vibratory compaction of asphaltic concrete: a field study

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summary

In order to assess the modified vibratory bituminous rollers, the Ministry conducted a comparison study of vibratory rolling versus conventional rolling (consisting of breakdown, intermediate and finish rollers). One tandem and four single drum vibratory rollers were tested on 12 paving contracts involving pavement lifts of one to six inches.

The test results indicated that:
1/ the single drum vibratory roller alone did not produce densities equivalent to our conventional equipment procedures;
2/ the tandem vibratory roller did produce densities equivalent to these; but
3/ detractions in surface texture, ride and joint compaction were present in various degrees for both types of vibratory rolling.

Modified rolling procedures involving combinations of vibratory and conventional roller types were also evaluated. A vibratory roller combined with a pneumatic tired roller and a static steel roller produced the most successful procedure.

VIBRATORY COMPACTION
OF ASPHALTIC CONCRETE

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INTRODUCTION

During recent years vibratory compaction has proven to be an efficient means of densifying granular materials. The equipment industry, thus, has looked into the possibility of using similar vibratory equipment in the field of asphaltic concrete paving. As a result vibratory rollers for granular materials have been altered slightly and tested on asphalt.

The Ministry's study [1] of such rollers in 1970 indicated that vibratory rollers could not properly compact asphaltic concrete. Since then vibratory rollers have been modified and the industry claims that they are now equal to or better than the conventional rolling train.

In Ontario, conventional rolling involves a steel drum static breakdown roller of ten tons followed by a pneumatic tire intermediate roller of nine or 28 tons and a final steel drum finishing roller of eight tons. The compaction industry is confident that the present vibratory rollers can replace at least two or possibly all three of the above conventional rollers with an attendant reduction in asphaltic concrete placement costs. The Ministry consequently undertook a further study of these rollers during the 1972 construction season.

STUDY OUTLINE

General

The Ministry studied five vibratory rollers over the 1972 paving season. Four of these were single drum machines and the other a double drum. Comparative studies were carried out on 12 contracts involving a total of 12 different hot mix types (encompassing H.L. 1, 3, 4, 5, 6 and 8).

The basic purpose of the study was to compare the effectiveness of the vibratory rollers as lone alternatives to conventional rolling trains and also to observe any economically and qualitatively acceptable rolling systems which combine these two approaches.

Attention was focused on quality of rolling and, particularly, compaction. At each contract site visited, both the vibratory rollers under study and each contractor's conventional rolling fleet were compared in the same rolling environment. The contractor's normal procedure was used as a standard for comparison on each contract. No attempt was made to influence the contractor's procedure.

Conventional Rolling

Conventional rolling as practised in Ontario is a three-stage operation involving breakdown, intermediate and finish rolling.

The breakdown roller is usually a 10 ton tandem steel drum unit. Its main purpose is to give initial compaction to the asphaltic concrete as close behind the paver as possible. Its second major function is to form a good longitudinal joint - a procedure involving an external pinching of this joint with the roller operating primarily on the adjacent cold lane of paving.

The intermediate roller is a pneumatic tire roller and, depending on the contract's geographic location or the production rate, may be either one of two types. It may be a nine ton - nine wheel or a 28 ton - seven wheel version. The intermediate roller is generally expected to bring compaction up to the final percentage achieved.

The finish roller, usually an eight ton tandem steel drum unit, follows well behind the intermediate. It is used when the asphaltic concrete has cooled enough to resist hairchecking while yet being sufficiently malleable to take a final levelling finish. In some cases, the pneumatic tire roller leaves a generally acceptable finish and the steel finish roller is unnecessary.

The following table indicates the average number of passes made for the various thicknesses (t) of asphaltic concrete pavement laid by each of these rollers at all the contract sites visited. The term pass is defined here as one machine coverage of pavement surface past any given reference point. This is a different definition from that used in conjunction with the vibratory rollers; a vibratory roller pass is equal to one drum coverage of a given point on the pavement surface.

AVERAGE CONVENTIONAL ROLLING ENCOUNTERED

	PASSES		
ROLLER	$1'' \leq t \leq 1\frac{1}{2}''$	$1\frac{1}{2}'' < t < 3''$	$3'' \leq t \leq 6''$
BREAKDOWN 10 - ton tandem steel tired	4	4	4
INTERMEDIATE: 9 or 28 ton pneumatic tired	25 26	17 15	20 -
FINISH tandem steel tired	5	5	5

Vibratory Roller Description

Steel drums: All vibratory rollers had steel drums of seven-foot width and approximately five-foot diameter, equipped with a spray and scraper system.

Vibration: Vibration was carried out at full throttle and controlled by frequency and amplitude. Vibration of the roller drums was achieved by revolving eccentric weight around a shaft within the drums. A change in the eccentricity was used to alter the amplitude of vibration; hence, at least two amplitudes were available on most rollers. (The industry recommends revolving this eccentric shaft in a direction opposite to the direction of drum rotation.)

Frequency: Frequency, measured in vibrations per minute (v.p.m.), represents the number of distinct drum impacts in a given time period. This may vary from maximums of 1700 v.p.m. to 2500 v.p.m. depending on the particular roller.

Amplitude: Total amplitude is the nominal (peak to peak) distance or excursion of motion of the vibrating drum in a stated direction per cycle and in a freely suspended condition. Typical amplitudes involved in the study varied from 0.8 to 3.0 millimetres depending on the particular make.

Impact force: A combination of frequency, amplitude and drum weight produces the impact force. The magnitudes of these impact forces were not readily available for all frequency and amplitude combinations used. Instead frequency, amplitude and drum weight were the variables studied. Drum weights were considered to be generally equal; hence, only frequency and amplitude were tabulated.

Drive wheels: The two drive wheels on the single drum machines were smooth pneumatic flotation tires. Both pneumatic tires and the optional steel drive wheels were studied. Pickup was prevented by a diesel fuel spray and scraper system on the pneumatic tires and by a water spray and scraper system on the steel. Three water-based substitutes for diesel fuel were studied for the pneumatic systems.

The only double drum roller studied had dual drum drive fitted with the water spray and scraper system.

Mini Road Logger

The Mini Road Logger was used to determine compacted asphalt densities. The logger is an electro-nuclear device which prints out a continuous log of densities in pounds/cubic feet. Combining the length abscissa and density ordinate of the log, a length-weighted average density may be obtained for any distance logged. Such logs were run on each test section attempted and each length of contractor's rolling that was sampled. Vibratory rolling was logged on each test section between the drive wheel paths since this area received steel drum contact only. Conventional rolling was logged in the centre of a lane and in lengths deemed to be representative of the contractor's average production.

Parameters

The following parameters were obtained for each test section studied.

General:

(i) test length and location

(ii) mix type and characteristics

(iii) mat thickness

(iv) immediately underlying base type

(v) rolling temperature

(vi) rolling procedure (function of the vibratory roller in the rolling sequence)

(vii) compacted density

Vibratory Rollers:

(i) type of pass (static or vibratory)

(ii) frequency

(iii) amplitude

(iv) number of passes (where one pass equals one drum coverage of a given point on the pavement surface)

(v) travel speed

Conventional Rollers:

(i) roller types

(ii) roller weights

(iii) roller sequence in paving train

(iv) number of passes by each roller (where one pass equals one machine coverage of pavement surface with reference to any given point).

Procedure

The contractor's rolling procedure recorded on each contract included the roller weights and types, the number of passes made by each, the rolling temperature and the mat thickness.

The vibratory roller was then injected into the paving train as a replacement for the steel breakdown roller.

As paving progressed, 500-foot test sections were established, each section employing a different combination of frequency, amplitude and number of vibratory passes.

The Mini Road Logger determined the density achieved by the vibratory roller in the path receiving only vibratory drum contact. (As the vibratory drum path was slightly lower in compaction than the paths of the single drum rollers' drive wheels, the vibratory drum path was chosen for use throughout the study.)

The contractor's pneumatic tire intermediate and tandem steel finish rollers then followed and, on some contracts, the specific test section was relogged behind them to detect any compaction improvement.

The compactive efficiency of the vibratory roller itself was compared to the compaction achieved by conventional means observed above.

In addition, qualitative observations were made throughout.

Restraints

The contractor's normal operations were not interfered with. Therefore, in most cases, the vibratory roller speed was dictated by the paving rate and the number of passes employed in the particular test section involved.

Rolling temperatures were those resulting from the mix temperatures provided by the contractor and any cooling that might occur immediately prior to actual coverage by the rollers in question.

The prevailing asphaltic mat thickness was a product of the contract requirements and field conditions.

The choice of mix types and thicknesses for study, however, were not readily available since conditions of geography, economics and contract requirements prevailed.

Operation of Vibratory Rollers

As most pavements encountered had a lane width of 11 feet or 12 feet, only two paths of travel were required of the seven-foot wide vibratory drums. This resulted in a slight overlap of the two paths. The rollers were usually driven with the drum facing the paver.

Longitudinal joints were rolled with the roller operating on the hot mat and with the drum first overlapping the joint sufficiently to allow a drive wheel (where applicable) to straddle and theoretically seal the joint. Some experimentation involved reversing the attitude of the roller; that is, the drive wheels faced the paver and hence, straddled the longitudinal joint before the vibratory drum followed. These techniques were attempted in both the vibratory and static modes of operation.

The vibration was always stopped prior to the above manoeuvres because the vibratory rollers could seriously rut a new mat if they were stopped or reversed while still vibrating. The vibration was easily stopped on all machines within a distance of 10 to 15 feet by using the vibration cutoff switch and drive stick.

The drum system was used continuously and the drive wheel spray as required.

OBSERVATIONS

I Operational

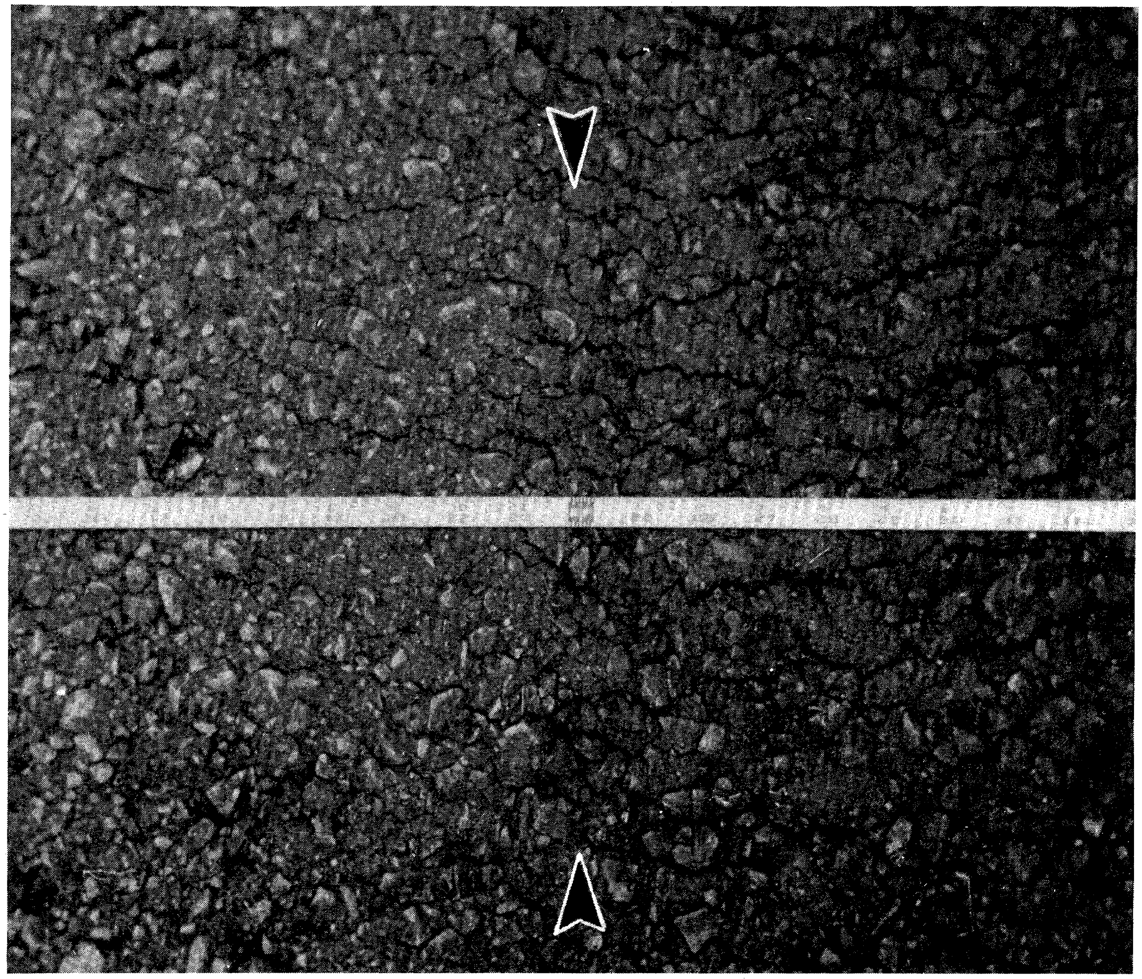
On lifts of three inches or less, hairchecking sometimes occurred with six vibratory drum passes.

On lifts in excess of three inches, eight vibratory drum passes sometimes caused hairchecking.

The single drum rollers generally required a minimum of four vibratory drum passes to remove ruts left by their own drive wheels.

Because the unconfined mat edge tended to push or shove, it had to be approached only when its stability would permit. For instance, if the drum covered the mat as far as the edge, the following drive wheel would distort the edge both downward and outward. On successive roller passes the remaining bulk of the mat supported the entire drum and the distorted edge could not be compacted.

When the single drum roller's drive wheel dropped over the pavement edge, the edge became rounded.



Over-Rolling — Severe hairchecking was produced on this four-inch lift of H.L.-5 on the right, which received 10 vibratory drum passes. The left side received both steel drum contact and also pneumatic drive wheel contact.

The last pass made by a vibratory roller, especially the double drum roller, could not overlap a longitudinal joint adjacent to a cold mat since one side of the drum was supported by the cold mat and the other drum edge cut into the tender mat just rolled.

The transverse sliding of the double drum vibratory rollers on superelevations of over two percent were avoided by increasing the travel speed a slight amount.

Single drum rollers encountered no traction problems on grades of up to five percent nor on mat thicknesses up to nine inches.

The double drum roller that was studied was not tested on any significant grades.

All drum systems employed water jets spraying directly on the steel drum and one or two steel or hard rubber scrapers. All systems, but one, were roughly comparable in efficiency. The configuration of water jet directly above the scraper was slightly superior.

Such systems are very sensitive to dirt. One manufacturer proposed the addition of coco mats which provide more dependable lubrication to the drum if kept saturated. The configuration of spray jets and scraper noted above achieved this lubrication to a degree by ponding water on the face of the drum between the jets and the scraper.

Most systems were rather difficult to drain in cold weather and particularly difficult to thaw out.

All rubber drive wheel spray and scraper systems on the single drum rollers were very similar, comprising a diesel fuel spray onto a coco mat and one or two scrapers.

These systems were quite effective and, with a reasonable amount of care, the diesel fuel could be regulated safely. A greater amount of diesel fuel was needed in cold weather.

With slow paving operations the inactive roller could not park on the mat because the saturated coco mats would puddle diesel fuel on the asphalt. The alternative of rolling back and forth to mark time was unacceptable because it caused severe hairchecking. The only solution was to drive off the warm mat and await the next load of mix.

As an alternative to diesel fuel, three lubricants were used, namely, Rollereze, Swift's Liquilube and Dow Corning's HV-490. Only the first of these was effective in the dilutions used, but it had to be used in impractical amounts.

The seven-foot wide drum of the vibratory rollers made manoeuvring along and around curb and gutter systems and protruding catchbasins very difficult.

The Ministry's operator found the hand controls to be too numerous. If some of these controls were foot operated instead of exclusively hand operated, the rollers would be easier to handle.

II Analytical Observations (Quantitative)

(1) Compaction - Compaction data was analysed in four thickness (t) groupings;

(i) $1'' \leqslant t \leqslant 1\frac{1}{4}''$

(ii) $t = 1\frac{1}{2}''$

(iii) $1\frac{1}{2}'' < t < 3''$

(iv) $3'' \leqslant t \leqslant 6''$

and within three temperature (F°) ranges;

(i) $T < 180°$

(ii) $180° \leqslant T \leqslant 250°$

(iii) $T > 250°$

The test records included all of the parameters previously outlined, but to simplify an analysis of these tests it was felt that only mat thickness and rolling temperature were required to provide a basis for comparing the compaction achieved by the two methods. That is to say, both the vibratory roller and the conventional rollers were compared in virtually identical environments, namely, the same mix, the same pavement structure and similar weather conditions. On any given contract, only the mat thickness and rolling temperature would vary significantly.

To further simplify the data, the differences in density of vibratory rolling versus conventional rolling were determined and converted to compaction units, viz.;

(i) density difference = density by vibratory - density by conventional methods

(ii) compaction difference = density difference - 150 x 100

where 150 lbs./cu. ft. =

100% compaction

e.g. density difference

= 148.0 - 149.5

= -1.5 lbs./cu. ft.

compaction difference =

(-1.5) ÷ 150 x 100

= 1%

(iii) Compaction differences were rounded to the nearest whole percent and a test "success" resulted when the compaction difference was equal to or greater than zero percent. Conversely, a test "failure" involved a compaction difference of -1 percent or less.

Using the preceding framework, the optimum combinations of frequency, amplitude and number of vibratory drum passes were sought for each temperature - thickness grouping. (This appraisal may be found in the Discussion and Tables 6, 7 and 8.)

(2) Roller Speed

Vibratory compaction is a series of successive drum impacts. The spacing of these impacts is a function of the frequency of vibration and the travel speed. It is logical to assume that the smaller the distance between these impacts, the more efficiently utilized is the vibratory aspect of these machines. For a given speed, it is obviously more advantageous to have a higher frequency.

Conversely, for a given frequency, it is also logical that a slower travel speed will decrease these inter-spacings. In fact, speeds of the 1.5 mile per hour (mph) magnitude were attempted (at the suggestion of one manufacturer) in the earlier part of the field study; but it soon became apparent that to keep pace with the paving operations, a speed this slow was totally impractical. The roller operator was instructed to use a speed compatible to the paving operations and this speed was then tabulated for all tests on each contract. The project average speed for the 12 contracts was 2.6 mph.

A small speed study was attempted on Contract 72-09 on August 24 using the control roller, 'A' (having the lowest maximum frequency of 1700 v.p.m.). The following table, extracted from Table 6, illustrates the effect of speed on this roller's compaction.

TEST NO.	FREQ. (v.p.m.)	AMP.	PASSES	ROLLER SPEED (mph)	COMPACTION DIFFERENCE PERCENT
1	1700	Min.	4	1.8	-1.0
2	1700	Min.	4	3.4	-3.0
3	1700	Max.	4	1.8	-2.0
4	1700	Max.	4	3.4	-3.0

Roller 'A' was tried out with the minimum and maximum amplitudes. It will be seen that the higher roller speed produced lower compaction values in both these amplitude settings.

With the same speeds but higher frequencies, this speed factor would probably diminish. Unfortunately, this phenomenon was not stûdied with rollers of higher maximum frequency.

It is interesting to note in the above case that at the lower travel speed of 1.8 mph, more compaction was obtained with the minimum amplitude setting than with the maximum. At the higher speed of 3.4 mph, however, there was no difference in compaction. This suggests that a low amplitude would have been more appropriate on the above one and a half inch mat.

(3) Density Versus Frequency

The advantage of small impact spacings by the drum was mentioned in (2). For a given speed, one would expect that increasing the frequency would improve compaction. In fact, there was no such indication in the study. The top frequencies of the rollers studied varied from 1700 to 2500 v.p.m., yet rollers with the higher frequencies did not stand out above the others.

(4) Ride

From the aspect of ride, however, the possibility of pavement rippling by the vibratory rollers increased with the speed of the roller. This phenomenon only occurred at excessive speeds of about 4.0 mph. It would be expected though that this threshold speed for rippling would be raised by increasing the frequency.

The study did not search for such a threshold, but an interesting contradiction to all the foregoing did present itself in the case of the double drum roller. At slow speeds of 1.0 to 1.5 mph and high frequency, the entire roller would slide transversely down a normal two percent crossfall. The remedy was to effect a slight increase in speed.

It is foreseeable that by over-zealously increasing the frequencies on such tandem machines, they would no longer be able to hold their footing at reasonable speeds; a pseudo-floating situation would result.

(5) Amplitude

All rollers but one operated in the low amplitude range on lifts of three inches or less. The exception was the standard roller with 1700 v.p.m. top frequency; it was found more efficient in the high amplitude setting for this thickness.

All rollers operated more effectively in the high amplitude settings for lifts exceeding three inches.

Rippling indicated the general unsuitability of high amplitude on lifts of three inches and less.

III Analytical Observations (Qualitative)

(1) Surface Texture

On asphalt lifts of three inches and less, significant hairchecking developed from all rollers after six to eight vibratory drum passes. The degree of this hairchecking was dependent on the characteristics of the hot mix in use.

Conventional rolling generally leaves a uniform closely-knit texture because of the kneading action provided by the pneumatic tire intermediate roller.

The double drum vibratory roller that was studied left a texture similar to that of conventional rolling. This was rather surprising since only steel drum contact was involved. One slight detraction was the loss of asphalt cement from the most prominently protruding coarse aggregate particles. The clear-starlit-night effect that it produced does not seem serious, unless it permits an eventual ingress of water into the aggregate particles.

The single drum vibratory rollers that were studied left a dual-textured mat. The areas subjected to exclusive steel drum contact were coarser or more open than those produced by both the double drum vibratory and conventional rolling. However, the areas that received both steel drum and rubber drive wheel contact were more closely knit than those receiving only the steel drum. The Mini Logger indicated that the compaction in this area was only slightly more than in the steel drum only area.

(2) Longitudinal Joint

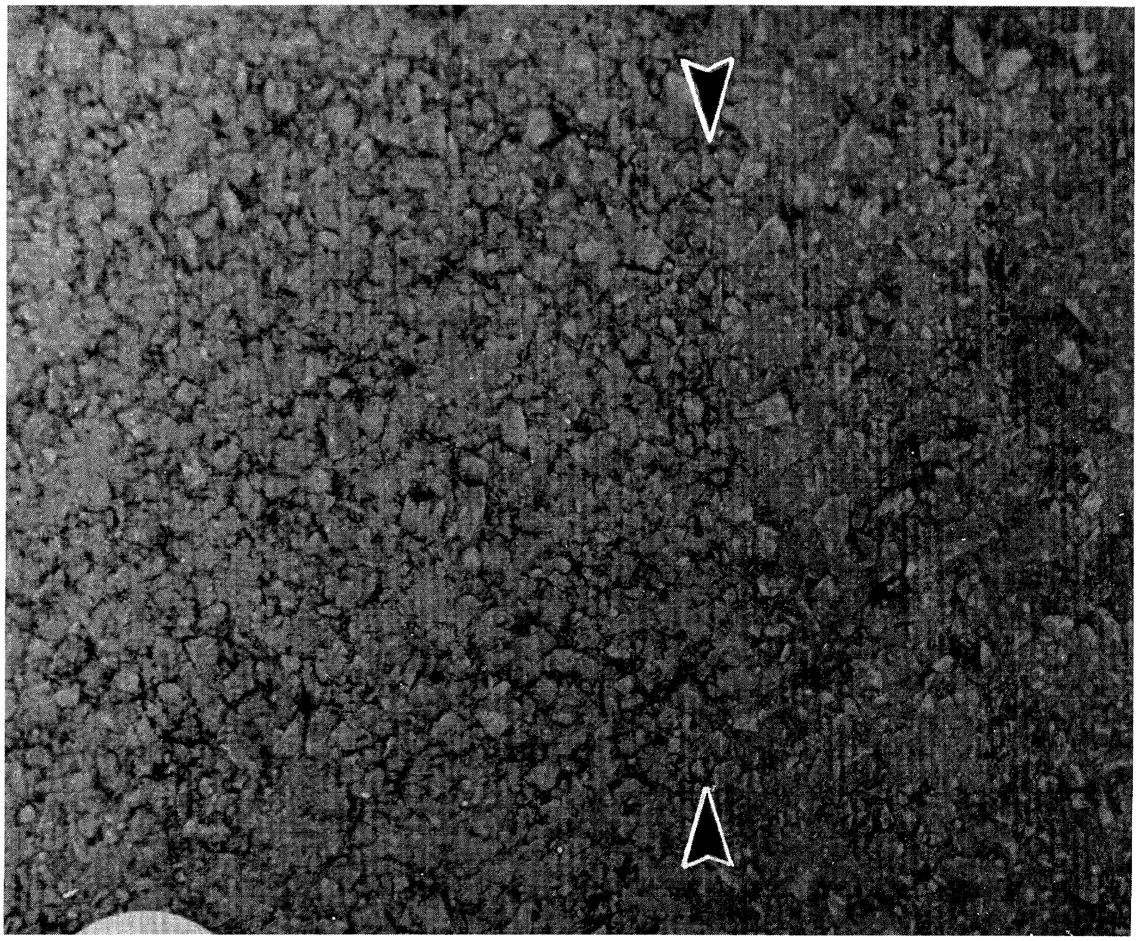
Conventional rolling of longitudinal joints is accomplished by operating the steel breakdown roller on the cold mat adjacent to the hot lane. By lapping this joint slightly from the outside, a pinching effect is obtained producing a flat, well-sealed joint.

The procedure recommended for the vibratory rollers involves operating exclusively on the hot mat. Both single and double drum vibratory rollers lap the joint slightly. The single drum roller laps this joint sufficiently to cause the drive wheel to straddle the joint as well. It is felt that the straddling of the longitudinal joint by the drive wheel will duplicate the pinching effect obtained by conventional rolling.

Most experimental work with the single drum rollers involved rolling this joint with the drum first and then the drive wheel. No care was taken to follow immediately behind the paver to ensure a hot joint. The result was a fairly well sealed but visually unattractive product.

When the single drum roller was reversed with the drive wheel making the first joint contact and when care was taken to pace the paver more effectively, a much improved joint resulted. However, the joint was still slightly visually inferior to that produced by conventional methods.

The double drum roller with drum-only contact did not roll this joint as well as the single drum or the



Surface Texture – The dual textured mat left by a single drum vibratory roller is quite evident in this four-inch lift of H.L.-5. The coarse texture on the left side resulted from exclusive vibratory steel drum contact and the more closed texture on the right side resulted from the same plus pneumatic drive wheels on the unit. This texture difference is less pronounced in finer mixes but still evident.

conventional rollers. The resulting joint would be acceptable for binder courses but not for surface courses.

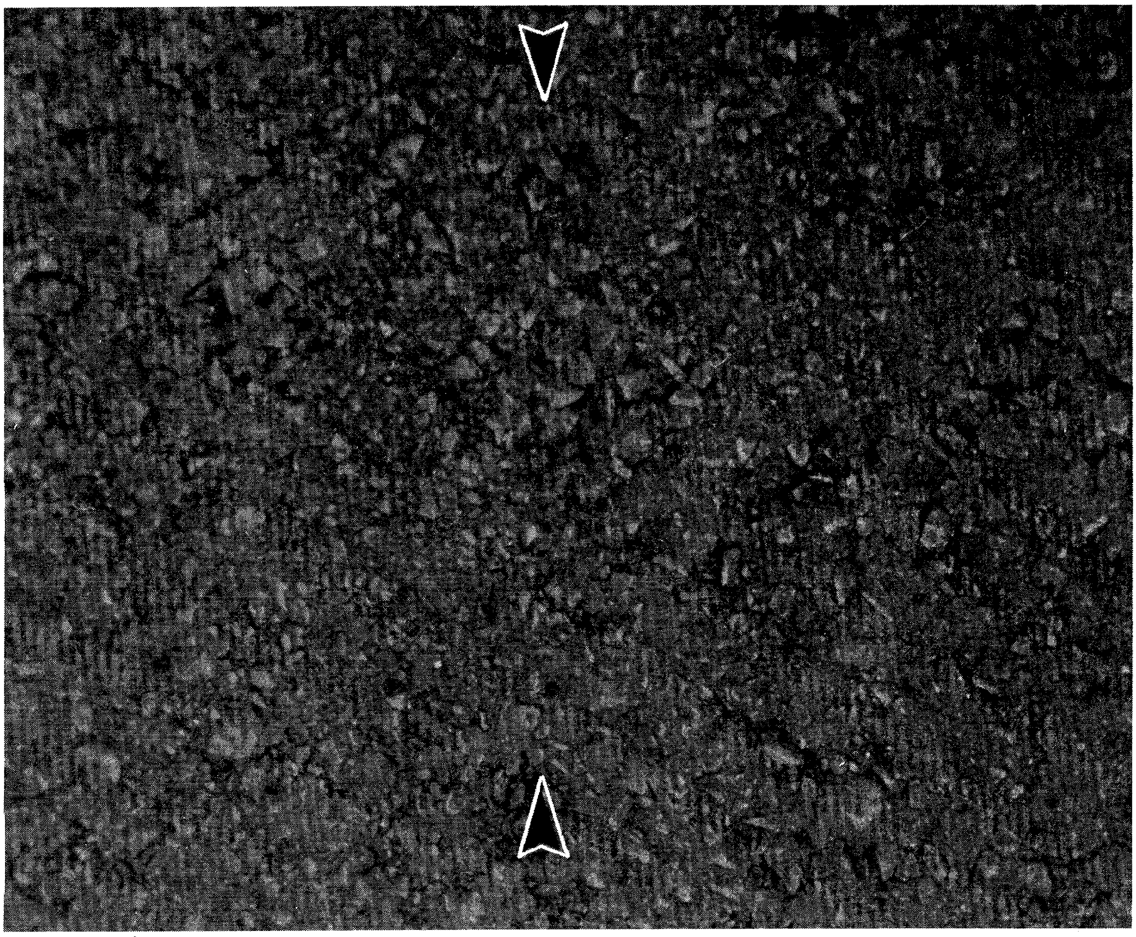
When the single drum vibratory was used in the vibratory mode to pinch the joint, a slight groove was created in the cold mat along the outer drum edge. Operated statically, this groove did not appear, but the vibratory roller was still not as effective as the normal breakdown roller because of the much lesser weight per lineal inch of drum.

Finally, the greater width of the vibratory drums proved to be a serious obstruction to traffic when this pinching was attempted on two-lane resurfacing contracts where traffic flow had to be maintained.

(3) Ride

The rippling effect that was predicted for vibratory rolling did not manifest itself unless unrealistic speeds or improper amplitudes were used. A similar problem did arise, namely, transverse ruts or bumps where the vibratory rollers stopped or reversed. Although these manoeuvres were accomplished statically and gently, the weight of the drum itself caused it to sink into the tender mat.

The sinking also occurred with conventional steel breakdown rollers but was overcome by stopping on a skew. Any ruts left were removed by the following pneumatic tire intermediate roller which followed. The seven-foot wide vibratory drum was too



Longitudinal Joint – An excellent longitudinal joint was achieved by the vibratory roller on a four-inch lift of H.L.-5.

cumbersome to park on an effective skew. Furthermore, if the vibratory was used alone there would be no roller to follow and remove the ruts.

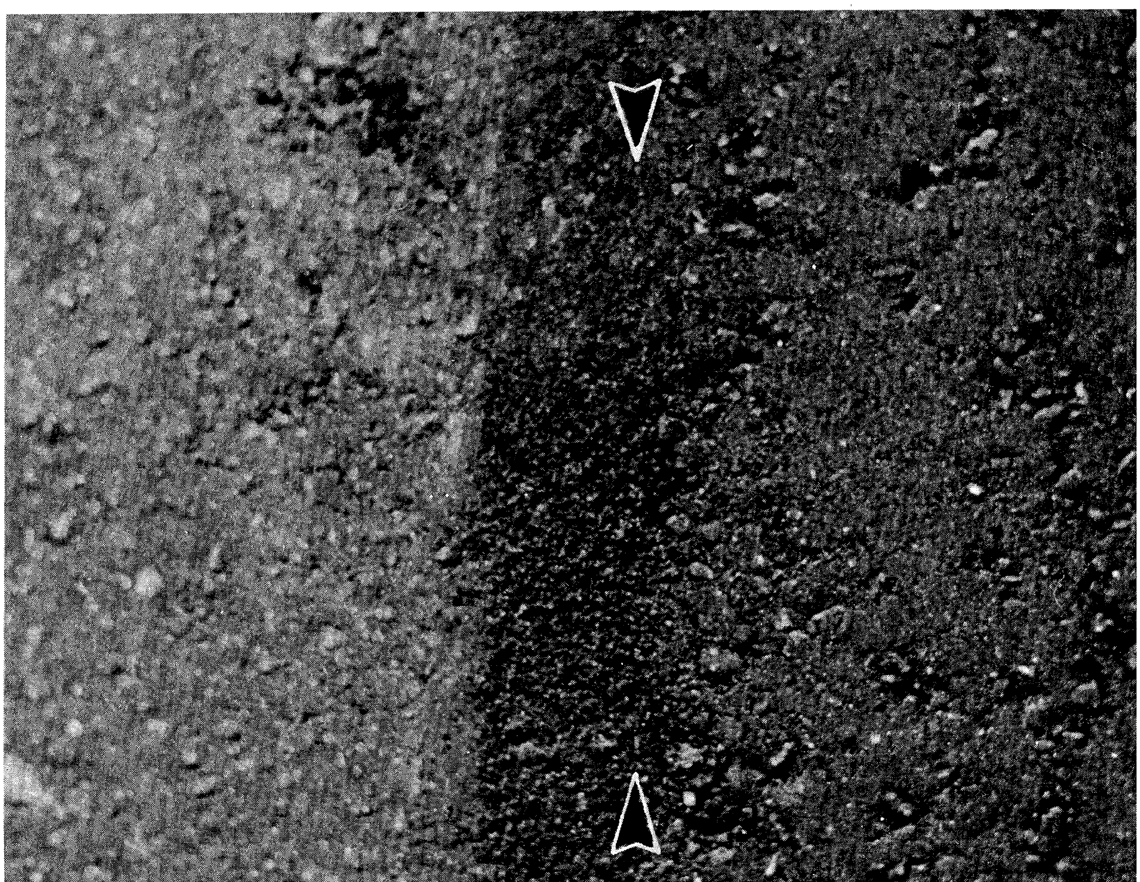
(4) Miscellaneous

Poor subgrades were well bridged by the vibratory rollers if the vibratory force was discretely limited. Good compaction could not be achieved in such a situation by either the vibratory or conventional rollers but the riding surface provided by the vibratory roller was far superior to the highly distorted surface produced by the conventional rolling.

DISCUSSION

General

The original direction of study involved the assessment of vibratory bituminous rollers as lone alternatives to conventional rolling. As the study progressed, field data suggested that they might fail to accomplish this. With this in mind, the same type of compaction data for the vibratory rollers themselves was still collected, but a combination of vibratory breakdown rolling and pneumatic tire intermediate and steel finish rolling was also studied.



Longitudinal Joint – Conventional and vibratory rolling of a longitudinal joint are contrasted here on a 1½ inch H.L.-4 surface course. The left section was rolled by a normal static steel breakdown roller and the right section by a vibratory roller. Although slight cooling had occurred prior to the vibratory rolling, a good deal of improvement in joint rolling is still required. Under the same cooling conditions, the normal static steel breakdown roller produced a better-compacted joint than the vibratory roller.

As analysis of the field data commenced, it also appeared that the study's double drum roller 'D' surpassed the single drum versions in both compaction and quality of rolling. As a result of this and the foregoing, the data was analysed in four blocks; single drum vibratory rollers working alone, double drum working alone, and each working with the pneumatic tire and steel finish following. The data is summarized in Tables 7 through 10.

Tables 1 through 5 contain contract descriptions, hot mix characteristics, and inventories of the conventional rolling encountered and the vibratory rollers studied.

All vibratory test sections are displayed in Table 6.

Compaction Analysis

(1) Framework - The total number of vibratory rolling tests conducted were as follows: 157 single drum, 16 double drum, 29 single drum plus (plus pneumatic tire and steel finish) and five double drum plus tests.

Table 8 is a summary of all tests attempted (as enumerated in Table 6). It displays all the successful vibratory methods (combinations of frequency, amplitude, and number of passes) in each temperature - thickness grouping of data that contains at least four tests (see Table 7). For example, Table 8 shows the following two successful methods for the grouping $T < 180°F$ and $t = 1½$ inches:

(i) frequency = 1700 v.p.m.

amplitude = maximum (or high)

passes = 4

(ii) as above but with six passes.

All the other test combinations of frequency, amplitude and number of passes not displayed in Table 8 either failed or fell into data groupings containing fewer than four tests.

(2) Comments - Successful rolling of asphalt cannot be gauged by compaction alone. For lifts of under three inches, two vibratory passes by the single drum rollers proved to be inadequate from the aspect of ride, even though some degree of success was achieved in compaction. Furthermore, for lifts under three inches, eight vibratory passes introduced significant hairchecking of the asphalt surface. Therefore, in studying Table 8 for this thickness range, only the tests involving four or six passes should warrant consideration.

(i) For a thickness of one and a half inches and less, the single drum rollers failed to equal conventional rolling but the double drum succeeded in eight of ten tests involving two to six passes.

(ii) For lifts between one and a half and three inches the only category containing a significant number of tests was the $180° \leqslant T \leqslant 250°F$ temperature range for the single drum rollers. Table 8 suggests that four passes in the high amplitude range will successfully compact this thickness. Caution must be practised here, however, for this was the critical thickness range in which rippling could occur at high amplitude settings.

(iii) For lifts of three to six inches only a single drum data is available. Table 8 suggests that six to eight passes at high amplitude will equal conventional rolling in the majority of cases; in the 10 tests using this approach, only two failed. This seems very conclusive but the nature of Table 8 must be understood before drawing any conclusions.

Table 8 shows all the successful vibratory tests. Each test is concerned with a particular make of roller operating at its own individual maximum frequency and amplitude. Most amplitudes can be summarized as generally high and low regardless of the make in question.

The wide range of successful frequencies in Table 8 suggests that all the frequencies from 1700 to 2500 v.p.m. perform comparably. Therefore, it would be permissible to group all tests involving high frequency and high amplitude.

If this grouping was employed, another nine failures in this six to eight pass, high-frequency, high-amplitude, three-inch – plus category could be found in Table 6. The revised totals would then be eight successes and 11 failures. Based on this poor success rate, one cannot conclude that the single drum rollers alone can efficiently compact these thicknesses.

In summary, Table 8 does not support the theory that the single drum vibratory rollers can reliably achieve compaction on any of the thicknesses studied; the double drum roller shows good potential for the one to 1½-inch range studied.

It is curious to observe that four vibratory drum passes with the double drum roller are more efficient than the same number by a single drum roller from the viewpoint of both compaction and surface texture. The reasons for this could be that drum drive by the double drum roller diminishes the bow wave effect ahead of the drums and secondly that the proximity of the two vibrating drums to each other has a composite effect that is more than equivalent to two single drum passes.

Factors Affecting Compaction

Asphaltic concrete paving has a preponderance of factors affecting the final compacted product. The relative approach that this study used was to attempt to eliminate as many of these factors as possible. The goal was to assess the vibratory rollers by comparing them to conventional rolling techniques in identical rolling environments.

The 500-foot length of the test sections eliminated any effects of minor fluctuations in the hot mix. The Mini Road Logger provided compaction data that represented an average of the complete test section's length (rather than an average of isolated spot checks inherent in coring or stationary nuclear techniques).

In order to observe the effectiveness of vibratory rollers on different mixes and to compare all the vibratory rollers to each other, control roller 'A' was used throughout the study and paired with each make. This pairing indicated a superiority of the double over the single drum rollers but there was no indication of significant difference among the single drum rollers themselves.

Table 9 indicates that the compactibility of a mix had no effect on the vibratory rollers' performances and that no particular single drum roller was more successful than another.

Modified Rolling Procedures

It has been established in the foregoing that the single drum vibratory rollers when working alone, do not equal the compaction of conventional rolling. Observations indicate that the quality of rolling from all vibratory rollers also falls short. They must be accompanied by conventional rollers. Table 10 documents the tests that involved a vibratory roller followed by a pneumatic tire and a tandem steel finish roller. It can be seen that for almost all of the 34 tests, the additional pneumatic and steel rollers improved compaction from one to two percent. Only seven of 34 vibratory roller - only tests were successful; but when additional rollers were added to the same 34 test sections, 15 more successes were achieved, resulting in 22 successes out of 34 tests. This in itself does not strongly support the modified rolling sequence, but one must analyse the rolling sequence as outlined in the Procedure section to assess it fully.

Because the additional rollers had to await the density reading made by the Mini Road Logger and because the logger had to await sufficient cooling of the mat to support the logger's sensing - detecting unit, the effectiveness of the additional rollers was somewhat less than if they had immediately followed the vibratory roller. Thus a greater success rate would be anticipated for this modified sequence if the additional rollers immediately followed the vibratory roller.

The rolling was at least equal in quality to conventional rolling in all areas except the longitudinal joint rolling. Further procedural investigations might provide a method which improves the quality of the joint.

A second modified rolling sequence could possibly involve a vibratory roller followed by a pneumatic tire roller. This secondary roller would close the surface texture, remove reversal bumps and ensure that proper compaction was achieved. But there are two strong detractions from this sequence - the longitudinal joint and the questionable suitability of the pneumatic tire roller as a finisher on some mixes. This sequence might be suitable for binder paving but not for surface course paving in general.

Vibratory Rolling

Capacity

The single drum rollers could handle an hourly production rate of 110 tons of one and a half inch paving. The double drum versions appear capable of handling at least twice this rate.

The vibratory rollers were designed for free-wheeling highway production work and as such become awkward in municipal work where a great deal of curb and gutter, catchbasin and manhole work is involved, not to mention the potential danger of destructive vibratory transmission to nearby private property.

Diesel Fuel Spray

Diesel fuel was sprayed on the cold rubber drive wheels of the single drum vibratory rollers to prevent pickup. Once the tires heated to a certain degree, the application of this asphalt solvent could be discontinued.

The three alternatives to diesel fuel that were sampled were all water-based and prevented the tires from warming; therefore, they had to be applied continually. Diesel fuel was much superior to the alternatives if used cautiously and was in ready supply on the construction jobs. Its use then would be acceptable; but as a complement to prevent rapid cooling of the tires, wheel skirts and perhaps exhaust diversion on the tires might be considered.

CONCLUSIONS

(1) Vibratory rollers did not prove themselves to be acceptable as lone alternatives to conventional rolling techniques in this study.

(2) Double drum vibratory rollers did achieve compaction equivalent to conventional rolling and would be acceptable on binder and surface course paving. However, as the finish surface may not be adequate, it may be necessary to use a pneumatic roller for the finish course until more experience is obtained.

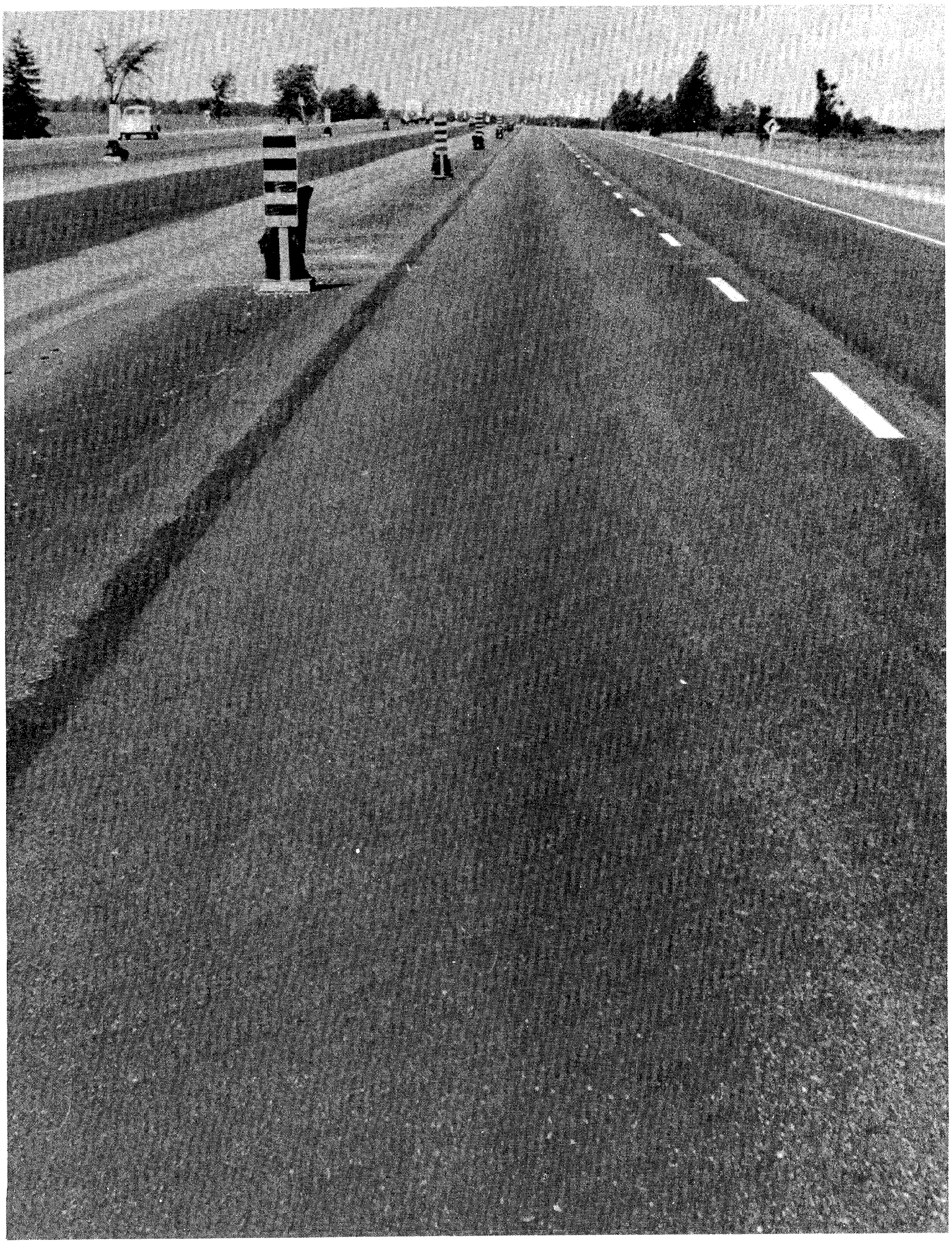
(3) With the limited data available, it appears that single drum vibratory rollers would be acceptable on binder and surface course paving if accompanied by at least one pneumatic tire roller.

REFERENCES

[1] MacKinnon, B.D.A., *Compaction of Asphaltic Concrete with Vibratory Rollers*, Department of Highways, Ontario, a preliminary report for the Materials and Testing Office, 1971.

[2] Parsons, E.G., *Evaluation of Asphalt Compaction Using the Mini Road Logger*, Ministry of Transportation and Communications, Ontario, Report IR48, 1972.

[3] Fromm, H.J., *The Compaction of Asphaltic Concrete on the Road*, Department of Highways, Ontario, Report No. 43, 1963.



Diesel Fuel Spray – The light bands on the pavement show the effect of over-using diesel fuel spray on the pneumatic drive wheels of a single drum vibratory roller. The pavement shown had been open to heavy traffic for one month prior to photographing.

Glossary of Terms
Used in Tables

average conventional density; the average density of the contractor's rolling for comparison with the vibratory rolling densities.

compaction difference; the density as expressed in compaction.

compactibility index; a combination of bituminous mix variables (flow, voids and stability) that indicate the difficulty in compacting that mix. Reference [3]

density difference; the arithmetic difference between the test average density and the average conventional density.

rolling temperature; the temperature in Fahrenheit degrees of the bituminous mat at the commencement of rolling.

sand asphalt levelling course; a fine graded, bituminous mix laid in a ¾-inch thickness over old pavements as a base for resurfacing.

sampled density; the density survey taken by the Mini Road Logger of the contractor's rolling on any given contract.

test average density; the density achieved by the vibratory roller in any particular test.

Table 1, Contract Locations

CONTRACT	DISTRICT	HWY.	DESCRIPTION
71-56	4	QEW	From 0.31 Mi. E. of Thompson Rd. (C.N.R.) E'ly 1.06 Mi. to the Peace Br. Plaza incl. Central Ave. Interchange Underpass, Erie St. Interchange Overpass and work on Petit Rd. and Petit St.
71-140	7	115 & 35	Intersection improvement at County Rd. No. 1 and the Twp. Rd. 0.5 Mi. N. of Orono and from 2.6 Mi. North of Hwy. 401 N'ly 9.09 Mi. (excl. 0.4 Mi.) and incl. Truck Climbing Lane 8.6 Mi.
71-146	6	400	From 4.01 Mi. N. of Hwy. 88 N'ly to 1.0 Mi. N. of Hwy. 89.
71-147	6	400	From 0.6 Mi. S. of County Rd. No. 21 to Thornton N'ly to 1.5 Mi. S. of Hwy. 27 Interchange.
72-09	10	62	From Bannockburn N'ly 19.1 Mi. to 0.2 Mi. S. of Sec. Hwy. 620.
72-50	7	401	From 0.5 Mi. W. of Hwy. 30 E'ly to Hwy. 33.
72-60	13	17	From Hwy. 531 E'ly 16.0 Mi. to 5.3 Mi. W. of Mattawa.
71-33	14	101	From the Pamour Mine Entrances E'ly 13.46 Mi. excl. 0.29 Mi. at Hwy. 67 and 0.23 Mi. at Sec. Hwy. 610
72-81	5	9 & 21	From 0.14 Mi. E. of Kincardine E. limits E'ly, incl. intersection improvement at Hwy. 9 and 21 in Kincardine.
72-66	1	79	Hwy. 79 from the N. limits of Bothwell Diversion N'ly to Watford S. limits excl. 0.2 Mi. at Brown's Creek.
71-192	8	2	From 1.9 Mi. E. of Trenton E'ly to Belleville W. limits incl. C.P.R. Overhead 0.6 Mi. W. of Belleville W. limits.
71-81	8	33 & 2	"A" - From Kingston W. limits W'ly 3.18 Mi. to Collins Bay. "B" - Hot Mix Patching - Hwy. 2, various locations.

Table 2, General Test and Contract Data

CONTRACT	71-56	71-140	71-146	71-147	72-09	72-50
MIX	HL-5	HL-1	HL-6	HL-6	HL-4	HL-4
THICKNESS (inches)	4"	1½"	4"	1½"-3"	1½"	1½"
BASE	Gran., HL-5	S.A.L.[1]	Gran., Exist.[2]	Exist.	S.A.L.	S.A.L.
CONV.[3] ROLLING LENGTH TESTED (feet)	950	2,500	3,550	3,650	7,450	3,360
NUMBER OF TEST SECTIONS	11	18	36	36	16	24
AVG. TEST LENGTH (feet)	475	375	450	490	425	390

CONTRACT	72-60	71-33	72-81	72-66	71-192	71-81	Total
MIX	HL-4	HL-4	HL-4	HL-3	HL-8	HL-4	-
THICKNESS (inches)	1½"	1½"	1½"	1½"	3½"	2"	-
BASE	S.A.L.	S.A.L.	HL-4	S.A.L.	Gran.	HL-4	-
CONV.[3] ROLLING LENGTH TESTED (feet)	2,000	800	5,900	2,050	2,500	2,700	37,410
NUMBER OF TEST SECTIONS	3	8	9	7	8	3	173
AVG. TEST LENGTH (feet)	485	380	560	610	450	685	455

NOTES:

[1]*S.A.L.; sand asphalt levelling course*

[2]*EXIST.; existing old pavement*

[3]*CONV.; conventional*

Table 3, Hot Mix Description

CONTRACT NUMBER	MIX TYPE	COARSE[1] AGGREGATE GEOLOGY	GRADATION: Ret. No. 4[3] Pass No. 4	GRADATION: 100% Pass	GRADATION: % Pass[4] No. 200	GRADATION: % Screenings	ASPHALT CEMENT: Pen.	ASPHALT CEMENT: Content (%)	MIX CHARACTERISTICS[2]: Voids (%)	MIX CHARACTERISTICS[2]: Stability (lbs.)	MIX CHARACTERISTICS[2]: Flow (.01")	MIX CHARACTERISTICS[2]: Comp.[5] Index
71-56	HL-5	Quar. Carb.	55/45	5/8"	5.0	22.5	85/100	5.4	1.2	2450	13.2	4.5
71-140	HL-1	Quar. Ign.	40/60	1/2"	5.4	12.0	85/100	5.3	2.0	2350	11.8	2.5
71-146	HL-6	Quar. Carb.	45/55	3/4"	5.6	—	85/100	5.4	1.8	1900	13.6	4.0
71-147	HL-6	Quar. Carb.	50/50	3/4"	5.3	—	85/100	5.4	1.1	1900	14.0	6.7
72-09	HL-4	Crush. Ign.	40/60	5/8"	7.3	—	150/200	4.9	1.7	2750	11.8	2.5
72-50	HL-4	Crush. Carb.	35/65	5/8"	4.2	—	85/100	5.5	3.8	2650	10.8	1.1
72-60	HL-4	Crush. Ign.	45/55	5/8"	5.9	—	150/200	5.8	2.1	2500	11.2	2.1
71-33	HL-4	Crush. Ign.	40/60	5/8"	5.8	—	150/200	5.1	3.6	2850	9.8	1.0
72-81	HL-4	Crush. Carb.	40/60	5/8"	6.9	—	150/200	5.6	2.0	2300	7.7	1.7
72-66	HL-3	Quar. Carb.	40/60	1/2"	7.4	20.0	85/100	5.2	4.2	2500	8.5	0.8
71-192	HL-8	Crush. Carb.	50/50	3/4"	10.1	17.0	85/100	5.3	0.9	1950	16.0	9.1
71-81	HL-4	Quar. Carb.	55/45	5/8"	7.8	11.0	85/100	5.4	1.5	2500	12.9	3.4

Notes:

[1] *Quar. Carb., Quarried Carbonate*
Quar. Ign.; Quarried Igneous
Crush Carb.; Crushed Carbonate
Crush Ign.; Crushed Igneous

[2] *Table based on recompacted mix samples. Values determined by M.T.C. Modified Marshall Method, using 60 blow Automatic Compactor.*
[3] *Based on aggregate fraction totalling 100.*
[4] *Based on pass no. 4 fraction.*
[5] *Comp. Index; Compactibility Index.*

Table 4, Conventional Rolling

CONTRACT NUMBER	DATE	WEATHER	MIX Type	MIX Thick. (in.)	Base	ROLLERS Weight (tons) / Type[1]/No. of Passes: Breakdown	Intermediate	Finish	ROLLING TEMP. (°F)	LENGTH SAMPLED (ft.)	SAMPLED DENSITY (lbs./c.f.)	AVERAGE CONVENTIONAL DENSITY (lbs./c.f.)
71-56	July 6	Sunny 70°F	H.L.5	4	Gran. (Med.)	10.5/2 S.W./4	9.5/P.T./40	10.5/2 S.W./4	310	130	143.0	
	July 6	Sunny, 70°F	H.L.5	4	"	10.5/2 S.W./4	9.5/P.T./22	10.5/2 S.W./4	310	300	143.0	143.0
	July 7	Sunny, 80°F	H.L.5	4	Gran. (Firm)	–	–	–	310	220	144.7	
	July 7		H.L.5	4	"	–	–	–	310	300	143.8	144.2
71-140	July 17	Sunny, 85°F	H.L.1	1½	H.L.1	9/2 S.W./4	8/P.T./15	8/2 S.W./5	245	1500	147.8	147.8
	July 20	Sunny, 85°F	H.L.1	1½	S.A.L.	–	–	–	290	1000	143.8	143.8
71-146	July 25	Windy, 80°F	H.L.6	5	Exist.	11/3 S.W./5	11/P.T./9	9/2 S.W./5	250	650	147.2	
	July 26	Cloudy, 65°F	H.L.6	5	Exist	11/3 S.W./5	11/P.T./12	9/2 S.W./5	250	900	143.2	143.2
	Aug. 9	Windy, 60°F	H.L.6	4	Gran. (Firm)	11/2 S.W./5	12/P.T./10	11/2 S.W./5	230	2000	142.9	142.9
71-147	July 31	Sunny, 85°F	H.L.6	1½	Exist.	12/2 S.W./–	25/P.T./–	8/2 S.W./–	–	350	137.5	
	July 31	Sunny, 85°F	H.L.6	1½	Exist.	12/2 S.W./–	25/P.T./–	8/2 S.W./–	–	2850	142.8	142.8
	Aug. 3	Cloudy, 70°F	H.L.6	4	Exist.	12/2 S.W./6	25/P.T./15	8/2 S.W./5	245	450	147.6	147.6
72-09	Aug.15	–	H.L.4	1½	S.A.L.	–	–	–	–	2350	139.5[2]	
	Aug.15	–	H.L.4	1½	S.A.L.	–	–	–	–	1100	141.3	140.8
	Aug.16	Cloudy, 70°F	H.L.4	1½	S.A.L.	10/2 S.W./3	9/P.T./31	8/2 S.W./3	250	700	140.1	
	Aug.17	Cloudy, 70°F	H.L.4	1½	S.A.L.	10/2 S.W./3	9/P.T./50[3]	8/2 S.W./3	180	400	140.3	
	Aug.22	Cloudy, 75°F	H.L.4	1½	S.A.L.	10/2 S.W./6	9/P.T./19	8/2 S.W./5	180	800	137.7	137.7
72-50	Aug.28	Sunny, 80°F	H.L.4	1½	S.A.L.	–	–	–	–	1360	135.9	135.9
	Aug.30	Sunny, 75°F	H.L.4	1¼	S.A.L.	10/2 S.W./6	9/2 S.W./31	8/2 S.W./6	200	500	136.9	
	Aug.30	Sunny, 75°F	H.L.4	1¼	S.A.L.	10/2 S.W./6	9/2 S.W./29	8/2 S.W./6	205	500	135.8	136.4
72-60	Sept. 6	Fair, 60°F	H.L.4	1½	S.A.L.	10/2 S.W./5	28/P.T./28	9/2 S.W./5	255	1500	144.3	
	Sept. 7	Fair, 60°F	H.L.4	1½	S.A.L.	10/2 S.W./6	28/P.T./23	9/2 S.W./6	270	500	141.4	143.6
71-33	Sept.19	Cloudy, 50°F	H.L.4	1½	S.A.L.	12.5/2 S.W./3	28.5/P.T./31	8/2 S.W./3	195	300	135.2	135.2
72-81	Oct. 3	Sunny, 70°F	H.L.4	1½	H.L.4	10.5/2 S.W./5	9/P.T./25	10/2 S.W./5	180	1050	137.1[4]	137.1
	Oct. 4	Sunny, 50°F	H.L.4	1½	H.L.4	–	–	–	–	2050	132.4	
	Oct. 5	Sunny, 50°F	H.L.4	1½	H.L.4	10.5/2 S.W./7	29/P.T./16	10/2 S.W./5	255	1000	138.3	
	Oct. 5	Sunny, 50°F	H.L.4	1½	H.L.4	–	–	–	–	1800	134.8	
72-66	Oct. 11	Cloudy, 55°F	H.L.4	1½	S.A.L.	12/2 S.W./3	10/P.T./31	8.5/2 S.W./3	180	1000	135.5	
	Oct. 13	Cloudy, 45°F	H.L.4	1½	S.A.L.	12/2 S.W./5	10/P.T./29	8.5/2 S.W./5	215	1050	135.3	135.4
71-192	Oct. 19	Clear, 40°F	H.L.8	3½	Gran. (Firm)	12/2 S.W./5	10/P.T./19	9/2 S.W./5	225	500	148.0	148.0
	Oct. 24	Clear, 40°F	H.L.8	2½	H.L.8	–	–	–	–	2000	147.0	147.0
71-81	Oct. 31	Clear, 40°F	H.L.4	2	S.A.L.	8/2 S.W./6	9.5/P.T./17	12/2 S.W./5	220	500	142.0	
	Oct. 31	Clear, 40°F	H.L.4	2	S.A.L.	–	–	–	–	2200	143.7[4]	143.7

Notes:

[1] *2 S.W.; tandem steel wheel*
3 S.W.; 3 steel wheel
P.T.; pneumatic tire roller

[2] *After 1 day of light traffic.*
[3] *Pneumatic intermediate roller passes doubled.*
[4] *Most typical for this contract.*

Table 5, Inventory of Vibratory Rollers

ROLLER	A	B	C	D	E
Net unit wt. (lbs.)	21,500	18,300	20,300	32,500	18,500
No. of drums	1	1	1	2	1
Drum dimensions:					
Diameter (in.)	60	59	60	60	59
Width (in.)	84	84	84	84	84
Static wt. (lbs.)	12,950	9,150	10,500	16,250	12,500
Amplitude (mm):					
Low	0[1]	1.3 (0.05")	0.8	0.8	1.1 (0.044")
High	3.0 (0.12")	2.6 (0.104")	1.6	1.6	–
Frequency (v.p.m.):[1]					
Low	900	1,200[2]	1,700		1,100
High	1,700	2,300	2,400	2,400[3]	2,500
Applied Force (lbs.):[4]					
(i) Max. Amp. - Hi Freq.	35,000	36,150[6]	47,100	52,250	
(ii) - Low Freq.		–	29,000	–	
(ii) Min. Amp. - Hi Freq.		–	28,800	34,250	46,000[7]
- Low Freq.	12,950[5]	–	19,750	–	–
Unit length (ft.)	18	17	17+	18.5	17+

Notes:
[1] *Variable.*
[2] *Two ranges: 1200 - 1700 v.p.m. for high amplitude.*
1200 - 2300 v.p.m. for low amplitude.
[3] *Recommended by Manufacturer for asphalt (not variable).*
[4] *Applied force = static wt. of drum + centrifugal force (or dynamic).*
[5] *Static drum weight.*
[6] *36,150 lbs. is max. applied force.*
[7] *Only low amplitude available on this prototype model.*

Table 6, Vibratory Rolling

CONTRACT NUMBER	DATE	WEATHER	MIX Type	MIX Thick. (in.)	MIX Base	ROLLER	TEST NUMBER	ROLLER SPEED (MPH)	ROLLING TEMP. (°F)	VIBRATION Frequency (v.p.m.)	VIBRATION Amplitude	NUMBER OF PASSES Stat.	NUMBER OF PASSES Vib.	NUMBER OF PASSES Stat.	TEST LENGTH (ft.)	TEST AVERAGE DENSITY (lbs./c.f.)	2. AVG. CONV. DENSITY (lbs./c.f.)	3. DENSITY DIFF. (1.–2.) (lbs./c.f.)	COMP'N. DIFF. (3.) x 100/150 (%)
71-56	July 6	Sunny, 70°	HL-5	4	Gran. (Firm)	B	1	1.5	300	1700/2300	High/Low	–	4/2	–	500	144.3	144.2	+0.1	0.0
	July 6	Sunny, 70°	HL-5	4	Gran. (Firm)	B	2	1.5	300	1700	High	–	6	–	360	141.5	144.2	–2.7	–2.0
	July 11	Sunny, 80°	HL-5	4	Gran. (Firm)	A	1	1.5	300	1500	Max.	–	4	–	400	142.3	144.2	–2.1	–1.0
	July 11	Sunny, 80°	HL-5	4	Gran. (Firm)	A	2	1.5	300	1700	Max.	–	4	–	400	141.4	144.2	–2.8	–2.0
	July 11	Sunny, 80°	HL-5	4	Gran. (Med)	B	3	1.5	300	1700	High	–	4	–	650	141.8	143.0	–1.2	–1.0
	July 12[1]	Sunny, 80°	HL-5	4	HL-5	A	1	1.5	200	1700	Max.	–	8	–	400	137.9	N/A	–	–
	July 12	Sunny, 80°	HL-5	4	HL-5	A	1A	1.5	280	1700	Max.	–	8	–	230	138.3	N/A	–	–
	July 12	Sunny, 80°	HL-5	4	HL-5	A	2	1.5	280	1700	Max.	–	6	–	220	136.9	N/A	–	–
	July 12	Sunny, 80°	HL-5	4	HL-5	A	3	1.5	290	1700	Max.	–	4	–	370	135.9	N/A	–	–
	July 12	Sunny, 80°	HL-5	4	HL-5	B	4	1.5	290	2300/1700	Low/High	–	6/2	–	1200	137.6	N/A	–	–
71-140	July 17	Sunny, 80°	HL-1	1-1/2	S.A.L.	B	1	2.5	250	2300	Low	–	2	–	400	143.4	143.8	–0.4	0.0
	July 17	Sunny, 80°	HL-1	1-1/2	S.A.L.	B	2	2.5	240	2000/2300	Low	–	1/1	–	400	145.0	143.8	+1.2	+1.0
	July 17	Sunny, 80°	HL-1	1-1/2	S.A.L.	B	3	2.5	245	1700/2300	Low	–	1/1	–	450	145.0	143.8	+1.2	+1.0
	July 17	Sunny, 80°	HL-1	1-1/2	S.A.L.	B	4	2.5	225	1700	Low	–	2	–	450	144.0	143.8	+0.2	0.0
	July 17	Sunny, 80°	HL-1	1-1/2	S.A.L.	B	5	2.5	230	2300	Low	–	1	1	145	143.5	143.8	–0.3	0.0
	July 17	Sunny, 80°	HL-1	1-1/2	S.A.L.	B	7	2.5	200	2300	Low	–	1	1	210	141.9	143.8	–1.9	–1.0
	July 17	Sunny, 80°	HL-1	1-1/2	S.A.L.	B	7	2.5	200	2300	Low	–	1	1	210	145.0[2]	143.8	+1.2	+1.0[2]
	July 17	Sunny, 80°	HL-1	1-1/2	S.A.L.	B	8	2.5	200	2300	Low	–	2	–	245	142.0	143.8	–1.8	–1.0
							8									145.5[2]	143.8	+1.7	+1.0[2]
	July 17	Sunny, 80°	H.L.-1	1-1/2	S.A.L.	B	9	2.5	200	2300	Low	–	1	1	375	143.8	143.8	0.0	0.0
							9									145.0[2]	143.8	+1.2	+1.0[2]
	July 17	Sunny, 80°	H.L.-1	1-1/2	S.A.L.	B	10	2.5	205	2000	Low	–	1	1	250	143.0	143.8	–0.8	–1.0
							10									144.0[2]	143.8	0.2	0.0[2]
	July 18	Sunny, 85°	HL-1	1-1/2	S.A.L.	B	1	2.5	200	2300	Low	1	1	–	145	139.7	143.8	–4.1	–3.0
	July 18	Sunny, 85°	HL-1	1-1/2	S.A.L.	B	1A	2.5	200	2300	Low	3	1	–	205	141.4	143.8	–2.4	–2.0
	July 18	Sunny, 85°	HL-1	1-1/2	S.A.L.	B	2	2.5	200	2300	Low	–	2	–	600	141.6	143.8	–2.2	–1.0
	July 18	Sunny, 85°	HL-1	1-1/2	S.A.L.	B	3	2.5	210	1700/2300	High/Low	–	1/1	–	370	143.0	143.8	–0.8	–1.0
	July 18	Sunny, 85°	HL-1	1-1/2	S.A.L.	B	4	2.5	230	2300	Low	1	1	–	330	141.4	143.8	–2.4	–2.0
	July 18	Sunny, 85°	HL-1	1-1/2	S.A.L.	A	5	2.5	200	1700	Min.	–	2	–	650	138.8	143.8	–5.0	–3.0
	July 19	Cloudy, 80°	HL-1	1-1/2	Exist.	C	1	2.8	235	2400	Low	–	2	–	960	146.9	147.8	–0.9	–1.0
	July 20	Sunny, 85°	HL-1	1-1/2	S.A.L.	C	1	2.8	200	2400	Low	–	2	–	310	141.2	144.0	–2.6	–2.0
	July 20	Sunny, 85°	HL-1	1-1/2	S.A.L.	C	2	2.8	200	2400	High	–	2	–	280	142.0	144.0	–1.8	–1.0
71-146	July 26	Cloudy, 65°	HL-6	6	Exist.	A	1	3.0	240	1700	Max.	–	6	–	200	141.0	143.2	–2.2	–1.0
	July 26	Cloudy, 65°	HL-6	6	Exist.	A	2	3.0	240	1700	Max.	–	8	–	150	140.9	143.2	–2.3	–2.0
	July 27	Sunny, 70°	HL-6	3-4	Exist.	C	1	2.0	250	2400	High	–	2	–	300	139.0	143.2	–4.2	–3.0
	July 27	Sunny, 70°	HL-6	3-4	Exist.	C	2	2.0	250	2400	High	–	4	–	250	138.1	143.2	–6.1	–4.0
	July 27	Sunny, 70°	HL-6	3-4	Exist.	C	3	2.0	230	2400	Low	–	2	–	175	138.1	143.2	–6.1	–4.0
	July 27	Sunny, 70°	HL-6	3-4	Exist.	C	4	2.0	230	2400	Low	–	4	–	175	138.0	143.2	–5.2	–3.0
	Aug. 9	Windy, 55°	HL-6	4	Gran. (Firm)	A	1	–	230	1700	Max.	–	4	2	500	140.1	142.9	–2.8	–2.0
	Aug. 9	Windy, 55°	HL-6	4	Gran. (Firm)	A	2	4.0	235	1700	Max.	–	8	2	400	141.9	142.9	–1.0	–1.0
	Aug. 9	Windy, 55°	HL-6	4	Gran. (Firm)	A	3	5.7	250	1700	3/4 Max.	–	4	2	500	140.9	142.9	–2.0	–1.0
	Aug. 9	Windy, 55°	HL-6	5	Gran. (Firm)	A	4	5.2	265	1700	3/4 Max.	–	8	2	400	143.4	142.9	+0.5	0.0
	Aug. 9	Windy, 55°	HL-6	4	Gran. (Firm)	C	1	–	245	2400	High/Low	–	1/3	–	450	140.7	142.9	–2.2	–1.0
	Aug. 9	Windy, 55°	HL-6	4	Gran. (Firm)	C	2	–	215	2000	High/Low	–	1/3	–	300	138.8	142.9	–4.1	–3.0
	Aug. 9	Windy, 55°	HL-6	4	Gran. (Firm)	C	3	3.4	220	2400	Low	–	6	–	600	139.2	142.9	–3.7	–2.0
	Aug. 9	Windy, 55°	HL-6	4	Gran. (Firm)	C	4	–	220	2400	Low	–	4	2	550	138.9	142.9	–4.0	–3.0
	Aug. 9	Windy, 55°	HL-6	3-3/4	Gran. (Firm)	C	5	–	225	2000	Low	–	4	2	900	140.2	142.9	–2.7	–2.0
	Aug. 9	Windy, 55°	HL-6	3-1/2	Gran. (Firm)	C	6	–	235	2000	Low	–	4	2	250	141.4	142.9	–1.5	–1.0
	Aug. 9	Windy, 55°	HL-6	3-1/2	Gran. (Firm)	C	7	2.0	235	2000	Low	–	4	2	445	143.4	142.9	+1.5	+1.0

Table 6 (Cont'd), Vibratory Rolling

CONTRACT NUMBER	DATE	WEATHER	MIX Type	MIX Thick. (in.)	MIX Base	ROLLER	TEST NUMBER	ROLLER SPEED (MPH)	ROLLING TEMP. (°F)	VIBRATION Frequency (v.p.m.)	VIBRATION Amplitude	NUMBER OF PASSES Stat.	NUMBER OF PASSES Vib.	NUMBER OF PASSES Stat.	TEST LENGTH (ft.)	TEST AVERAGE DENSITY (lbs./c.f.)	2. AVG. CONV. DENSITY (lbs./c.f.)	3. DENSITY DIFF. (1.–2.) (lbs./c.f.)	COMP'N. DIFF. (3.) x 100/150 (%)
	Aug. 10	Windy, 70°	HL-6	4	Gran. (Firm)	A	1	3.3	250	1700	1/2 Max.	–	4	–	400	142.9	142.9	0.0	0.0
	Aug. 10	Windy, 70°	HL-6	4	Gran. (Firm)	A	2	3.3	255	1700	1/2 Max.	–	8	–	500	143.6	142.9	+0.7	0.0
	Aug. 10	Windy, 70°	HL-6	4	Gran. (Firm)	A	3	3.4	250	1700	1/4 Max.	–	4	–	500	140.0	142.9	-2.9	-2.0
	Aug. 10	Windy, 70°	HL-6	4	Gran. (Firm)	A	4	3.4	250	1700	1/4 Max.	–	8	–	500	141.3	142.9	-1.6	-1.0
	Aug. 10	Windy, 70°	HL-6	4-1/4	Gran. (Firm)	A	5	3.3	250	1700	Max.	–	6	–	500	142.8	142.9	-1.0	-1.0
	Aug. 10	Windy, 70°	HL-6	3-1/2	Gran. (Firm)	A	6	3.3	235	1700	3/4 Max.	–	6	–	500	141.4	142.9	-1.5	-1.0
	Aug. 10	Windy, 70°	HL-6	4	Gran. (Firm)	A	7	3.3	230	1700	1/2 Max.	–	6	–	500	143.0	142.9	+0.1	0.0
	Aug. 10	Windy, 70°	HL-6	3-1/2	Gran. (Firm	A	8	3.3	235	1700	1/4 Max.	–	6	–	500	141.2	142.9	-1.7	-1.0
	Aug. 10	Windy, 70°	HL-6	3-1/2	Gran. (Firm)	A	9	3.4	240	1700	Max.	–	10	–	500	141.4	142.9	-1.5	-1.0
	Aug. 10	Windy, 70°	HL-6	4	Gran. (Firm)	A	10	3.3	210	1700	Min.	–	10	–	600	141.3	142.9	-1.6	-1.0
	Aug. 10	Windy, 70°	HL-6	4-1/2	Gran. (Firm)	A	11	3.3	240	1700	Max./Min.	–	1/1	–	800	138.2	142.9	-4.7	-3.0
	Aug. 11	Cloudy, 70°	HL-6	2-3/4	Gran. (Firm)	C	1	3.6	210	2400	High	–	4	–	500	142.3	142.9	-0.6	0.0
	Aug. 11	Cloudy, 70°	HL-6	3-1/2	Gran. (Firm)	C	2	4.6	250	2400	High	–	6	–	500	140.5	142.9	-2.4	-2.0
	Aug. 11	Cloudy, 70°	HL-6	3	Gran. (Firm)	C	3	5.2	210	2400	High	–	8	–	500	142.0	142.9	-0.9	-1.0
	Aug. 11	Cloudy, 70°	HL-6	2-3/4	Gran. (Firm)	C	4	4.6	220	2000	High	–	4	–	500	143.8	142.9	+0.9	+1.0
	Aug. 11	Cloudy, 70°	HL-6	3-3/4	Gran. (Firm)	C	5	5.2	215	2000	High	–	6	–	500	145.8	142.9	+2.9	+2.0
	Aug. 11	Cloudy, 70°	HL-6	4-1/2	Gran. (Firm)	C	6	5.0	200	2000	High	–	8	–	500	141.6	142.9	-1.3	-1.0
	Aug. 11	Cloudy, 70°	HL-6	4	Gran. (Firm)	C	7	2.1	210	2400	High/Low	–	4/2	–	500	141.8	142.9	-1.1	-1.0
	Aug. 11	Cloudy, 70°	HL-6	5-1/2	Gran. (Firm)	C	8	–	–	2400	High	–	4	–	455	139.8	142.9	-3.1	-2.0
71-147[3]	July 31	Sunny, 85°	HL-6	1-1/2	Exist.	A	1	3.3	–	1700	Max.	–	2	–	600	138.4	142.8	-4.4	-3.0
	July 31	Sunny, 85°	HL-6	1-1/2	Exist.	A	2	3.3	170	1700	Max.	–	1	1	500	138.4	142.8	-4.4	-3.0
	July 31	Sunny, 85°	HL-6	1-1/2	Exist	A	3	3.3	200	1700	3/4 Max.	–	1	1	650	139.4	142.8	-3.4	-2.0
	July 31	Sunny, 85°	HL-6	1-1/2	Exist.	A	4	3.3	215	1700	3/4 Max.	–	2	–	450	140.7	142.8	-2.1	-1.0
	July 31	Sunny, 85°	HL-6	1-1/2	Exist.	A	5	3.3	220	1700	1/2 Max.	–	2	–	350	140.0	142.8	-2.8	-2.0
	July 31	Sunny, 85°	HL-6	1-1/2	Exist.	A	6	3.3	210	1700	1/2 Max.	–	1	1	500	140.3	142.8	-2.5	-2.0
	July 31	Sunny, 85°	HL-6	1-1/2	Exist.	A	7	3.3	220	1700	1/2 Max.	1	1	–	500	139.9	142.8	-2.9	-2.0
	July 31	Sunny, 85°	HL-6	1-1/2	Exist.	A	8	3.3	200	1700	3/4 Max.	1	1	–	300	139.8	142.8	-3.0	-2.0
	July 31	Sunny, 85°	HL-6	1-1/2	Exist.	A	9	3.3	220	1700	Max.	–	1	–	500	141.5	142.8	-1.3	-1.0
	July 31	Sunny, 85°	HL-6	1-1/2	Exist.	A	10	3.3	220	1700	Max.	–	2	–	500	141.6	142.8	-1.2	-1.0
	July 31	Sunny, 85°	HL-6	2-1/2	Exist.	A	10A	3.3	235	1700	Max.	–	2	–	500	142.9	N/A	–	
	July 31	Sunny, 85°	HL-6	1-1/2	Exist.	A	11	3.3	215	1700	Max.	–	4	–	500	141.0	142.8	-1.8	-1.0
	July 31	Sunny, 85°	HL-6	1-1/2	Exist.	A	12	3.3	200	1700	1/4 Max.	–	4	–	200	141.0	142.8	-1.8	-1.0
	Aug. 1	Sunny, 75°	HL-6	1-1/2	Exist.	C	1	2.3	150	2400	Low	–	2	–	500	138.2	142.8	-4.6	-3.0
							1									143.3[4]	142.8	+0.5	
	Aug. 1	Sunny, 75°	HL-6	1-1/2	Exist.	C	2	2.3	150	2000	Low	–	2	–	500	138.3	142.8	-4.5	-3.0
							2									143.3[4]	142.8	+0.5	
	Aug. 1	Sunny, 75°	HL-6	1/2	Exist.	C	3	2.0	150	1800	Low	–	2	–	700	138.6	N/A	–	–
							3									143.1[4]	N/A	–	
	Aug. 1	Sunny, 75°	HL-6	1-1/2	Exist.	C	4	3.8	180	2400	Low	–	4	–	400	140.2	142.8	-2.6	-2.0
							4									143.6[4]	142.8	+0.8	
	Aug. 1	Sunny, 75°	HL-6	1-3/4	Exist.	C	5	5.2	150	2000	Low	–	4	–	500	139.7	142.8	-3.1	-2.0
							5									143.6[4]	142.8	+0.8	
	Aug. 1	Sunny, 75°	HL-6	1-1/4	Exist.	C	6	5.7	170	1800	Low	–	4	–	600	138.7	142.8	-4.1	-3.0
							6									141.4[4]	142.8	-1.4	
	Aug. 1	Sunny, 75°	HL-6	1-1/2	Exist.	C	7	5.7	160	2400	Low	–	3	1	500	141.5	142.8	-1.3	-1.0
							7									143.3[5]	142.8	+0.5	
	Aug. 1	Sunny, 75°	HL-6	1-1/2	Exist.	C	8	5.7	160	2000	Low	–	3	1	500	140.8	142.8	-2.0	-1.0
							8									144.5[4]	142.8	+1.7	
	Aug. 1	Sunny, 75°	HL-6	1-1/2	Exist.	C	9	5.2	205	1800	Low	–	3	1	500	138.4	142.8	-4.4	-3.0
							9									143.6[4]	142.8	+0.8	
	Aug. 1	Sunny, 75°	HL-6	4-1/2	Exist.	C	10	5.7	200	2400	Low	–	2	–	300	137.8	142.8	-4.8	-3.0
							10									143.7[4]	142.8	+0.9	
	Aug. 1	Sunny, 75°	HL-6	4-1/2	Exist	C	11	4.6	220	2000	Low	–	2	–	500	142.9	142.8	+0.1	0.0
							11									145.1[4] •	142.8	+2.2	

Table 6 (Cont'd), Vibratory Rolling

CONTRACT NUMBER	DATE	WEATHER	MIX Type	MIX Thick. (in.)	MIX Base	ROLLER	TEST NUMBER	ROLLER SPEED (MPH)	ROLLING TEMP. (°F)	VIBRATION Frequency (v.p.m.)	VIBRATION Amplitude	NUMBER OF PASSES Stat.	NUMBER OF PASSES Vib.	NUMBER OF PASSES Stat.	TEST LENGTH (ft.)	TEST AVERAGE DENSITY (lbs./c.f.)	2. AVG. CONV. DENSITY (lbs./c.f.)	3. DENSITY DIFF. (1.–2.) (lbs./c.f.)	COMP'N. DIFF. (3.) x 100/150 (%)
71-147[3]	Aug. 3	Cloudy, 70°	HL-6	2-1/2	Exist.	C	1	2.7	190	1800	Low	–	4	–	600	143.1	N/A	–	
	Aug. 3	Cloudy, 70°	HL-6	1-3/4	Exist.	C	2	2.7	180	1800	Low	–	2	–	400	138.1	142.8	-4.7	-3.0
	Aug. 3	Cloudy, 70°	HL-6	1-1/4	Exist.	C	3	2.7	145	1800	Low	–	6	–	600	140.1	142.8	-1.7	-1.0
	Aug. 3	Cloudy, 70°	HL-6	2-1/2	Exist.	C	4	4.6	160	2000	Low	–	6	–	1100	144.2	N/A	–	
							4									146.6[5]	N/A	–	
	Aug. 3	Cloudy, 70°	HL-6	1-3/4	Exist.	C	5	4.6	170	2400	Low	–	6	–	500	146.8	142.8	+4.0	+3.0
							5									148.4[5]	142.8	+5.6	
	Aug. 3	Cloudy, 70°	HL-6	3	Exist.	C	6	4.6	205	2400	High/Low	–	1/1	–	600	139.5	147.6[6]	-8.1	-5.0
							6									146.3[5]	147.6[6]	-1.3	
	Aug. 3	Cloudy, 70°	HL-6	2	Exist.	C	7	4.6	170	1800	High/Low	–	1/1	–	500	138.5	142.8	-4.3	-3.0
							7									146.0[5]	142.8	+3.2	
	Aug. 3	Cloudy, 70°	HL-6	1-3/4	Exist.	C	9	4.6	200	2400	Low/High	–	1/1	–	700	140.0	142.8	-2.8	-2.0
							9									145.8[5]	142.8	+3.0	
	Aug. 3	Cloudy, 70°	HL-6	2-3/4	Exist.	C	10	3.8	230	2000	Low/High	–	1/1	–	500	142.0	147.6[6]	-5.6	-4.0
							10									143.2[4]	147.6[6]	-4.4	
							10									146.8[5]	147.6[6]	-0.8	
	Aug. 3	Cloudy, 70°	HL-6	3	Exist.	C	11	4.6	250	2400	Low	–	6	–	500	145.1	147.6[6]	-2.5	-2.0
							11									145.7[4]	147.6[6]	-1.9	
							11									148.1[5]	147.6[6]	+0.5	
	Aug. 3	Cloudy, 70°	HL-6	3-3/4	Exist.	C	12	3.4	240	2400	High/Low	–	2/2	–	500	143.7	147.6[6]	-3.9	-3.0
							12									143.5[4]	147.6[6]	-4.1	
							12									148.0[5]	147.6[6]	+0.4	
	Aug. 3	Cloudy, 70°	HL-6	3	Exist.	C	13	–	225	2400	Low	–	4	–	600	142.0	147.6[6]	-5.6	-4.0
							13									142.9[4]	147.6[6]	-4.7	
							13									147.5[5]	147.6[6]	-0.1	
72-09	Aug. 16	Cloudy, 70°	HL-4	1-1/2	S.A.L.	D	1	2.5	230	2400	Low	–	2	–	230	139.5	140.8	-1.5	-1.0
	Aug. 17	Cloudy, 70°	HL-4	1-1/2	S.A.L.	A	1	2.6	180	1700	Max.	–	6	–	530	139.2	140.8	-1.6	-1.0
	Aug. 22	Cloudy, 75°	HL-4	1-1/2	S.A.L.	A	1	1.0	195	1700	Max.	–	4	–	500	137.2	137.7	-0.5	0.0
							1									140.3[2]	137.7	+2.6	+2.0[2]
	Aug. 22	Cloudy, 75°	HL-4	1-1/2	S.A.L.	A	2	3.4	235	1700	Max.	–	4	–	500	135.5	137.7	-2.2	-1.0
							2									139.3[2]	137.7	+1.6	+1.0[2]
	Aug. 22	Cloudy, 75°	HL-4	1-1/2	S.A.L.	A	3	2.7	195	1700	Max.	–	6	–	500	134.0	137.7	-3.7	-2.0
							3									139.4[2]	137.7	+1.7	+1.0[2]
	Aug. 22	Cloudy, 75°	HL-4	1-1/2	S.A.L.	A	4	3.4	185	1700	Max.	–	2	–	500	137.1	137.7	-0.6	0.0
	Aug. 22	Cloudy, 75°	HL-4	1-1/2	S.A.L.	A	5	3.1	225	1700	1/2 Max.	–	4	–	500	136.0	137.7	-1.7	-1.0
	Aug. 22	Cloudy, 75°	HL-4	1-1/2	S.A.L.	A	6	3.0	245	1700	1/2 Max.	–	2	–	500	135.0	137.7	-2.7	-2.0
	Aug. 22	Cloudy, 75°	HL-4	1-1/2	S.A.L.	A	7	2.7	195	1700	Min.	–	6	–	470	135.5	137.7	-2.2	-1.0
72-09	Aug. 24	Fair, 70°	HL-4	1-1/2	S.A.L.	A	1	1.8	230	1700	Min.	–	4	–	300	136.0	137.7	-1.7	-1.0
							1									137.0[2]	137.7	-0.7	0.0[2]
	Aug. 24	Fair, 70°	HL-4	1-1/2	S.A.L.	A	2	3.4	215	1700	Min.	–	4	–	300	133.9	137.7	-3.8	-3.0
							2									135.0[2]	137.7	-2.7	-2.0[2]
	Aug. 24	Fair, 70°	HL-4	1;1/2	S.A.L.	A	3	1.8	210	1700	Max.	–	4	–	300	135.4	137.7	-2.3	-2.0
							3									135.6[2]	137.7	-2.1	-1.0[2]
	Aug. 24	Fair, 70°	HL-4	1-1/2	S.A.L.	A	4	3.4	185	1700	Max.	–	4	–	400	133.4	137.7	-4.3	-3.0
							4									136.2[2]	137.7	-1.5	-1.0[2]
	Aug. 24	Fair, 70°	HL-4	1-1/2	S.A.L.	D	5	–	225	2400	Low	–	4	–	270	132.8	137.7	-4.9	-3.0
							5									134.4[2]	137.7	-3.3	-2.0[2]
	Aug. 24	Fair, 70°	HL-4	1-1/2	S.A.L.	D	6	–	225	2400	Low	–	2	2	400	135.5	137.7	-2.2	-1.0
							6									137.1[2]	137.7	-0.6	0.0[2]

Table 6 (Cont'd), Vibratory Rolling

CONTRACT NUMBER	DATE	WEATHER	MIX Type	MIX Thick. (in.)	MIX Base	ROLLER	TEST NUMBER	ROLLER SPEED (MPH)	ROLLING TEMP. (°F)	VIBRATION Frequency (v.p.m.)	VIBRATION Amplitude	NUMBER OF PASSES Stat.	NUMBER OF PASSES Vib.	NUMBER OF PASSES Stat.	TEST LENGTH (ft.)	TEST AVERAGE DENSITY (lbs./c.f.)	2. AVG. CONV. DENSITY (lbs./c.f.)	3. DENSITY DIFF. (1.–2.) (lbs./c.f.)	COMP'N. DIFF. (3.) x 100/150 (%)
72-50	Aug. 28	Sunny, 80°	HL-4	1-1/2	S.A.L.	D	1	–	185	2400	Low	–	4	–	500	135.8	135.9	-0.1	0.0
							1									137.1[2]	135.9	+1.2	+1.0[2]
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	D	1	–	210	2400	Low	–	4	–	400	136.2	135.9	+0.3	0.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	2	3.0	170	1700	Max.	–	4	–	400	135.7	135.9	-0.2	0.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	3	3.0	175	1700	Max.	–	2	–	400	131.7	135.9	-4.2	-3.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	4	3.0	160	1700	Max.	–	6	–	400	132.7	135.9	-3.2	-2.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	5	3.0	165	1700	1/2 Max.	–	4	–	400	132.8	135.9	-3.1	-2.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	6	3.0	175	1700	1/2 Max.	–	2	–	400	133.6	135.9	-2.3	-2.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	7	3.0	160	1700	1/2 Max.	–	6	–	400	135.0	135.9	-0.9	-1.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	8	3.0	160	1700	Min.	–	4	–	400	133.9	135.9	-2.0	-1.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	9	2.8	165	1700	Min.	–	4	–	500	134.5	135.9	-1.4	-1.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	10	3.3	155	1700	Min.	–	8	–	300	133.8	135.9	-2.1	-1.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	11	2.8	160	1700	Min.	–	4	–	500	132.1	135.9	-3.8	-3.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	12	2.8	165	1700	Max.	–	4	–	500	132.6	135.9	-3.3	-2.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	A	13	2.8	175	1700	Max.	–	6	–	150	135.4	135.9	-0.4	0.0
	Aug. 29	Sunny, 80°	HL-4	1-3/4	S.A.L.	D	14	–	195	2400	Low	–	2	2	400	136.6	135.9	+0.7	0.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	D	15	–	220	2400	Low	–	8	–	400	134.8	135.9	-1.1	-1.0
	Aug. 29	Sunny, 80°	HL-4	1-1/2	S.A.L.	D	16	–	195	2400	Low	–	6	2	400	136.8	135.9	+0.9	+1.0
	Aug. 29	Sunny, 80°	HL-4	1-1/4	S.A.L.	D	17	–	155	2000	Low	–	4	–	150	136.0	136.4	-0.4	0.0
72-50	Aug. 30	Fair, 75°	HL-4	1-1/4	S.A.L.	D	1	3.1	185	2000	Low	–	8	–	500	136.0	136.4	-0.4	0.0
							1									136.5[7]	136.4	+0.1	
	Aug. 30	Fair, 75°	HL-4	1-1/4	S.A.L.	D	2	2.8	195	2000	Low	–	4	–	500	137.5	136.4	+1.1	+1.0
							2									138.3[7]	136.4	+1.9	
	Aug. 30	Fair, 75°	HL-4	1-1/4	S.A.L.	D	3	3.1	235	2000	Low	–	12	–	300	140.0	136.4	+3.6	+2.0
							3									137.7[7]	136.4	+1.3	
	Aug. 30	Fair, 75°	HL-4	1-1/2	S.A.L.	D	4	2.7	205	2400	Low	–	2	2	300	139.0	135.9	+3.1	+2.0
							4									139.5[7]	135.9	+3.6	
	Aug. 30	Fair, 75°	HL-4	1-1/4	S.A.L.	D	5	3.4	205	2400	Low	–	4	–	500	139.1	136.4	+2.7	+2.0
							5									138.0[7]	136.4	+1.1	
							5									135.9[2]	136.4	-0.5	0.0[2]
	Aug. 30	Fair, 75°	HL-4	1-1/4	S.A.L.	D	6	2.4	160	2400	Low	–	8	–	300	138.5	136.4	+2.1	+1.0
							6									139.0[7]	136.4	+2.6	
							6									138.5[2]	136.4	+2.1	+1.0[2]
72-60	Sept. 6	Fair, 70°	HL-4	1-1/2	S.A.L.	A	1	3.1	210	1700	Max.	–	4	–	500	138.3	143.6	-5.3	-4.0
							1									140.7[2]	143.6	-2.9	-2.0[2]
	Sept. 6	Fair, 70°	HL-4	1-1/2	S.A.L.	A	2	2.8	200	1700	Max.	–	6	–	650	139.6	143.6	-4.0	-3.0
							2									141.0[2]	143.6	-2.6	-2.0[2]
	Sept. 8	Cloudy, 65°	HL-4	1-1/2	S.A.L.	A	1	2.5	270	1700	Max.	–	4	–	300	141.0	143.6	-2.6	-2.0
							1									142.3[2]	143.6	-1.3	-1.0[2]
71-33	Sept. 19	Cloudy, 50°	HL-4	1-1/4	S.A.L.	C	1	3.1	230	2400	Low	–	4	–	400	134.0	135.2	-1.2	-1.0
							1									135.9[2]	135.2	+0.7	0.0[2]
	Sept. 19	Cloudy, 50°	HL-4	1-3/4	S.A.L.	C	2	2.7	195	2400	Low	–	2	–	400	131.9	135.2	-3.3	-2.0
							2									134.6[2]	135.2	-0.6	0.0[2]
	Sept. 19	Cloudy, 50°	HL-4	1-1/2	S.A.L.	C	3	2.7	175	2400	Low	–	6	–	280	133.6	135.2	-1.6	-1.0
							3									135.8[2]	135.2	+0.6	0.0[2]
	Sept. 20	Fair, 55°	HL-4	1-3/4	S.A.L.	A	1	2.7	230	1700	Max.	–	4	–	400	135.5	135.2	+0.3	0.0
							1									135.6[2]	135.2	+0.4	0.0[2]
	Sept. 20	Fair, 55°	HL-4	1-1/2	S.A.L.	A	2	2.7	240	1700	Max.	–	2	–	400	134.5	135.2	-0.7	0.0
							2									136.6[2]	135.2	+1.4	+1.0[2]
	Sept. 20	Fair, 55°	HL-4	1-3/4	S.A.L.	A	3	2.1	215	1700	Max.	–	6	–	400	133.4	135.2	-1.8	-1.0
							3									137.3[2]	135.2	+2.1	+1.0[2]

Table 6 (Cont'd), Vibratory Rolling

CONTRACT NUMBER	DATE	WEATHER	MIX Type	MIX Thick. (in.)	MIX Base	ROLLER	TEST NUMBER	ROLLER SPEED (MPH)	ROLLING TEMP. (°F)	VIBRATION Frequency (v.p.m.)	VIBRATION Amplitude	NUMBER OF PASSES Stat.	NUMBER OF PASSES Vib.	NUMBER OF PASSES Stat.	TEST LENGTH (ft.)	TEST AVERAGE DENSITY (lbs./c.f.)	2. AVG. CONV. DENSITY (lbs./c.f.)	3. DENSITY DIFF. (1.–2.) (lbs./c.f.)	COMP'N. DIFF. (3.) x 100/150 (%)
	Sept. 20	Fair, 55°	HL-4	1-3/4	S.A.L.	A	4	1.8	225	1700	1/2 Max.	–	2	–	400	132.8	135.2	-2.4	-2.0
							4									135.5[2]	135.2	+0.3	0.0[2]
	Sept. 20	Fair, 55°	HL-4	1-1/2	S.A.L.	A	5	1.7	230	1700	1/2 Max.	–	4	–	370	133.6	135.2	-1.6	-1.0
							5									136.0[2]	135.2	+0.8	+1.0[2]
72-81	Oct. 3	Fair, 70°	HL-4	1-1/2	HL-4	A	1	2.4	250	1700	Max.	–	4	–	1100	134.5	137.1	-2.6	-2.0
							1									137.4[2]	137.1	+0.3	0.0[2]
							1									139.0[8]	137.1	+1.9	
	Oct. 3	Fair, 70°	HL-4	1-1/2	HL-4	A	2	2.4	220	1700	Max.	–	2	–	400	131.9	137.1	-5.2	-3.0
							2									136.1[2]	137.1	-1.0	-1.0[2]
							2									136.5[8]	137.1	-0.6	
	Oct. 3	Fair, 70°	HL-4	1-3/4	HL-4	A	3	2.4	210	1700	Max.	–	6	–	700	133.6	137.1	-3.5	-2.0
							3									136.8[2]	137.1	-0.3	0.0[2]
							3									137.0[8]	137.1	-0.1	
	Oct. 4	Clear, 50°	HL-4	1-1/2	HL-4	A	1	2.8	220	1700	Max.	–	8	–	500	134.9	137.1	-2.2	-1.0
	Oct. 4	Clear, 50°	HL-4	1-1/2	HL-4	E	2	3.1	230	2500	Low	–	4	–	500	131.9	137.1	-5.2	-3.0
	Oct. 4	Clear, 50°	HL-4	1-1/2	HL-4	E	3	3.1	250	2500	Low	–	6	–	400	132.0	137.1	-5.1	-3.0
	Oct. 5	Clear, 50°	HL-4	1-1/2	HL-4	E	2	3.1	285	2500	Low	–	4	–	400	133.5	137.1	-3.6	-2.0
							2									135.0[2]	137.1	-2.1	-1.0[2]
	Oct. 5	Clear, 50°	HL-4	1-1/2	HL-4	A	3	2.8	225	1700	Max.	–	4	–	500	133.5	137.1	-3.6	-2.0
72-66	Oct. 11	Cloudy, 55°	HL-3	1-1/4	S.A.L.	E	1	2.0	225	2500	Low	–	4	–	500	131.2	135.4	-4.2	-3.0
	Oct. 11	Cloudy, 55°	HL-3	1-1/2	S.A.L.	E	2	2.0	215	2500	Low	–	6	–	500	133.7	135.4	-1.7	-1.0
	Oct. 11	Cloudy, 55°	HL-3	1	S.A.L.	E	3	2.0	210	2500	Low	–	8	–	300	131.5	N/A		
	Oct. 12	Windy, 45°	HL-3	1-1/2	S.A.L.	E	1	1.7	215	2500	Low	–	4	–	1000	131.6[2]	135.4	-3.8	-3.0[2]
	Oct. 12	Windy, 45°	HL-3	1-1/2	S.A.L.	E	2	1.7	240	2500	Low	–	2	–	1000	131.0[2]	135.4	-4.4	-3.0[2]
	Oct. 16	Windy, 50°	HL-3	1-1/2	S.A.L.	A	1	2.5	235	1700	Max.	–	4	–	500	130.0	135.4	-5.4	-4.0
	Oct. 16	Windy, 50°	HL-3	1-1/2	S.A.L.	A	2	2.5	225	1700	Max.	–	6	–	450	133.3	135.4	-2.1	-1.0
71-192	Oct. 18	Cloudy, 50°	HL-8	3-1/2	Gran. (Firm)	A	1	2.1	220	1700	Max.	–	6	–	450	147.0	148.0	-1.0	-1.0
	Oct. 18	Cloudy, 50°	HL-8	3	Gran. (Firm)	A	2	1.8	250	1700	Max.	–	4	–	500	144.5	148.0	-3.5	-2.0
	Oct. 18	Cloudy, 50°	HL-8	3	Gran. (Firm)	A	3	1.6	240	1700	Max.	–	8	–	430	148.5	148.0	+0.5	0.0
	Oct. 18	Cloudy, 50°	HL-8	3	Gran. (Firm)	E	1	2.1	240	2500	Low	–	6	–	170	145.5	148.0	-2.5	-2.0
	Oct. 19	Clear, 40°	HL-8	3-1/2	Gran. (Firm)	E	1	1.7	275	2500	Low	–	8	–	500	147.1	148.0	-0.9	-1.0
	Oct. 19	Clear, 40°	HL-8	3-1/2	Gran. (Firm)	E	2	1.9	275	2500	Low	–	4	–	500	144.5	148.0	-3.5	-2.0
	Oct. 19	Clear, 40°	HL-8	3-1/2	Gran. (Firm)	E	3	1.5	280	2500	Low	–	6	–	450	144.0	148.0	-4.0	-3.0
	Oct. 20	Clear, 50°	HL-8	4	Gran. (Firm)	E	1	2.0	270	2500	Low	–	4	–	600	146.5[2]	148.0	-1.5	-1.0[2]
71-81	Oct. 31	Clear, 40°	HL-4	2	S.A.L.	D	1	1.5	210	2400	Low	–	2	–	1050	141.5	143.7	-2.2	-1.0
	Nov. 1	Clear, 50°	HL-4	2-1/4	HL-4	A	1	3.0	270	1700	Max.	–	6	–	500	144.0	143.7	+0.3	0.0
	Nov. 1	Clear, 50°	HL-4	2	HL-4	A	2	3.0	270	1700	Max.	–	4	–	500	139.0	143.7	-4.7	-3.0

Notes:

[1] *For comparison of the vibratory roller tests on this day only.*
[2] *Vibratory roller + pneumatic intermediate + tandem steel finish roller.*
[3] *Very open textured mat.*
[4] *Vibratory drum + rubber drive wheel path.*
[5] *Overlap of two roller paths = twice the drum coverage + twice the rubber drive wheel coverage.*
[6] *Possibly not representative of conventional rolling for this thickness.*
[7] *Overlap by the double drum roller.*
[8] *Single drum overlap + rubber drive wheel + tandem steel finish roller.*

Table 7, Vibratory Roller Tests: (Total Number/Successful Number) in Each Temperature - Thickness Grouping

ALL SINGLE DRUM

	$T < 180^\circ F$	$180^\circ \leqslant T \leqslant 250^\circ F$	$T > 250^\circ F$
$1'' \leqslant t \leqslant 1\frac{1}{4}''$	2/00	3/00	–
$t = 1\frac{1}{2}''$	18/2	56/9	2/0
$1\frac{1}{2}'' < t < 3''$	4/1	11/3	2/1
$3'' \leqslant t \leqslant 6''$	–	43/6	15/3

TOTAL = 157/25

ALL SINGLE DRUM + P.T. + 2S.W.

	$T < 180^\circ F$	$180^\circ \leqslant T \leqslant 250^\circ F$	$T > 250^\circ F$
$1'' \leqslant t \leqslant 1\frac{1}{4}''$	–	1/1	–
$t = 1\frac{1}{2}''$	1/1	19/11	2/0
$1\frac{1}{2}'' < t < 3''$	–	5/5	–
$3'' \leqslant t \leqslant 6''$	–	–	1/0

TOTAL = 29/18

DOUBLE DRUM

	$T < 180^\circ F$	$180^\circ \leqslant T \leqslant 250^\circ F$	$T > 250^\circ F$
$1'' \leqslant t \leqslant 1\frac{1}{4}''$	2/2	4/4	–
$t = 1\frac{1}{2}''$	–	8/4	–
$1\frac{1}{2}'' < t < 3''$	–	2/1	–
$3'' \leqslant t \leqslant 6''$	–	–	–

TOTAL = 16/11

DOUBLE DRUM + P.T. + 2S.W.

	$T < 180^\circ F$	$180^\circ \leqslant T \leqslant 250^\circ F$	$T > 250^\circ F$
$1'' \leqslant t \leqslant 1\frac{1}{4}''$	–	2/2	–
$t = 1\frac{1}{2}''$	–	3/2	–
$1\frac{1}{2}'' < t < 3''$	–	–	–
$3'' \leqslant t \leqslant 6''$	–	–	–

TOTAL = 5/4

Table 8, Vibratory Rolling Methods That Showed Success

SINGLE DRUM ROLLERS

ROLLING TEMPERATURE (°F)	THICK. (In.)	TESTS Freq. (v.p.m.)	Ampl.	Passes	Number of tests	RESULTS Failure	Success
T< 180	t=1½	1700	Max.	4	2	1	1
		1700	Max.	6	2	1	1
				Total	4	2	2
	1½<t<3	2400	Low	6	1		1
180⩽T⩽250	t=1½	1700	Max.	4	10	9	1
		1700	Max.	2	4	2	2
		2300	Low	2	3	2	1
		2000/2300	Low	1/1	1		1
		1700/2300	Low	1/1	1		1
		1700	Low	2	1		1
		2300	Low	1+1 Stat.	3	1	2
				Total	23	14	9
	1½<t<3	2400	High	4	1		1
		2000	High	4	1		1
		1700	Max.	4	1		1
				Total	3		3
	3⩽t⩽6	2000	Low	4+2 Stat.	3	2	1
		1700	½ Max.	8	2	1	1
		1700	½ Max.	6	1		1
		2000	High	6	1		1
		2000	Low	2	1		1
		1700	Max.	8	2	1	1
				Total	10	4	6
T> 250	3⩽t⩽6	1700/2300	High/Low	4/2	1		1
		1700	¾ Max.	8	1		1
		1700	½ Max.	8	1		1
				Total	3		3

DOUBLE DRUM ROLLER

ROLLING TEMPERATURE (°F)	THICK. (In.)	TESTS Freq. (v.p.m.)	Ampl.	Passes	Number of tests	RESULTS Failure	Success
180⩽T⩽250	1⩽t⩽1¼	2000	Low	8	1		1
		2000	Low	4	1		1
		2000	Low	12	1		1
		2400	Low	4	1		1
				Total	4		4
	t=1½	2400	Low	4	4	2	2
		2400	Low	6+2 Stat.	1		1
		2400	Low	2+2 Stat.	1		1
				Total	6	2	4

Table 9, Performance of the Control Vibratory Roller and Others, on a Contract Basis

CONTRACT		71-56	71-140	71-146	71-147	72-09	72-50
MIX		HL-5	HL-1	HL-6	HL-6	HL-4	HL-4
THICKNESS (in.)		4	1½	4	1½	1½	1½
BASE		Gran(Firm)	S.A.L.	Gran(Firm)	Exist.	S.A.L.	S.A.L.
COMPACTIBILITY INDEX		4.5	2.5	4.0	6.7	2.5	1.1
*Control Roller 'A'	4 Passes	-1.0[1]	N/A	-2.0[1]	-1.0[1]	-1.5[4]	-1.0[2]
	6 Passes	N/A	N/A	-1.0[1]	N/A	-1.5[2]	-1.0[2]
	8 Passes	N/A	N/A	-1.0[1]	N/A	N/A	N/A
Best Vibratory Test	Roller	B	B	C	A	A	D
	Freq. (v.p.m.)	1700/2300	1700/2300	2000	1700	1700	2400
	Amplitude	High/Low	Low	High	Max	Max	Low
	Passes	4/2	1/1	6	2	4	2
	Comp. Diff. (%)	0.0	+1.0	+2.0	-1.0	0.0	+2.0

CONTRACT		72-60	71-33	72-81	72-66	71-192	71-81
MIX		HL-4	HL-4	HL-4	HL-3	HL-8	HL-4
THICKNESS (in.)		1½	1½	1½	1½	3½	2
BASE		S.A.L.	S.A.L.	HL-4	S.A.L.	Gran(Firm)	HL-4
COMPACTIBILITY INDEX		2.1	1.0	1.7	0.8	9.1	3.4
*Control Roller 'A'	4 Passes	-3.0[2]	0.0[1]	-2.0[2]	-4.0[1]	-2.0[1]	-3.0[1]
	6 Passes	-3.0[1]	-1.0[1]	-2.0[1]	-1.0[1]	-1.0[1]	0.0[1]
	8 Passes	N/A	N/A	-1.0[1]	N/A	0.0[1]	N/A
Best Vibratory Test	Roller	A	A	A	E	A	A
	Freq. (v.p.m.)	1700	1700	1700	2500	1700	1700
	Amplitude	Max	Max	Max	Low	Max	Max
	Passes	4	4	8	6	8	8
	Comp. Diff. (%)	-2.0	0.0	-1.0	-1.0	0.0	0.0

**Roller 'A' was used on all contracts possible as a control roller. Its compaction difference at 1700 v.p.m. and Max. amplitude in 4, 6, and 8 passes is shown above. The value displayed indicates the compaction difference (%) based on that number of tests bracketed immediately afterwards. Furthermore, the most successful test section by any vibratory roller is described under Best Vibratory Test.*