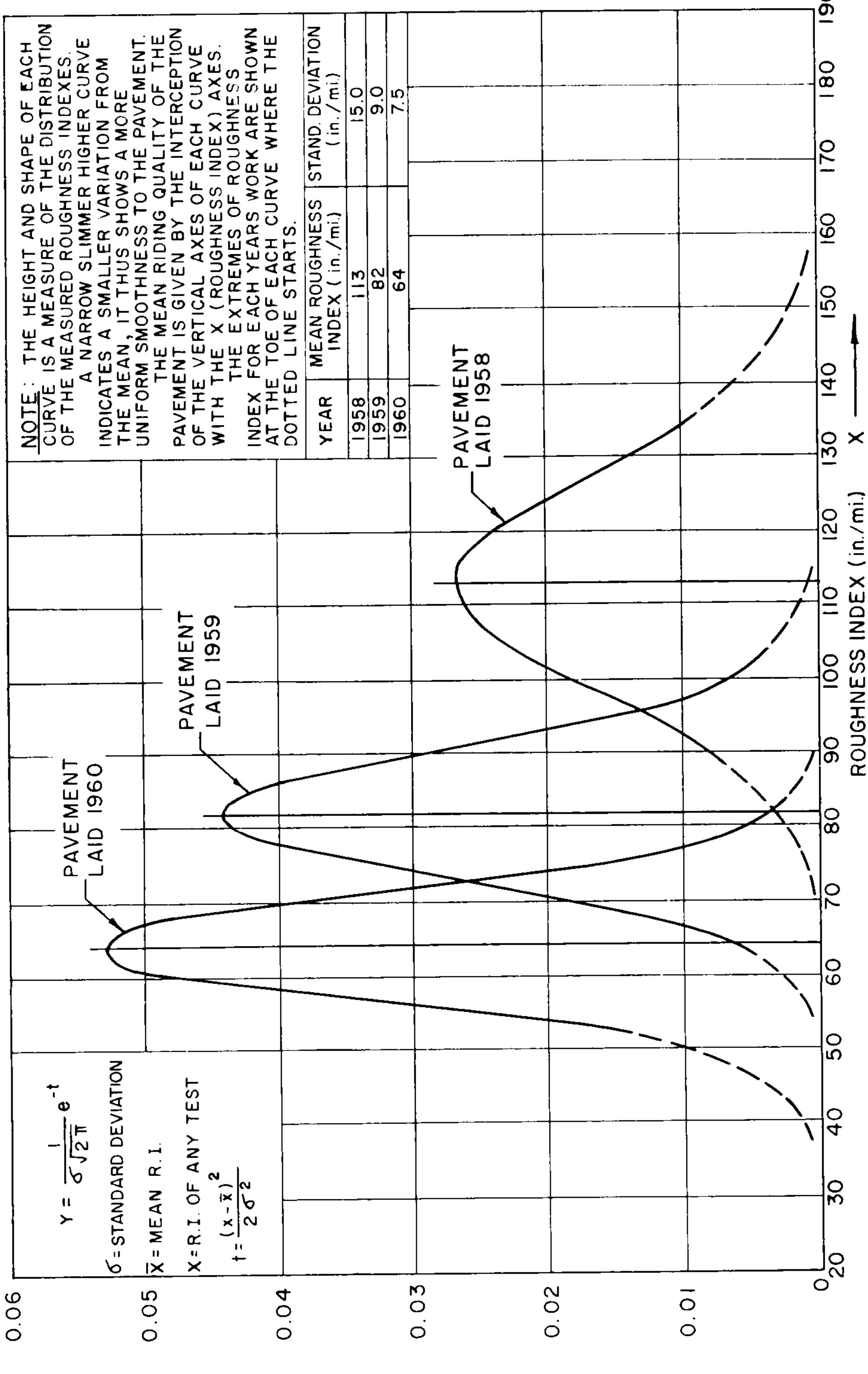

Figure 2. Probability curves showing improvement in riding quality of concrete pavement since starting to use a trial area specification Roughness measured by BPR machine immediately after construction on 32 consecutive miles of concrete pavement laid by same contractor during three summers.

shown by the fact that the author, who has to some measure been responsible for the introduction of the system described, has had the privilege and pleasure of their fullest cooperation as well as that of the Department's own supervisors, even on many a dark first day of concrete paving.

It is by no means intended to claim that the Golden Age of concrete paving is at hand, but it is thought that the matters described have brought a little closer the attainment of a high quality, durable, good riding pavement while allowing the contractor a reasonable profit.

ACKNOWLEDGMENTS

This paper is presented with the permission of the Materials and Research Section, headed by A. Rutka, Materials and Research Engineer, of the Ontario Department of Highways, of which W. A. Clarke is Chief Engineer.

REFERENCES

1. KIDD, R. A., "The Oxton By-Pass Extension." Road Paper No. 50, *Proc. Inst. Civil Eng.*, Part II, Vol. 5, No. 2 (June 1956).
2. GOLDBECK, A. T., AND GRAY, J. E., "A Method of Proportioning Concrete for Strength, Workability and Durability." National Crushed Stone Assn., Bull. No. 11, Revised 1953.
3. HARWOOD, W., "Adjustment of Concrete Paving Equipment." HRB Bull. 265 (1960).
4. PATCH, O. G., "An 8-Hour Accelerated Strength Test for Field Concrete Control." *Jour. Am. Conc. Inst.* (Mar.-Apr. 1933).
5. KING, J. W. H., "Concrete Quality Control—A Technique of Accelerated Testing Developed at Queen Mary's College for the Port of London Authority." Bull. Inst. Civil Eng. (Nov. 1955); and private communications.
6. AKROYD, T. N. W., AND SMITH-GANDER, R. G., "Accelerated Curing of Concrete Test Cubes." *Engineering* (Feb. 17, 1956).
7. DUNAGAN, W. M., "A Proposed System for the Analysis and Field Control of Fresh Concrete." Iowa State College Eng. Exper. Sta., Bull. 113 (1933).
8. HIME, W. G., AND WILLIS, R. A., "A Method for the Determination of the Cement Content of Plastic Concrete." ASTM Bull. 209 (Oct. 1955).
9. MOLIUKA, M., KELLY, J. W., AND BEST, C. H., "A Physical Method for Determining the Composition of Hardened Concrete." ASTM Spec. Tech. Publ. No. 205 (1956).
10. MIELENZ, R. C., "Discussion of Study of the Rate of Hydration of Portland Cement by Microscopical Linear Traverse Technique." Unpubl.; presented at 39th Ann. Mtg., HRB (1960).
11. BATE, E. E. H., AND STEWARD, D. A., "A Survey of Modern Concrete Technique." *Proc. Inst. Civil Eng.*, Part III, Vol. 4, No. 3 (Dec. 1955).
12. KIRKHAM, R. H. H., "Factors Affecting the Riding Quality of Machine Laid Concrete Roads." Road Paper 41, Part II, *Proc. Inst. Civil Eng.*, Vol. 2, No. 3, (Oct. 1953); and subsequent published works.
13. American Concrete Institute Standards: Standard 325, "Recommended Practice for Design of Concrete Pavements" (1958); and Standard 617, "Specifications for Concrete Pavements and Concrete Bases" (1958).
14 PEYTON, R. L., "Criteria for

Present Day Concrete Pavement Construction." HRB Bull. 162 (1957).

15. Portland Cement Assn., "Concrete Pavement Inspector's Manual." (1959).

APPENDIX

CHRONOLOGICAL SEQUENCE FOR COORDINATING CONCRETE PAVING OPERATIONS UNDER A TRIAL AREA SPECIFICATION

Contract called on prequalification-of-contractor basis, which allows 5 weeks before bids close. If C Day is taken as the date bids close:

C—35	Contractor takes out plans, specifications and tender documents, which include strip map showing locations and information on aggregate sources investigated by the Department. Chief Engineer by this date of any alternatives in equipment or construction methods he proposes to use.
C—7	Chief Engineer must accept or reject the alternatives by this day.
C Day	Bids close; tenders opened in public.
C Day to C+20	Tenders examined, successful contractor advised, contract signed. Date for start of working days established.

Contractor arrives on site and commences preparatory work. If D Day is taken as the start of laying concrete:

D—42	(Untested deposits)	) Contractor) requests) preliminary) sampling) and quality) testing of) aggregates.) These are) minimum) periods to) allow testing) and mix) design.
D—28	(Commercial aggregate sources)	

D—21	Processed quality-acceptable materials to grading must be available for concrete mix design.
D—21 to D—7	Equipment checked as it is set up on site. Form grading and setting starts.
D—11	Last day on which to make laboratory trial mixes if 10-day beam strengths are to be available by the start.
D—7 to D—1	(a) Contractor advised as to whether lab mixes appear satisfactory and given ratio of large to small stone so materials can be brought to site. (b) Equipment inspected and checked as necessary. (c) Meeting held to explain organization, specifications, trial area, etc.
D—1	Final check of grade, forms and equipment. Full-scale trial mixes run.
D Day	(a) 1,000-ft trial area laid, equipment and mix adjusted as needed, organization assessed, concrete quality control tests made. (b) At end of 1,000-ft trial run, if all is satisfactory, concreting proceeds; if not, contractor is held until corrections are made and pavement examined.
D+1	(a) Trial area inspected,

surface accuracy measured, cores taken to check compaction.	D+7	First 7-day cylinder strengths available to check on mix in use.
(b) Decision made as to whether full-scale operations can proceed.	D+10	First 10-day flexural strengths available to check on mix in use.