HIGHWAY RESEARCH CIRCULAR

Number 46 | Subject Classification: Bituminous Materials and Mixes, Construction. | September 1966

Technical Papers Sponsored by:

Committee on Bituminous Aggregate Bases
Department of Materials and Construction
Highway Research Board

SINGLE LIFT CONSTRUCTION WITH HOT PLANT MIX BASE

by

Charles W. Beagle
Department of Public Works
Woodbridge, New Jersey

and

ASPHALT STABILIZATION OF SELECTED SAND AND GRAVEL BASE COURSES

by

John C. Riley, Asphalt Institute, College Park, Md.
and
G.C. Blomquist, Michigan State University, East Lansing, Mich.

EXPLANATION:

These papers were presented at the meeting of Committee MC-A7, "Bituminous Aggregate Bases", on Monday, January 17, 1966.

The papers were reviewed by members of the committee and recommended by the committee for publication in a circular. The recommendations were accepted by the division and the department.

The opinions and conclusions expressed in this publication are those of the authors and not necessarily those of the Highway Research Board.

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL NATIONAL ACADEMY OF SCIENCES - NATIONAL ACADEMY OF ENGINEERING
2101 CONSTITUTION AVENUE, N.W. WASHINGTON, D.C. 20418

SINGLE LIFT CONSTRUCTION
WITH HOT PLANT MIX BASE

In September, 1962, Woodbridge Township initiated a street construction program using Bituminous Stabilized Base instead of Dry Bound Macadam Base.

The subsoil prevalent throughout the Township was the chief cause of a slower than normal rate of construction. The Woodbridge area has been the source of commercial clays for the past 160 years.

The Stabilized Base used is a hot plant mix of bank run gravel and asphalt cement having a penetration of 85 to 100.

A sieve analysis is made of the bank run gravel before going into production. When necessary, crushed stone or washed gravel of the size and amount required to satisfy the gradation of the mix design, is added to the cold feed.

A Marshall Stability of 1000 pounds at 140 degrees Fahrenheit is required.

The mixing temperature is 300 to 350 degrees.

The idea was conceived that if a layer of Stabilized Base could be laid which would provide a cohesive strength sufficient to support the wheel load without deflection, then the clay would be confined; and the same principles applied to rigid construction design could be applied to the Stabilized Base design.

It was believed that 5 inches of Stabilized Base applied in a single lift and 2 inches of Bituminous Concrete surface would provide sufficient strength to achieve the desired result.

However, the sources of information available indicated that Stabilized Base should not be applied in lifts thicker than 3 inches.

When the program was started, several sections of streets were laid with two lifts of 2-1/2 inches in compacted thickness for comparison with the base laid in a single 5 inch lift.

Cores taken from the streets and tested indicated that a greater bulk density was obtained with the single lift construction. The results were far better than had been anticipated.

It was also found that where cores were removed from locations where granular subbase had been used, the subbase material contained water. Cores removed from locations where no subbase material was used and where the Stabilized Base was placed directly on the clay subgrade, no water was found on the subgrade. This indicated that the Bituminous Stabilized Base acted as a vapor barrier. It apparently kept the clay subsoil at near optimum

moisture which provided maximum stability.

The discovery that a greater bulk density was obtained with single lift construction and that the Bituminous Stabilized Base acted as a vapor barrier to the clay subsoil established two concepts:

1. That no granular subbase material is required for Stabilized base construction over Woodbridge clay soil.

2. That Hot Plant Mixed Bituminous Stabilized Base can be laid in a single lift to its designed thickness, at least to 5 inches in depth.

These two concepts and the new thickness design method developed by the Asphalt Institute became the basis for designing pavements in Woodbridge.

Traffic counts are taken on streets which are to be constructed and a design traffic number selected from the traffic analysis chart.

California Bearing Ratios are measured in place at selected locations and the designed elevation of the new subgrade.

The Traffic Number and the California Bearing Ratio are used with the thickness design chart to determine the total thickness of pavement required. By subtracting the minimum thickness of the surface course, the depth of the Bituminous Stabilized Base is determined. The base course is constructed in a single lift on the natural subgrade.

Since the inception of this method of construction, more than 35 miles of Municipal streets have been completed; and to date, not a single failure has occurred. There has been no deformity in the crown or the surface.

Using strength numbers that were determined by the A.S.S.H.O. Road Test, the pavement constructed with Bituminous Stabilized Base has 10 per cent more strength than the 9 inch pavement previously constructed.

The cost of constructing the pavement with single lift Stabilized Base proves to be 6 per cent less than the cost of the older type pavement. This cost comparison was based on total construction cost. It includes excavation, the removal of poor subgrade, and the placement of any subbase material.

The time required to construct pavement with Bituminous Stabilized Base was found to be one-fourth the time required to construct the older type pavement.

In attempting to find the reason for the results obtained, temperatures were taken near the top of the Stabilized Base and near the bottom of the Stabilized Base when it was first laid. The temperature recorded at the bottom of the Stabilized Base was 50 degrees lower than the temperature at the top of the base. A thermometer inserted into the subgrade at a depth of 1-1/2 inches recorded a rise in temperature of 40 degrees. These temperature recordings indicated that perhaps temperature was a factor contributing to the densities that were obtained.

A program was set up with the cooperation of the Contractor and the Testing Laboratory. Using a milli-volt potentiometer, a gang switch, and thermocouples, temperatures were recorded at vertical intervals of 1-1/2 inches from a point 3 inches below the subgrade upwards through the depth of the Stabilized Base to be laid.

Temperatures were recorded at 5 minute intervals until after all the rolling was completed.

Temperatures were recorded for:

1. A single lift of 2-1/2 inches compacted thickness.

2. A single lift of 5 inches compacted thickness.

3. A single lift of 7-1/2 inches compacted thickness.

4. A second lift of 2-1/2 inches compacted thickness placed on a 2-1/2 inch lift.

The laboratory analysis of the bank run sand and gravel to be used in the mix showed a deficiency of 3/4 inch aggregate. The addition of 20 per cent 3/4 inch stone and 2 per cent mineral filler produced the following results:

Sieve Size	Per Cent Passing
1-1/2	100
3/4	87.4
3/8	63.8
No. 4	49.6
10	41.6
40	26.1
80	7.6
200	3.4
Asphalt Cement	5.6

The Marshall Stability was 1100 pounds at 140 degrees Fahrenheit, and the per cent voids in the total mix was 6.5.

The Bituminous Stabilized Base for all compacted thicknesses was laid on the natural subgrade; no granular subbase was used.

California Bearing Ratios were measured in place at all test locations immediately after the subgrade was prepared and before the Stabilized Base was applied.

The Stabilized Base was spread with a Jersey Spreader powered by a Caterpillar 977H loader. Through experience it was learned that the Stabilized Base spread in this manner required a thickness of loose material equal to 1-1/3 times the designed compacted thickness. Between 6-1/2 and 7 inches was required for a 5 inch compacted base. Initial rolling was done with a 12 ton, 3 wheel roller and finished with a 20 ton, 3 axle tandem roller.

The thermocouples were placed in the subgrade prior to the spreading of the Stabilized Base. This permitted the recording of the subgrade temperature before application of the material. After the material was spread, a hole was dug in the freshly applied base material and the thermocouples were inserted at vertical intervals of 1-1/2 inches into the wall of the hole that was dug.

As soon as the hole was backfilled and leveled, the recording of temperatures commenced and continued until the rolling operation was completed. A gang switch was used to select the different thermocouples for recording the temperature with the milli-volt potentiometer.

The temperatures recorded were first plotted against the location of the thermocouples shown in inches above and below the subgrade. This produced curves showing the variation in temperature vertically through the base and the subgrade for periods of elapsed time after placing the material.

The temperatures recorded were also plotted against the elapsed time. This produced curves which show the temperature change at the various depths through the base and the subgrade.

The California Bearing Ratios measured in place were recorded in per cent at 1/10 inch penetration.

The per cent of natural moisture in the subgrade was determined in the laboratory from samples taken.

The subgrade temperatures were recorded at a depth of 3 inches below the subgrade.

The air temperature was recorded at the time the material was received and applied. The air temperature was also recorded when the rolling was completed.

The vertical spacing of the thermocouples at 1-1/2 inch intervals is a true dimension for the subsoil placements. The intervals through the Stabilized Base gradually reduced during the rolling procedure. For plotting purposes 1-1/2 inches was used.

SINGLE LIFT--2-1/2 INCHES COMPACTED THICKNESS

The temperature curves through the base at elapsed time after application (Plate 1) show an initial loss of 15 degrees in temperature near the top surface of the Stabilized Base and an initial loss of 43 degrees at the bottom of the base. The same curve shows a rise of 13 degrees in the subgrade at a depth of 1-1/2 inches.

After an elapsed time of 90 minutes, the temperature at the surface of the base dropped an additional 85 degrees. This is at the rate of about 1 degree per minute of elapsed time. During the same period of time, the temperature at the bottom of the base dropped an additional 63 degrees.

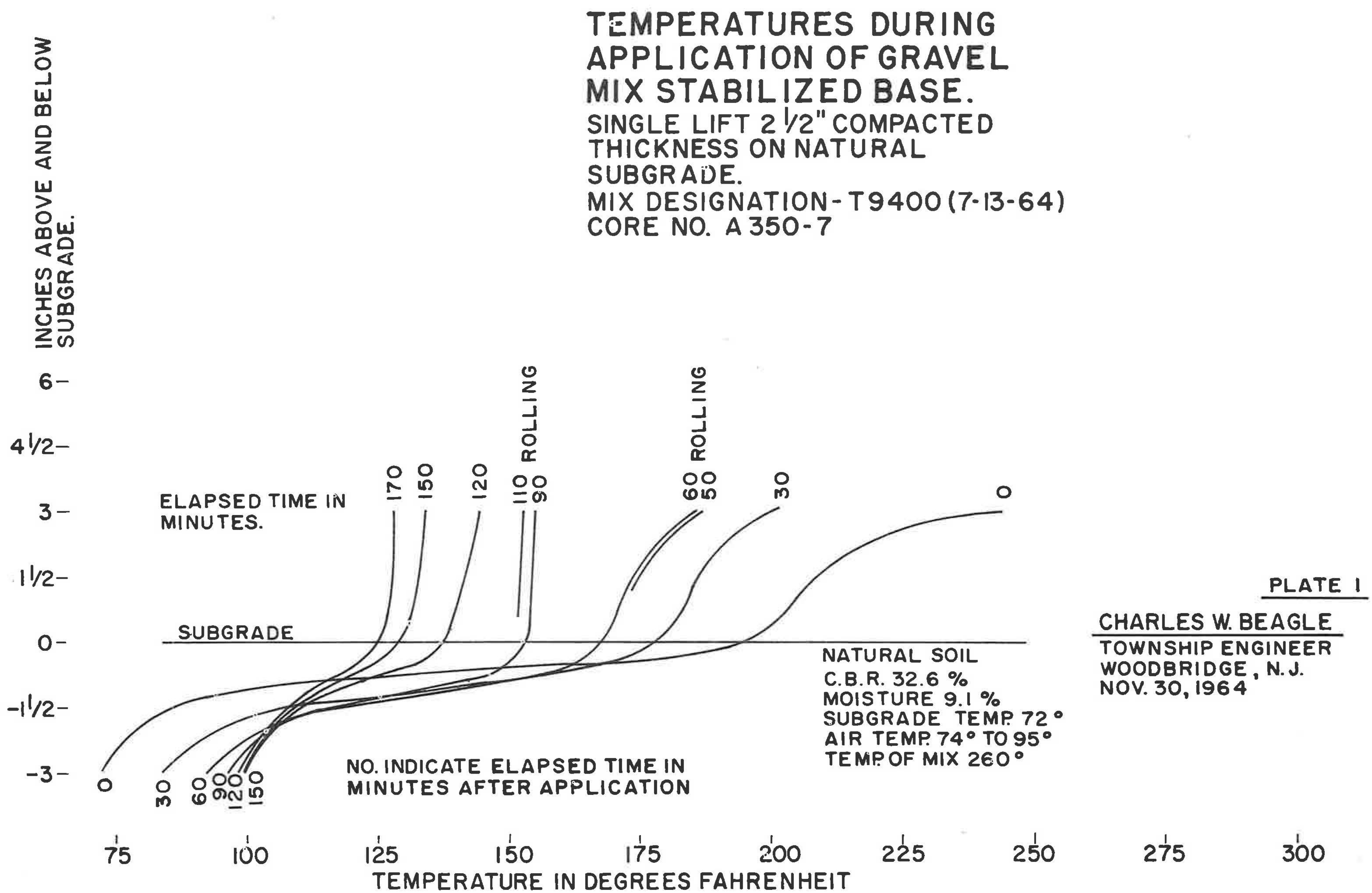
At a depth of 1-1/2 inches below the subgrade, there was an additional rise of 29 degrees, and at 3 inches deep in the subgrade there was a rise of 25 degrees in temperature.

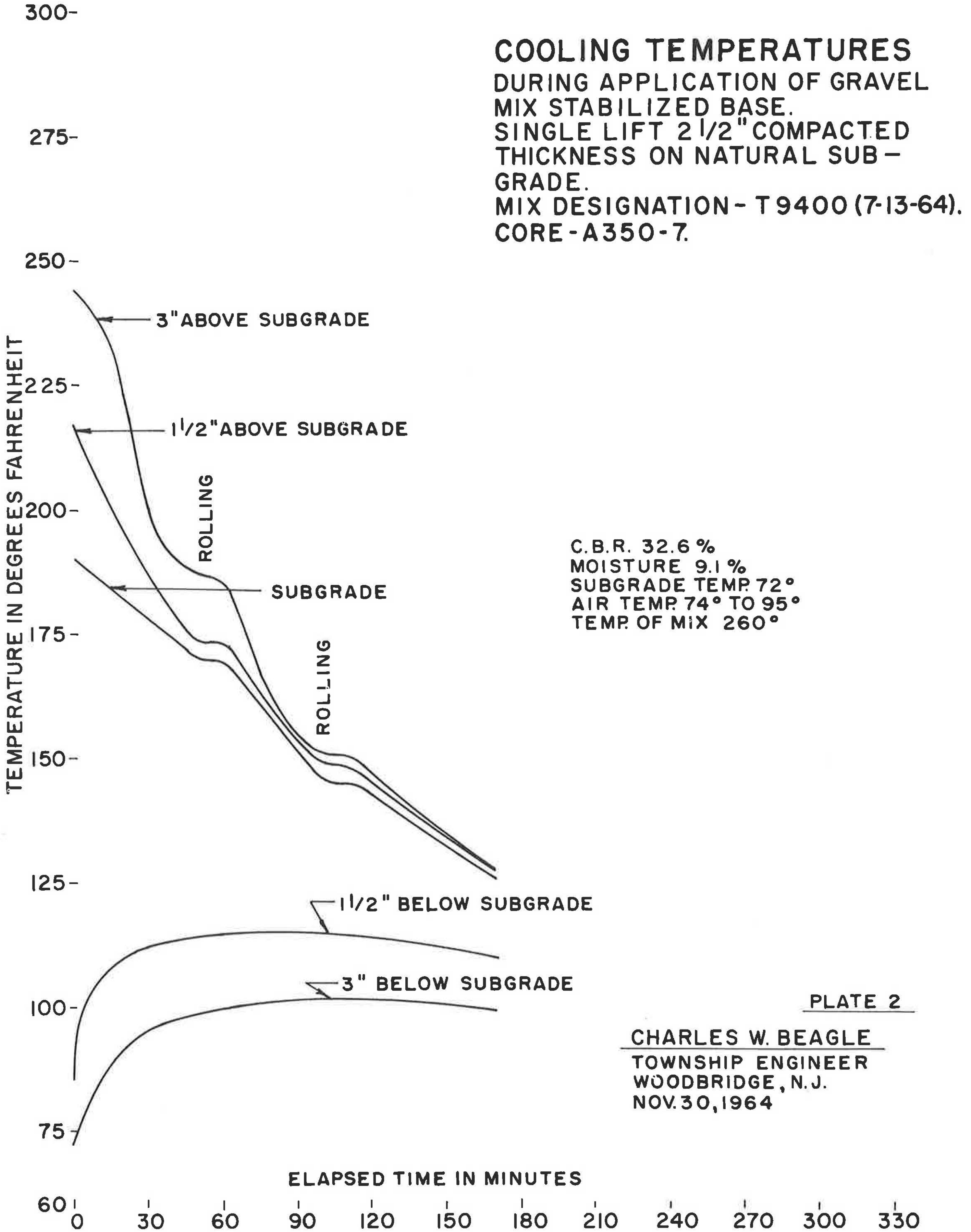
The temperature in the Stabilized Base was transmitted into the subgrade. The transmission of heat was so rapid that any cooling effect due to ambient temperature does not show on the curves.

The rate at which the material was cooling was retarded during the rolling operation. This can be seen much better when the temperatures are plotted against the elapsed time. (Plate 2)

The loose material cooled at the rate of about 1 degree per minute. During the rolling procedure, the cooling rate was reduced to 1/4 the rate. When the rolling stopped, the mix cooled at the rate of the loose material.

The heat from the mix continued to be transmitted to the subgrade. The subgrade temperature continued to rise until the rolling was completed. After the rolling is completed, the curves appear to be approaching a common point which would be the uniform temperature reached when completely cooled.


TEMPERATURES DURING APPLICATION OF GRAVEL MIX STABILIZED BASE.
SINGLE LIFT 2 1/2" COMPACTED THICKNESS ON NATURAL SUBGRADE.
MIX DESIGNATION - T9400 (7-13-64)
CORE NO. A 350-7
INCHES ABOVE AND BELOW SUBGRADE.
6
4 1/2
3
1 1/2
0
-1 1/2
-3
ELAPSED TIME IN MINUTES.
170
150
120
110
90
ROLLING
60
50
ROLLING
30
0
SUBGRADE
0
30
60
90
120
150
NO. INDICATE ELAPSED TIME IN MINUTES AFTER APPLICATION
NATURAL SOIL
C.B.R. 32.6 %
MOISTURE 9.1 %
SUBGRADE TEMP. 72°
AIR TEMP. 74° TO 95°
TEMP. OF MIX 260°
75
100
125
150
175
200
225
250
275
300
TEMPERATURE IN DEGREES FAHRENHEIT
PLATE I
CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE, N.J.
NOV. 30, 1964


COOLING TEMPERATURES
DURING APPLICATION OF GRAVEL MIX STABILIZED BASE.
SINGLE LIFT 2 1/2" COMPACTED THICKNESS ON NATURAL SUB-GRADE.
MIX DESIGNATION - T 9400 (7-13-64).
CORE - A350-7.
3" ABOVE SUBGRADE
1 1/2" ABOVE SUBGRADE
SUBGRADE
ROLLING
ROLLING
1 1/2" BELOW SUBGRADE
3" BELOW SUBGRADE
C.B.R. 32.6 %
MOISTURE 9.1 %
SUBGRADE TEMP. 72°
AIR TEMP. 74° TO 95°
TEMP. OF MIX 260°
TEMPERATURE IN DEGREES FAHRENHEIT
300
275
250
225
200
175
150
125
100
75
60
ELAPSED TIME IN MINUTES
0
30
60
90
120
150
180
210
240
270
300
330
PLATE 2
CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE, N.J.
NOV. 30, 1964

SINGLE LIFT--5 INCHES COMPACTED THICKNESS

The recorded temperatures through the base at elapsed time (Plate 3) show an initial loss of 12 degrees near the surface of the Stabilized Base and an initial loss of 41 degrees at the bottom of the Base, which is about the same as for the 2-1/2 inch lift. There is only a slight loss in the mid-section of the base.

The same curve shows a rise of 15 degrees in the subgrade at a depth of 1-1/2 inches.

After an elapsed time of 90 minutes, the temperature at the surface of the base dropped an additional 53 degrees. This is at the rate of about 6/10 of a degree per minute. During the same period of time, the temperature at the bottom of the base dropped an additional 59 degrees. The temperature in the mid-section dropped but was about 12 degrees higher than the temperature at the surface.

At a depth of 1-1/2 inches below the subgrade, there was an additional rise of 65 degrees; and at 3 inches deep in the subgrade, there was a rise of 46 degrees.

This group of curves shows the loss of heat by transmission into the subgrade to be 4 to 5 times greater than the loss due to ambient temperatures.

At one location selected for a 5 inch single lift, the per cent of natural moisture in the soil was 25. Plotting the temperature curves for this location shows a point of interest (Plate 4).

Twenty-five per cent moisture in the subsoil absorbs the heat from the base much more rapidly and has a deeper penetration. The temperature in the mid portion of the base remains at more than 175 degrees for 3 hours.

The temperature plotted against elapsed time (Plate 5) shows the rapid loss of temperature in the base at a point 1-1/2 inches above the subgrade. The temperature at 1-1/2 inches below the subgrade showed an immediate rise of 118 degrees, and after 30 minutes of elapsed time, became the same temperature as that recorded at the subgrade. The temperature at 3 inches below the subgrade shows a rise of 64 degrees.

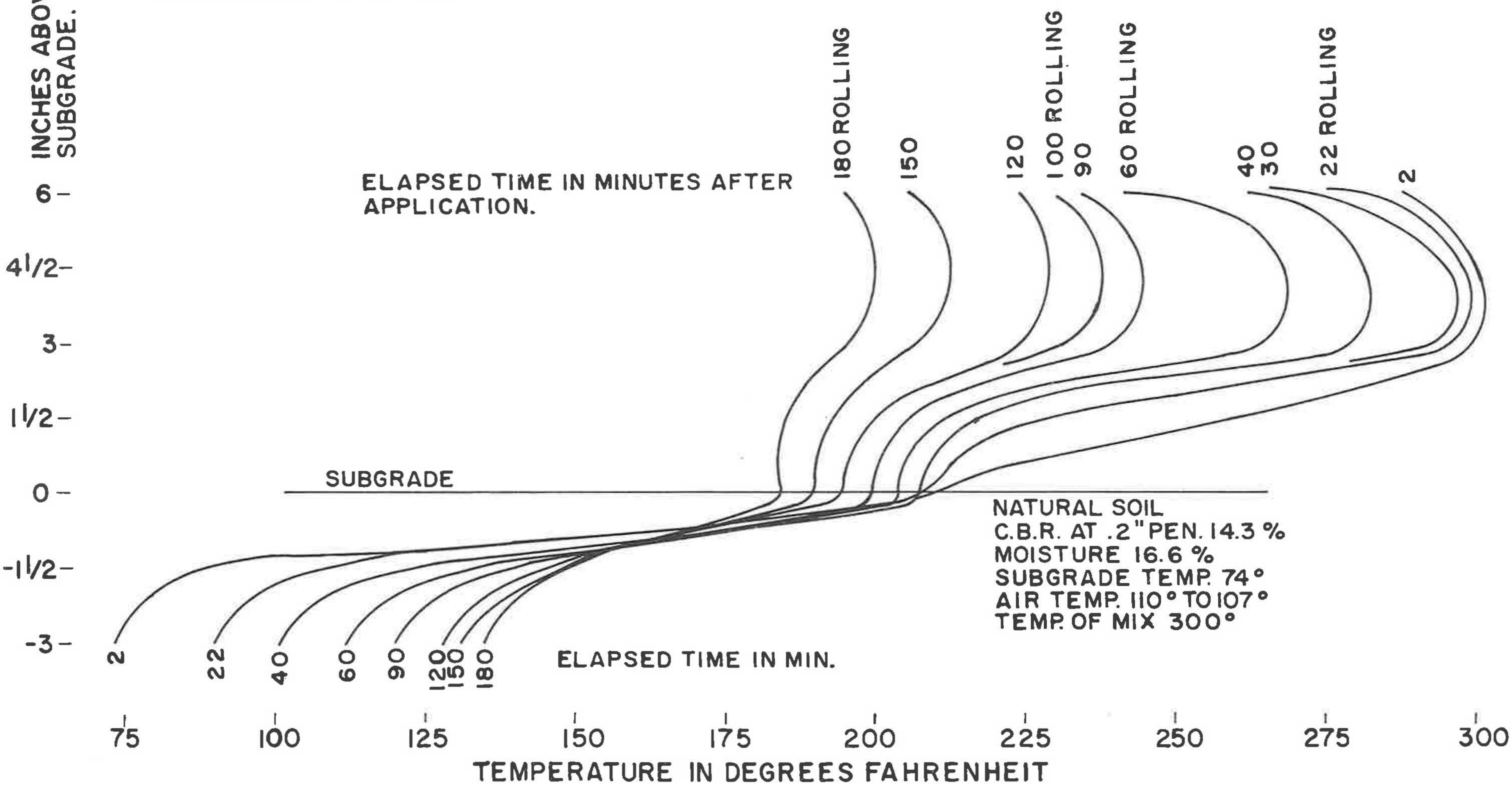
The highest temperature was at the 4-1/2 inch level until after 90 minutes of elapsed time. When the compaction rolling was completed, all curves appear to be converging.

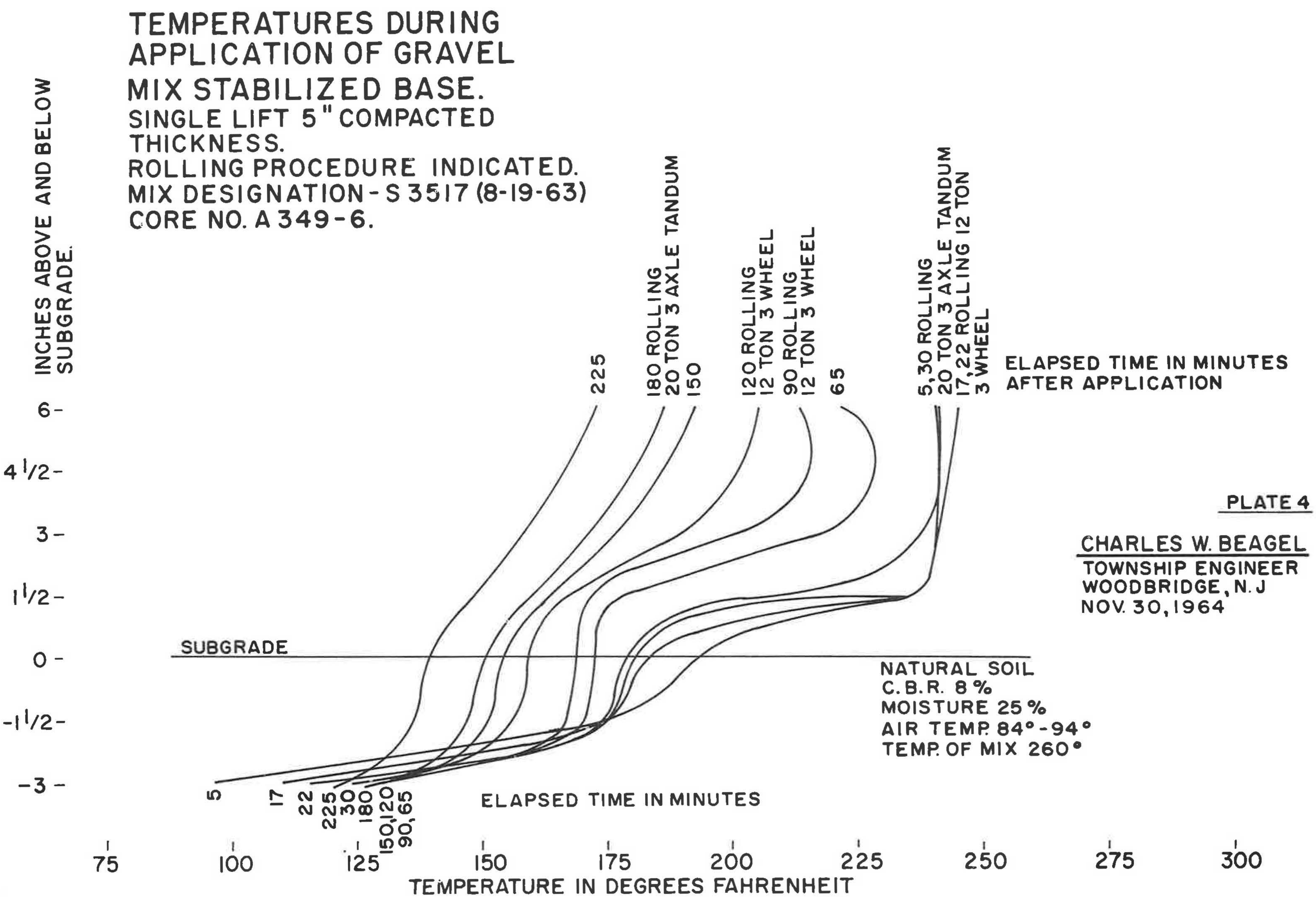
PLATE 3

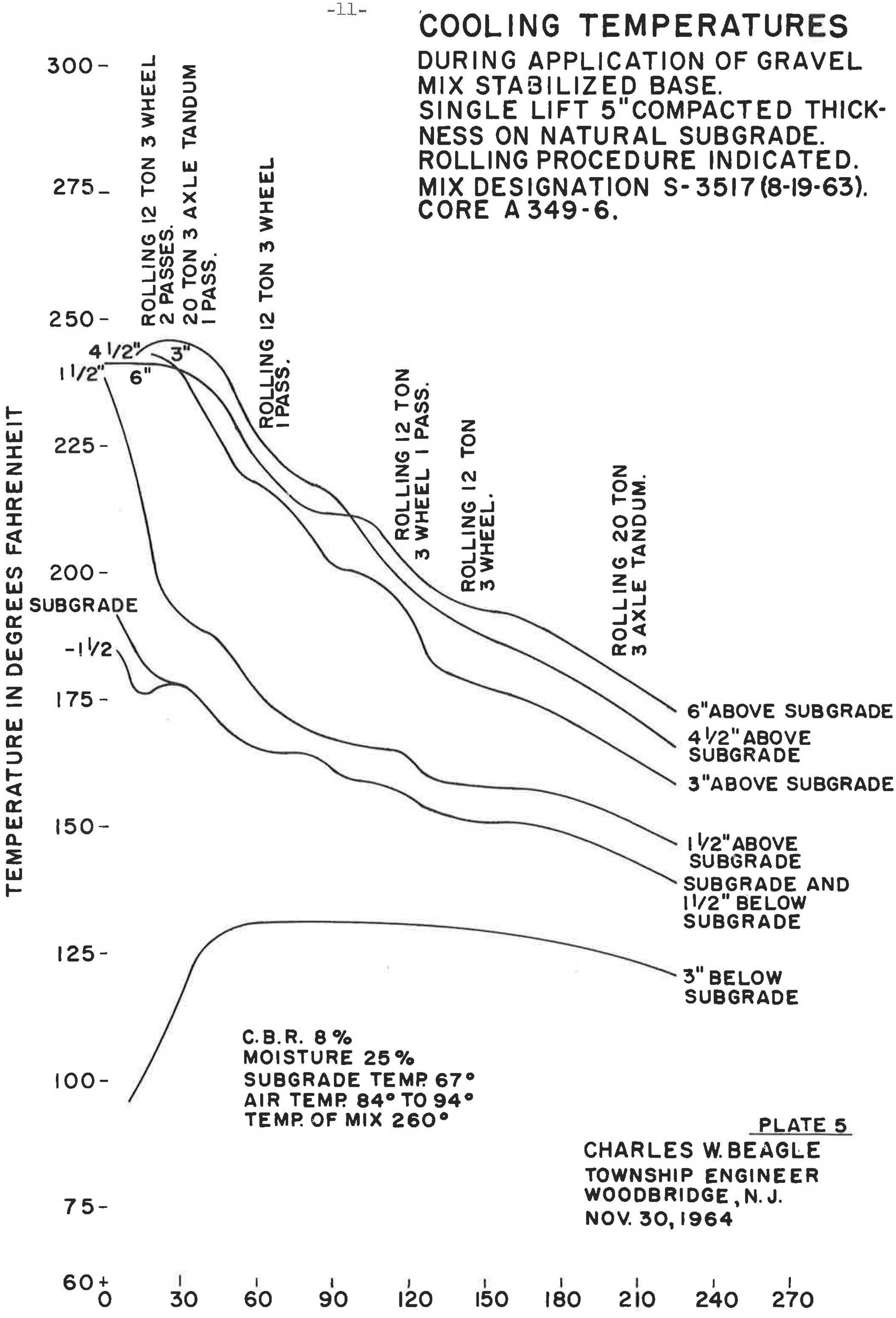
CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE, N.J.
NOV. 30, 1964

TEMPERATURES DURING APPLICATION OF GRAVEL MIX STABILIZED BASE.

SINGLE LIFT 5" COMPACTED THICKNESS ON NATURAL SUBGRADE.
MIX DESIGNATION - S-3517 (8-19-63)
CORE NO. A-347-4).




TEMPERATURES DURING APPLICATION OF GRAVEL MIX STABILIZED BASE.
SINGLE LIFT 5" COMPACTED THICKNESS.
ROLLING PROCEDURE INDICATED.
MIX DESIGNATION - S 3517 (8-19-63)
CORE NO. A 349-6.
INCHES ABOVE AND BELOW SUBGRADE.
6
4 1/2
3
1 1/2
0
-1 1/2
-3
225
180 ROLLING 20 TON 3 AXLE TANDUM
150
120 ROLLING 12 TON 3 WHEEL
90 ROLLING 12 TON 3 WHEEL
65
5,30 ROLLING 20 TON 3 AXLE TANDUM
17,22 ROLLING 12 TON 3 WHEEL
ELAPSED TIME IN MINUTES AFTER APPLICATION
SUBGRADE
NATURAL SOIL
C.B.R. 8 %
MOISTURE 25 %
AIR TEMP. 84° - 94°
TEMP. OF MIX 260°
5
17
22
225
30
180
150,120
90,65
ELAPSED TIME IN MINUTES
75
100
125
150
175
200
225
250
275
300
TEMPERATURE IN DEGREES FAHRENHEIT
PLATE 4
CHARLES W. BEAGEL
TOWNSHIP ENGINEER
WOODBRIDGE, N. J
NOV. 30, 1964


COOLING TEMPERATURES
DURING APPLICATION OF GRAVEL MIX STABILIZED BASE.
SINGLE LIFT 5" COMPACTED THICKNESS ON NATURAL SUBGRADE.
ROLLING PROCEDURE INDICATED.
MIX DESIGNATION S-3517 (8-19-63).
CORE A 349-6.
TEMPERATURE IN DEGREES FAHRENHEIT
300
275
250
225
200
175
150
125
100
75
60
0
30
60
90
120
150
180
210
240
270
ROLLING 12 TON 3 WHEEL 2 PASSES.
20 TON 3 AXLE TANDUM 1 PASS.
ROLLING 12 TON 3 WHEEL 1 PASS.
ROLLING 12 TON 3 WHEEL 1 PASS.
ROLLING 12 TON 3 WHEEL.
ROLLING 20 TON 3 AXLE TANDUM.
4 1/2"
3"
1 1/2"
6"
SUBGRADE
-1 1/2
6" ABOVE SUBGRADE
4 1/2" ABOVE SUBGRADE
3" ABOVE SUBGRADE
1 1/2" ABOVE SUBGRADE
SUBGRADE AND 1 1/2" BELOW SUBGRADE
3" BELOW SUBGRADE
C.B.R. 8 %
MOISTURE 25 %
SUBGRADE TEMP. 67°
AIR TEMP. 84° TO 94°
TEMP. OF MIX 260°
PLATE 5
CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE, N. J.
NOV. 30, 1964

SINGLE LIFT--7-1/2 INCHES COMPACTED THICKNESS

The temperature curves through the base at elapsed time after application (Plate 6) show an initial loss of only 3 degrees near the top surface of the Stabilized Base and an initial loss of 60 degrees near the bottom of the base. The same curve shows a rise of 31 degrees in the subgrade at depth of 1-1/2 inches.

After an elapsed time of 90 minutes, the surface temperature dropped an additional 61 degrees. This is a rate of less than 7/10 of a degree per minute of elapsed time.

During the same period of time the temperature at the bottom of the base dropped an additional 45 degrees.

At a depth of 1-1/2 inches below the subgrade, there was an additional rise of 40 degrees; and at 3 inches deep in the subgrade, there was an additional rise of 38 degrees. Again, the loss of heat by transmission into the subgrade was 4 to 5 times greater than the loss due to ambient temperature. The mid-section of the base remained at a higher temperature throughout the rolling procedure.

The temperatures plotted against elapsed time (Plate 7) show clearly the temperature loss at the subgrade and at the 1-1/2 inches above subgrade levels.

The temperature at 7-1/2 inches and 9 inches above the subgrade show the loss in temperature due to ambient temperature. The temperatures at the levels of 3 inches to 6 inches, inclusive, show that higher temperatures are retained for a longer period of time. The 4-1/2 level sustains the highest temperature just as it did in the 5 inch lift.

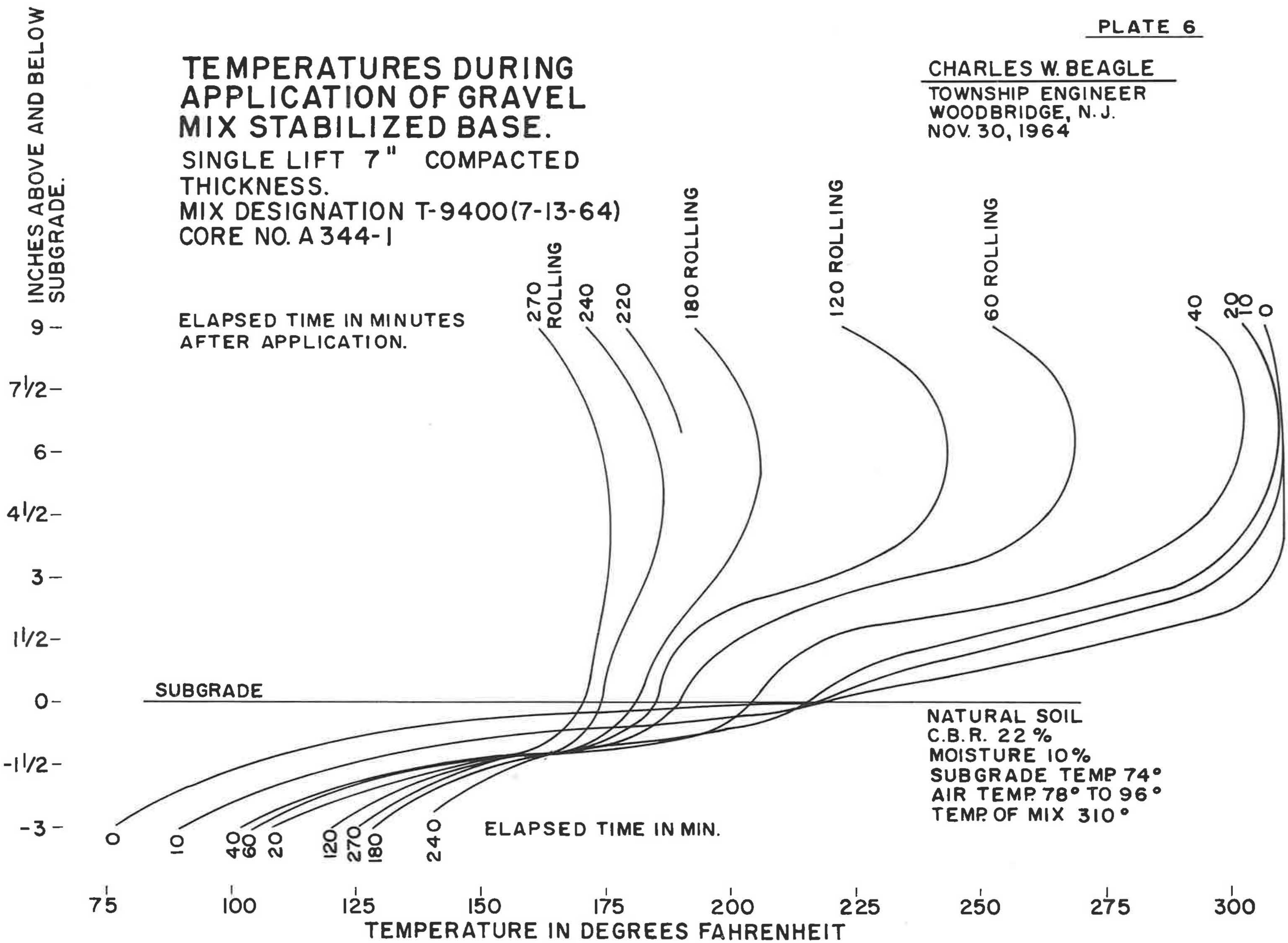
The thermocouples located at 4-1/2 inches above the subgrade and 3 inches below the subgrade were broken during the test but not before the general character of the curves was indicated.

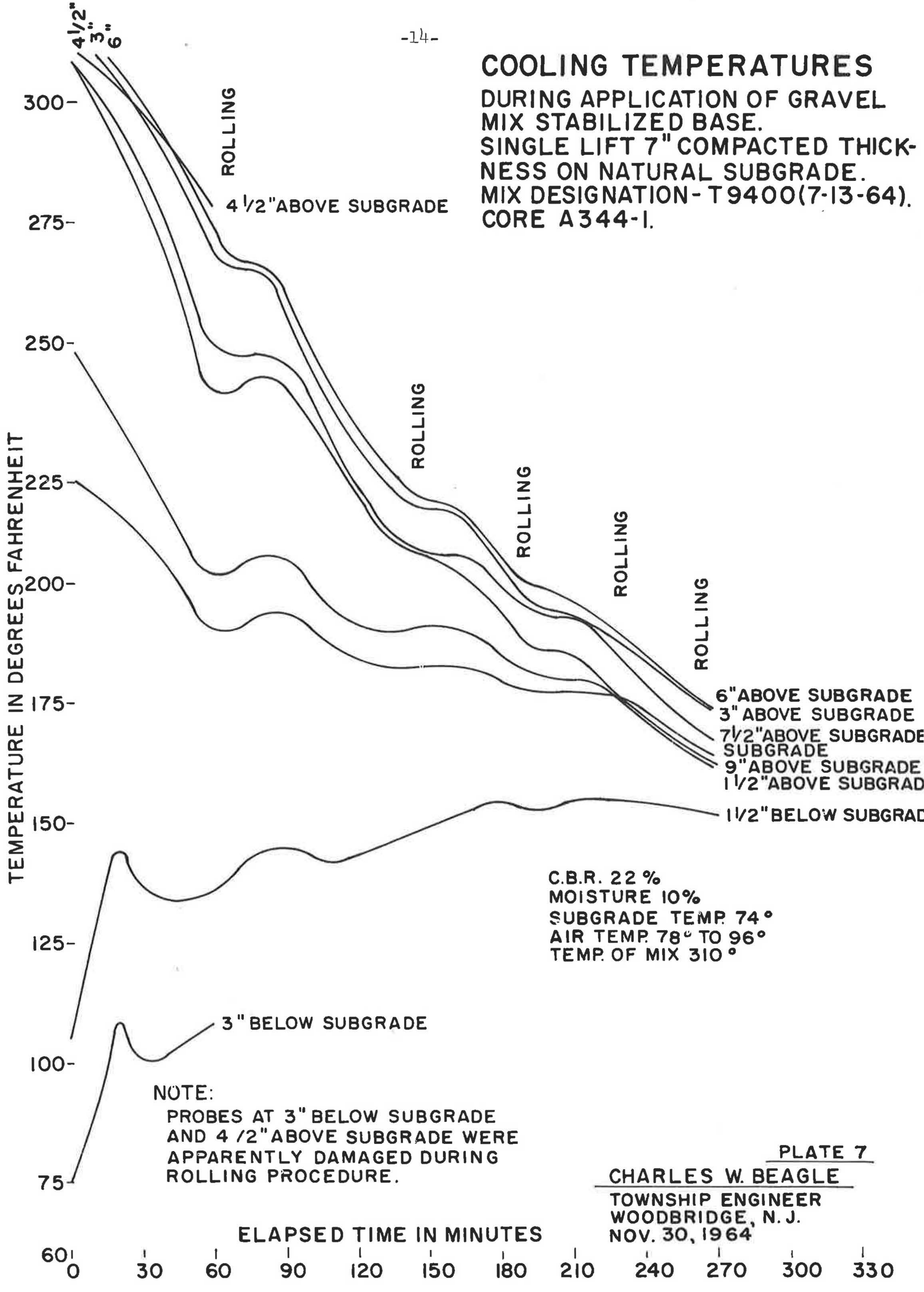
PLATE 6

CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE, N. J.
NOV. 30, 1964

TEMPERATURES DURING APPLICATION OF GRAVEL MIX STABILIZED BASE.

SINGLE LIFT 7" COMPACTED THICKNESS.
MIX DESIGNATION T-9400(7-13-64)
CORE NO. A 344-1




COOLING TEMPERATURES
DURING APPLICATION OF GRAVEL MIX STABILIZED BASE.
SINGLE LIFT 7" COMPACTED THICKNESS ON NATURAL SUBGRADE.
MIX DESIGNATION- T9400(7-13-64).
CORE A344-1.
4 1/2"
3"
6"
ROLLING
4 1/2" ABOVE SUBGRADE
ROLLING
ROLLING
ROLLING
ROLLING
6" ABOVE SUBGRADE
3" ABOVE SUBGRADE
7 1/2" ABOVE SUBGRADE
SUBGRADE
9" ABOVE SUBGRADE
1 1/2" ABOVE SUBGRAD
1 1/2" BELOW SUBGRAD
3" BELOW SUBGRADE
C.B.R. 22 %
MOISTURE 10%
SUBGRADE TEMP. 74°
AIR TEMP. 78° TO 96°
TEMP. OF MIX 310°
NOTE:
PROBES AT 3" BELOW SUBGRADE AND 4 /2" ABOVE SUBGRADE WERE APPARENTLY DAMAGED DURING ROLLING PROCEDURE.
TEMPERATURE IN DEGREES FAHRENHEIT
300
275
250
225
200
175
150
125
100
75
60
ELAPSED TIME IN MINUTES
0
30
60
90
120
150
180
210
240
270
300
330
PLATE 7
CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE, N. J.
NOV. 30, 1964

2-1/2 INCH LIFT ON 2-1/2 INCHES COMPACTED THICKNESS OF BITUMINOUS STABILIZED BASE

When the temperatures were recorded for the single lift of 2-1/2 inches in compacted thickness, the thermocouples were left in place.

The equipment was set up in the same location--the existing thermocouples connected and new thermocouples added for the second lift of 2-1/2 inches compacted thickness.

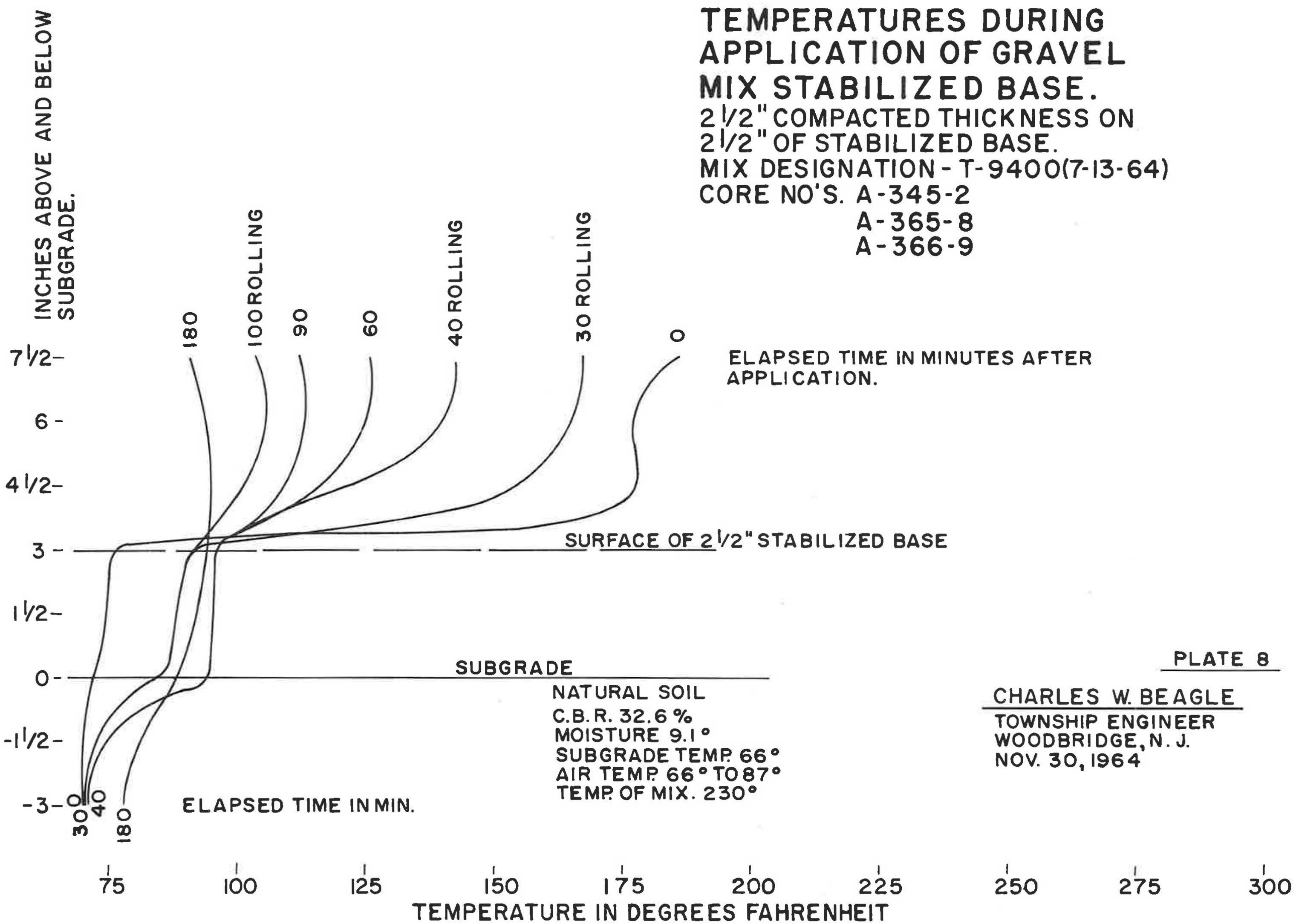
The temperatures at periods of elapsed time (Plate 8) show that the first lift absorbed heat from the second lift being applied and limited the amount of temperature transmitted to the subgrade.

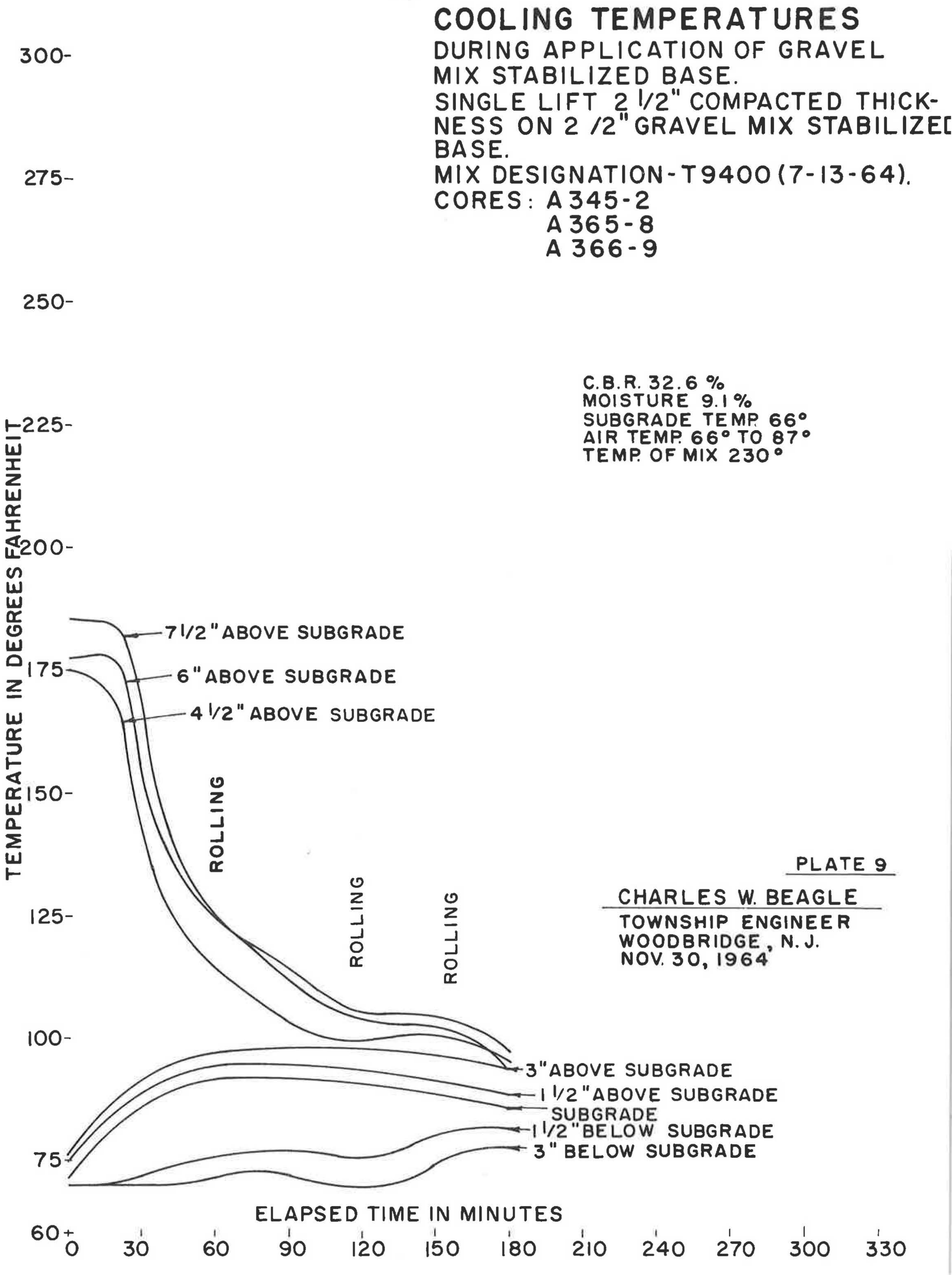
Within 40 minutes of elapsed time, the temperature rise in the original (first) 2-1/2 inch lift was 29 degrees and fairly uniform throughout the full depth of the lift.

The rise in temperature in the subgrade during the same period was only 11 degrees at a depth of 1-1/2 inches and 6 degrees at a depth of 3 inches.

The first lift absorbs and retains heat from the second lift when it is being applied.

The temperatures plotted against elapsed time (Plate 9) show the rapid rate at which temperature is lost from the second lift being applied and the steady and distinct rise in temperature in the first lift. The rise in temperature in the subgrade is slight and not as pronounced as it was when the first lift was applied.


TEMPERATURES DURING APPLICATION OF GRAVEL MIX STABILIZED BASE.
2 1/2" COMPACTED THICKNESS ON 2 1/2" OF STABILIZED BASE.
MIX DESIGNATION - T-9400(7-13-64)
CORE NO'S. A-345-2
A-365-8
A-366-9
INCHES ABOVE AND BELOW SUBGRADE.
7 1/2
6
4 1/2
3
1 1/2
0
-1 1/2
-3
180
100 ROLLING
90
60
40 ROLLING
30 ROLLING
0
ELAPSED TIME IN MINUTES AFTER APPLICATION.
SURFACE OF 2 1/2" STABILIZED BASE
SUBGRADE
NATURAL SOIL
C.B.R. 32.6 %
MOISTURE 9.1°
SUBGRADE TEMP. 66°
AIR TEMP. 66° TO 87°
TEMP. OF MIX. 230°
0
30
40
180
ELAPSED TIME IN MIN.
PLATE 8
CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE, N. J.
NOV. 30, 1964
75
100
125
150
175
200
225
250
275
300
TEMPERATURE IN DEGREES FAHRENHEIT


COOLING TEMPERATURES
DURING APPLICATION OF GRAVEL MIX STABILIZED BASE.
SINGLE LIFT 2 1/2" COMPACTED THICKNESS ON 2 1/2" GRAVEL MIX STABILIZED BASE.
MIX DESIGNATION - T9400 (7-13-64).
CORES: A345-2
A365-8
A366-9
C.B.R. 32.6 %
MOISTURE 9.1 %
SUBGRADE TEMP. 66°
AIR TEMP. 66° TO 87°
TEMP. OF MIX 230°
TEMPERATURE IN DEGREES FAHRENHEIT
300-
275-
250-
225-
200-
175-
150-
125-
100-
75-
60
7 1/2" ABOVE SUBGRADE
6" ABOVE SUBGRADE
4 1/2" ABOVE SUBGRADE
ROLLING
ROLLING
ROLLING
3" ABOVE SUBGRADE
1 1/2" ABOVE SUBGRADE
SUBGRADE
1 1/2" BELOW SUBGRADE
3" BELOW SUBGRADE
ELAPSED TIME IN MINUTES
0 30 60 90 120 150 180 210 240 270 300 330
PLATE 9
CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE, N.J.
NOV. 30, 1964

Three weeks after the pavements were laid, 4 inch diameter cores were taken. Laboratory tests were made to determine densities, per cent compaction, and per cent voids.

Per cent voids are used for comparison:

Pavement	Average of 6 Cores Two 2-1/2" Lifts	Average of 6 Cores Single 5" Lift	Average of 2 Cores Single 7-1/2" Lift
Per Cent voids in mix design	6.5	6.5	6.5
Per cent voids in specimen (bulk)	6.65	5.5	4.6
Top 2-1/2"	6.8	5.2	4.6
Middle 2-1/2"			3.9
Bottom 2-1/2"	6.5	5.8	5.1

From laboratory results, it appears that the higher temperatures in the middle section of the single lift construction assisted the compaction effort. This could account for the better compaction obtained in the 5 inch lift and the 7-1/2 inch lift.

Comparison of the per cent voids in bulk indicate that the mix design was met by the two 2-1/2 inch lift construction using a 12 ton, 3 wheel roller for compaction. As the depth of the lift increased the per cent voids decreased using the same rolling procedure.

It was decided to change the mix design by using 3/4 inch washed gravel to obtain the desired gradation instead of the 3/4 inch crushed stone. The one per cent mineral filler was eliminated to increase the voids in the laboratory mix by about one per cent.

The following chart shows the changes made in the mix in an attempt to satisfy the requirements for a single lift of 7-1/2 inches compacted thickness:

Material	20% 3/4" Crushed Stone Mix in use % total mix	New Mix 30% 3/4" Washed Gravel % total mix
3/4" Bin	28.9	30.2
3/8" Bin	11.9	12.3
1/4" Bin	11.9	9.4
Sand Bin	39.9	42.4
Mineral filler	2.0	--
Asphalt cement	5.6	5.7
Per cent voids in total mix	6.5	7.6

The newly designed mix was used to place a 2-1/2 inch lift, a base constructed with two 2-1/2 inch lifts, and a 7-1/2 inch lift.

Cores were cut and laboratory tests made.

	2-1/2" lift	Two 2-1/2" lifts	7-1/2" lift
Per cent voids mix design	7.6	7.6	7.6
Per cent voids in specimen (bulk)	12.7	10.0	7.7
Top 2-1/2"		8.0	8.4
Middle 2-1/2"			7.2
Bottom 2-1/2"	12.7	12.0	7.7

The construction method and rolling procedure remained the same. The only change made was the type of aggregate used. The addition of 30 per cent 3/4 inch washed gravel instead of the addition of 20 per cent 3/4 inch crushed stone.

The Marshall design showed an increase of 1.1 per cent voids in the total mix-about 17 per cent.

Cores taken from the finished base and tested in the laboratory from both the 2-1/2 inch lift and the 7-1/2 inch lift had 85 per cent more voids than was found when using the mix with 20 per cent crushed stone.

It was concluded that the type of aggregate as well as the mix design was a very important consideration when dense base was desired.

It was decided to determine whether the higher temperatures in the middle sections of 5 inch and 7-1/2 inch lifts contributed to the compaction of the base material.

The new mix design, having 7.6 per cent voids, was used. A one inch thick styrofoam sheet was stapled to the subgrade before the base material was applied.

For this test the milli-volt potentiometer was used to record temperatures through the base being applied and through the subgrade, as had been done in previous tests. One thermocouple was placed on the subgrade beneath the styrofoam sheet, and one thermocouple was placed on top of the styrofoam sheet.

The temperatures plotted to show the temperature vertically through the base and the subgrade at various values of elapsed time (Plate 10) proved to be of great interest. There was an initial temperature loss of 80 degrees in the mix immediately at the surface of the styrofoam. After an elapsed time of 40 minutes, there was a temperature recovery of 25 degrees on top of the styrofoam; and at this same elapsed time of 40 minutes, the coolest part of the base material was at the surface. The greater temperature loss was due to ambient temperature. After an elapsed time of 40 minutes, the coolest level of the mix was the exposed surface.

The subgrade temperatures are interesting. The surface of the subgrade under the styrofoam sheet shows practically no change in temperature. At a depth of 1-1/2 inches in the subgrade, the temperature rose 45 degrees in 3 hours, then slowly cooled 14 degrees in the next 3 hours. At 3 inches below the subgrade level, the temperature slowly rose 25 degrees in 6 hours.

When plotting temperatures against elapsed time (Plate 11), it is readily seen that the highest temperature after 40 minutes

of elapsed time is at the level 1-1/2 inches above the subgrade. The lowest temperature is at the surface of the mix, 6 inches above the subgrade.

Recovery of temperature due to rolling is much in evidence in this set of curves.

It is also interesting to note that when temperature in the mix is recovered due to rolling, the temperature in the subgrade drops. When the temperature in the base is cooling, the temperature in the subgrade rises.

When cores were cut for test purposes, it was found that the styrofoam was only 1/8 inch thick and was compressed. It was not melted.

The cores were laboratory tested. The mix design had a per cent voids of the total mix of 7.6.

The per cent voids in the Top 2-1/2 inches of the cores tested was 7.0.

The per cent voids in the Bottom 2-1/2 inches of the cores tested was 6.8.

The greater compaction occurred in the bottom half of the base where the temperature was higher. It appears that the compaction is greater where the temperature is higher. Temperature of the mix is an important factor in the compaction of Deep Lift Hot Plant Mix Base.

The rolling procedure employed was to use the 12 ton 3 wheel roller immediately behind the laying equipment and to follow with a 20 ton 3 axle tandem roller.

It was decided to record the temperatures when only the 20 ton tandem roller was used and when a rubber tired roller was used so that the densities obtained could be compared.

Temperatures were recorded during the rolling of a 5 inch deep base using a 20 ton, 3 axle tandem roller. The drive roll was 60 inches in diameter, 54 inches wide and had a compaction effort of 233 pounds per linear inch.

The temperatures plotted against elapsed time (Plate 12) show that some compaction effort was made through the base, but nothing so pronounced and definite as that made by the 12 ton, 3 wheel roller.

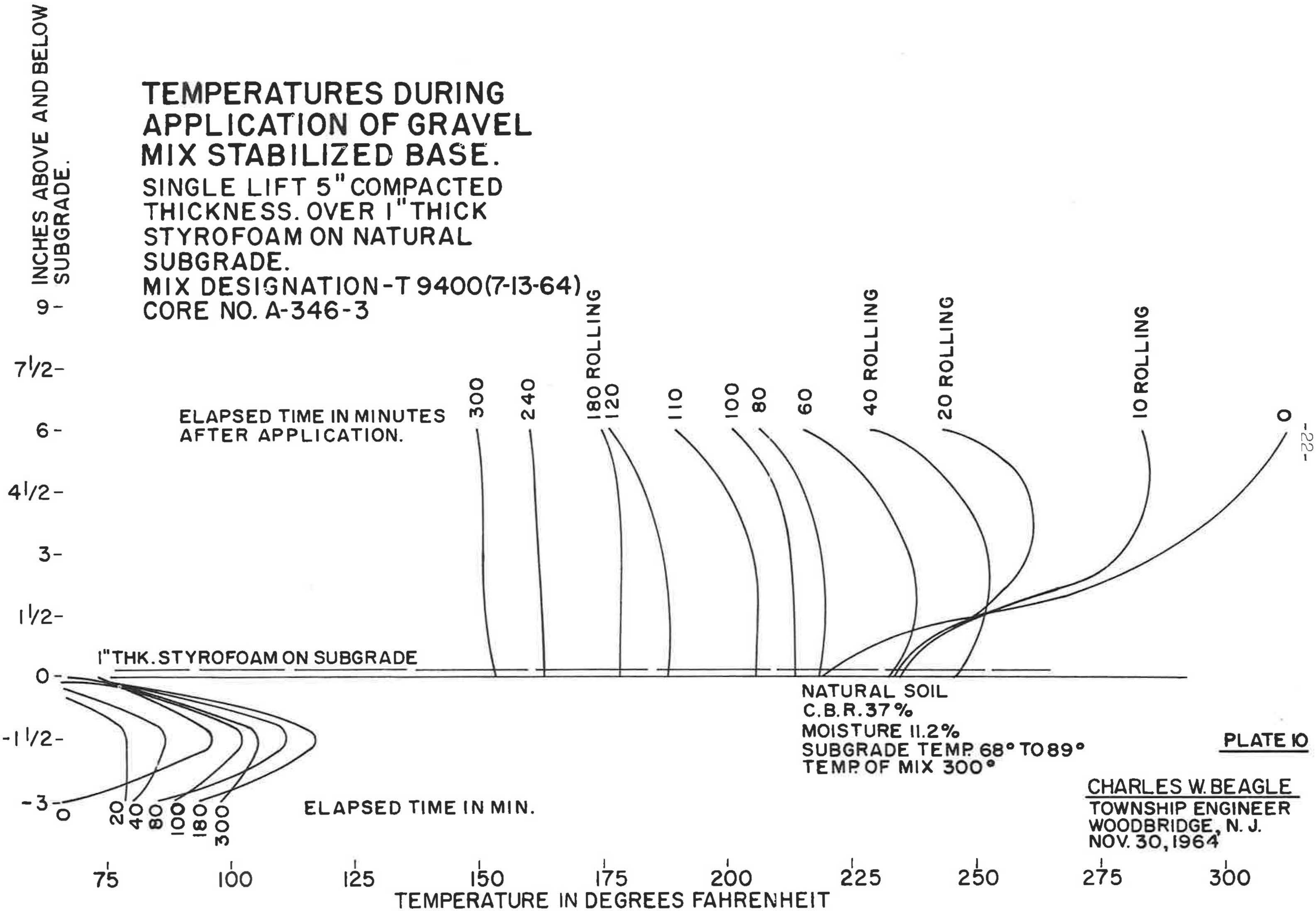
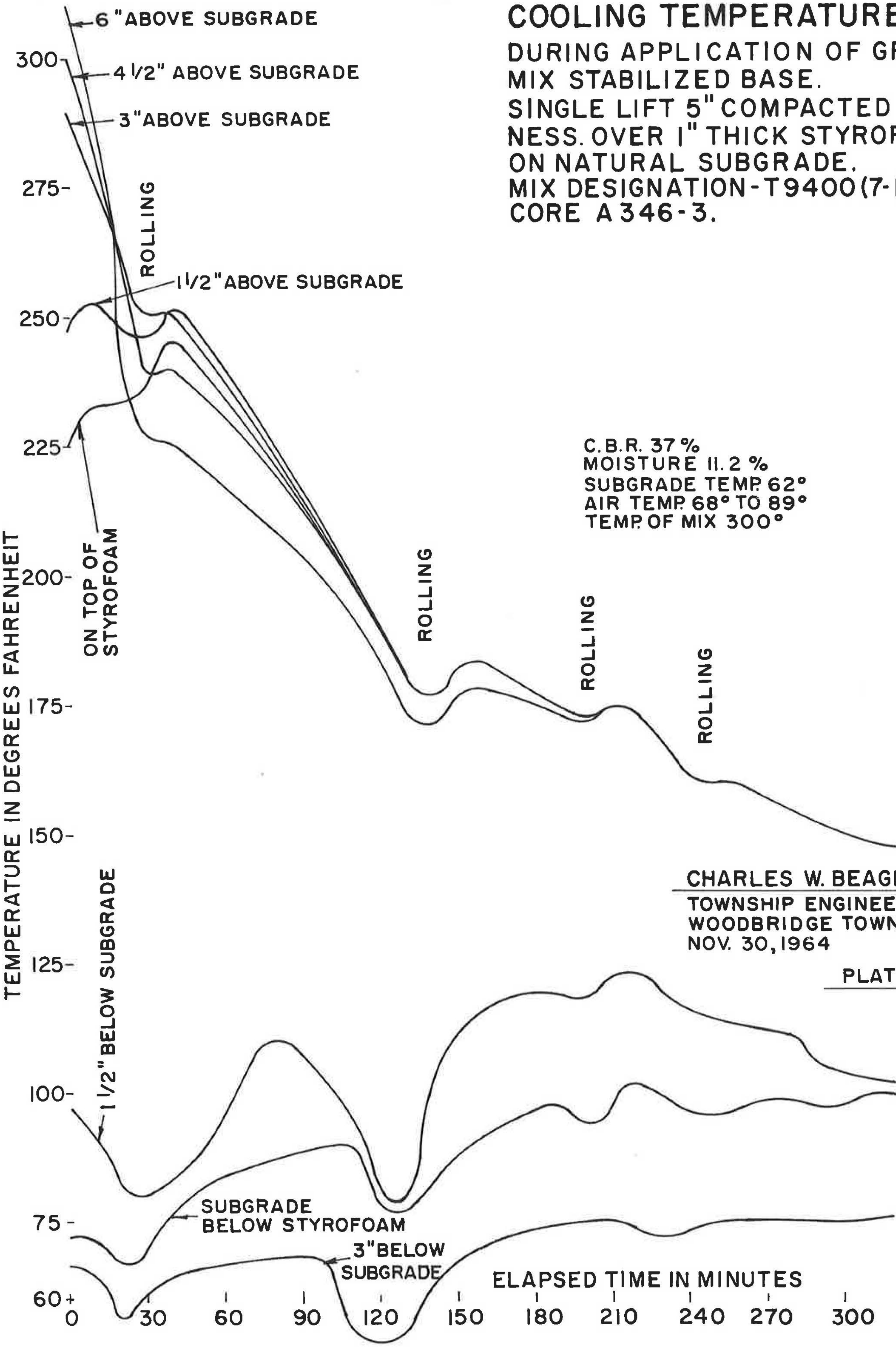


PLATE 10

CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE, N. J.
NOV. 30, 1964

COOLING TEMPERATURES

DURING APPLICATION OF GRAVEL MIX STABILIZED BASE.
SINGLE LIFT 5" COMPACTED THICKNESS. OVER 1" THICK STYROFOAM ON NATURAL SUBGRADE.
MIX DESIGNATION-T9400 (7-13-64).
CORE A346-3.



C.B.R. 37 %
MOISTURE 11.2 %
SUBGRADE TEMP. 62°
AIR TEMP. 68° TO 89°
TEMP. OF MIX 300°

CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE TOWNSHIP
NOV. 30, 1964

PLATE 11

Before using the rubber tired roller the initial rolling was done with the 20 ton, 3 axle tandem roller. When the temperature of the base cooled to 200 degrees, a 9 wheel pneumatic tire roller was used. The roller was fitted with 7.50 x 15 tires, and the tire pressure was 90 pounds. The reason for waiting for the temperature to drop to 200 degrees before using the pneumatic tire roller was that it was believed that the wheels would sink into the mix. It was thought best to provide a platform just with the 20 ton, 3 axle tandem first. It has since been learned that our fears were unfounded.

The pneumatic tire roller was used for 6 passes before the tires started to pick up the surface material. Rolling was finished with the 20 ton, 3 axle tandem.

The temperatures plotted against elapsed time (Plate 13) show nothing unusual until the pneumatic tire roller was used. Then there is a distinct change in the cooling rate. Every curve from the subgrade level vertically through the mix flattens out almost to the horizontal. The effect is also seen in the curves at 1-1/2 inches and 3 inches below subgrade. Both these curves show a rise of 6 degrees in temperature. This is interpreted as an indication that compaction was accomplished in depth.

The test results of cores taken from the locations, it was believed, would indicate the importance of the proper selection of compaction equipment for single lift construction.

The mix design had a per cent voids in the total mix of 6.5. The cores were cut into two sections in order to compare the values of the top and bottom sections.

Roller	3 wheel, 12 ton	20 ton, 3 axle tandem	9 wheel pneumatic tire
Per cent voids Top 2-1/2"	5.8	7.1	5.9
Per cent voids Bottom 2-1/2"	5.6	9.7	4.5
Per cent voids Bulk	5.7	8.4	5.2

The pneumatic tire roller produced the greater bulk density of the three rollers and the greatest compaction on the bottom 2-1/2 inches of the base.

The 12 ton, 3 wheel roller appears to produce a more uniform density.

COOLING TEMPERATURES

DURING APPLICATION OF GRAVEL MIX STABILIZED BASE.
SINGLE LIFT 5" COMPACTED THICKNESS. ON NATURAL SUBGRADE.
ROLLING PROCEDUR INDICATED.
MIX DESIGNATION- S3517(8-19-63).
CORE A-348-5.

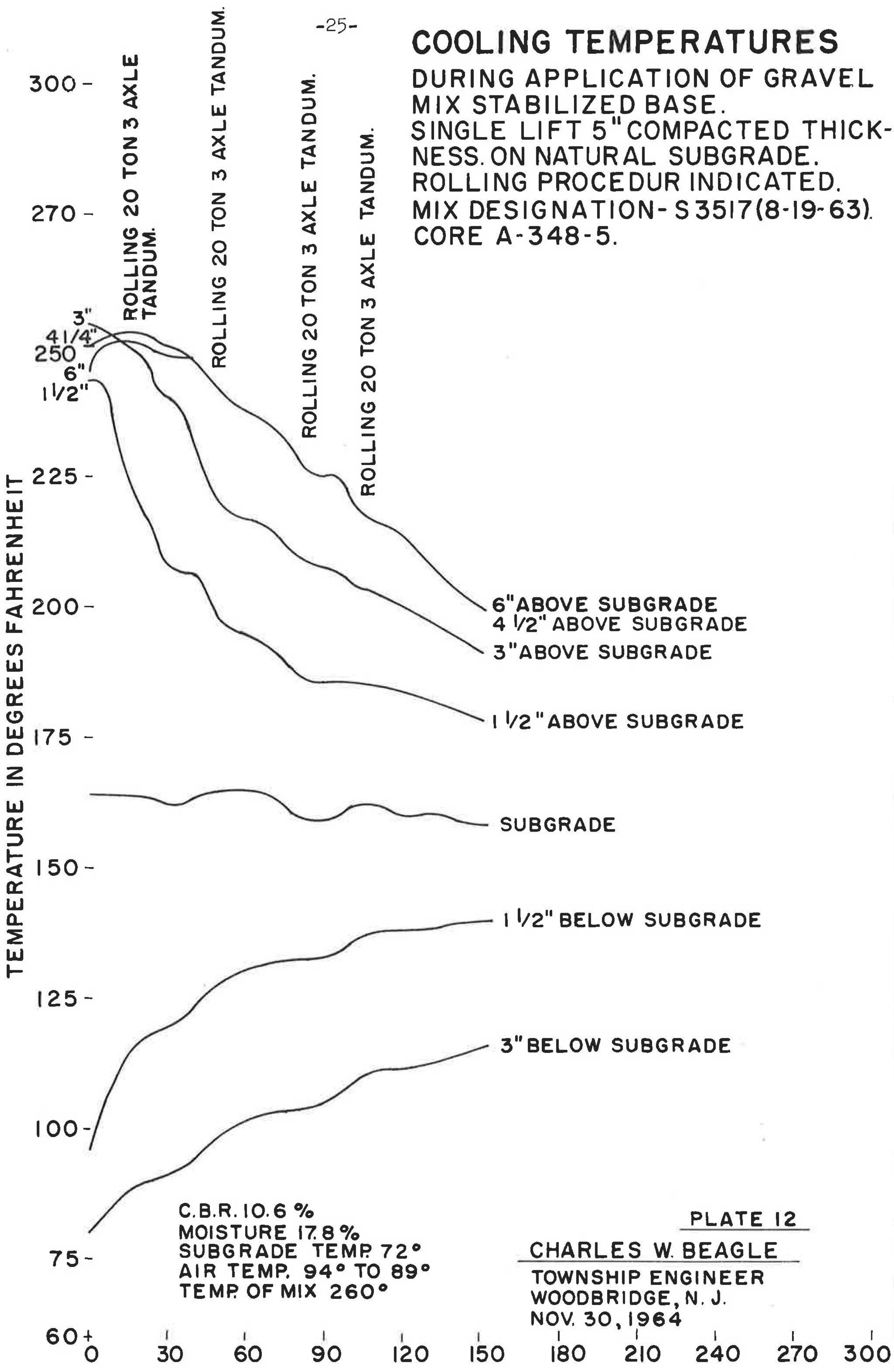


PLATE 12

CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE, N. J.
NOV. 30, 1964

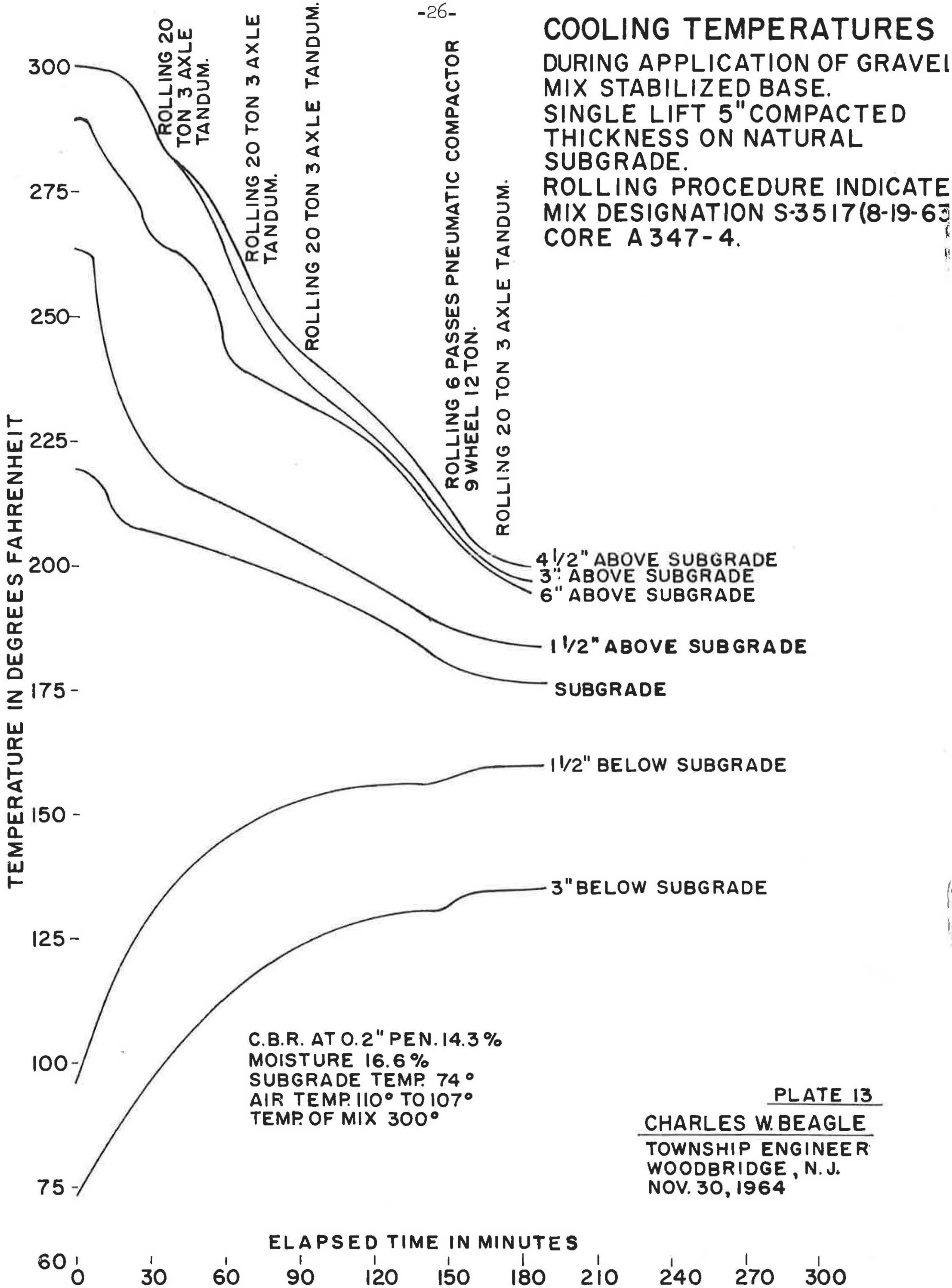


PLATE 13

CHARLES W. BEAGLE
TOWNSHIP ENGINEER
WOODBRIDGE, N.J.
NOV. 30, 1964

The pneumatic tire roller appears to have produced a greater density in depth.

It is evident that the selection of the compaction equipment to be used in single lift construction is important to the final result.

It must be noted that the time, money, and facilities necessary to good research are very limited at the Township level.

It must also be noted that the conclusions made as a result of these experiments are based entirely on the kind of clay soil found in Woodbridge, New Jersey, local available aggregates and a specific mix design.

Results obtained from this experimental program seem to prove that single lift construction with Hot Plant Mix Bituminous Stabilized Base is both feasible and practical.

That the type of aggregate used as well as the mix design is a very important consideration in single lift construction.

That mix temperature is a factor to be considered for different thicknesses of single lift construction.

That the proper selection of the compaction equipment is important in obtaining the desired density in the base.

It seems evident that with proper determination and design, using local available materials for producing Hot Plant Mix Stabilized Base, single lift construction could be applicable anywhere.

Caterpillar 977H, with a Jersey Spreader attached, spreads the Hot Plant Mix 7 in. deep. This is compacted to 5 in. Note how well the loose mix supports the Caterpillar 977H. Base course is placed directly on the natural soil subgrade.

The spreading of the Hot Plant Mix is immediately followed by the rolling operation. The 12-ton, 3-wheel roller is used for initial rolling followed by a 20-ton, 3-axle tandem roller.

Core cut from completed pavement shows the base course 5 in. compacted with a 2-in. surface of Bituminous Concrete New Jersey Type SM.