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MICHIGAN
STATE HIGHWAY DEPARTMENT
G. Donald Kennedy
State Highway Commissioner

CONSTRUCTION

OF

EXPERIMENTAL SOIL-CEMENT STABILIZATION

ROAD SURFACE

STOCKBRIDGE, MICHIGAN

By

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Research Project 36 E-5 (2)

Research Laboratory
Testing and Research Division
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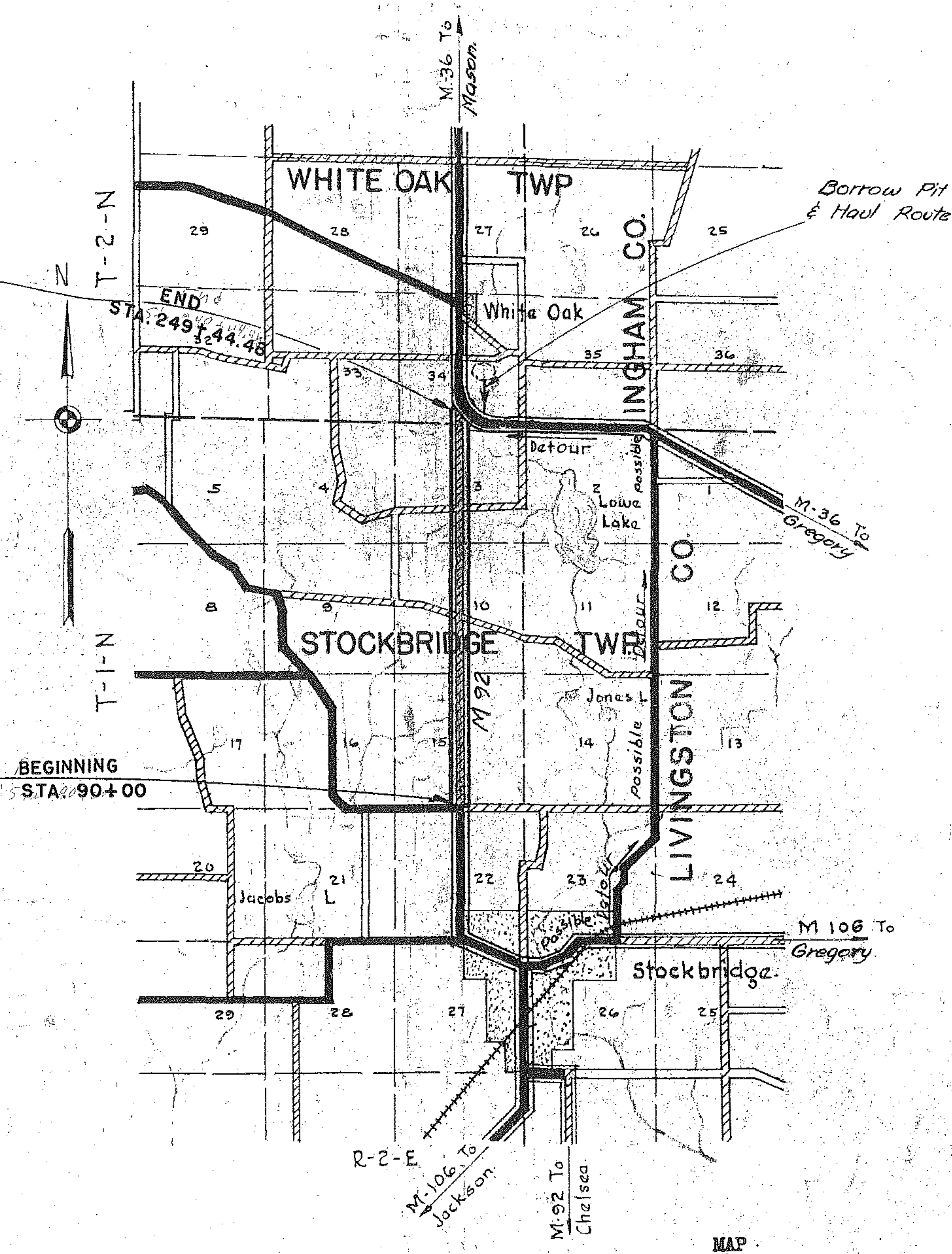
PREFACE

This report presents a complete account of the design and construction of an experimental soil-cement stabilization project using the existing roadway material, new material and Portland cement to produce a low cost, light traffic surface.

The report includes the important factual data relevant to the project, such as description, purpose and scope of the project, cost, preliminary laboratory studies, construction procedure, condition survey data and conclusions.

The soil-cement stabilization project is 3.02 miles in length, located on M-92, north of Stockbridge to M-36 and designated as state project M 33-50, Cl.

The project was constructed under regular contract and construction procedure using the Michigan State Highway Department's 1940 plans and specifications with necessary supplementals. The contract was awarded to Ray Sablain, Lansing, Michigan. The construction of the project was under the supervision of the Construction and Research Divisions of the Highway Department.



MAP
OF
PROJECT - LOCATION
M 33-50

PROJECT STATISTICS

Construction project - M 33-50, C1

Location - M-92, Stockbridge north to M-36.

Length - 3.02 miles

Bids opened - June 18, 1941

Contract awarded - July 15, 1941

Contractor - Ray Sablain, Lansing, Michigan

Start work - July 25, 1941

Completed - November 1, 1941

Start cement stabilization - September 24, 1941

Completed cement stabilization - October 21, 1941

Length - 164.23 station

Width - 22 feet

Total Cost - $56,485.85

MATERIALS

Cement - 3652.5 bbls. at $2.00	= $ 7,305.00
Manipulation - 164.23 sta. at $75.00	12,317.25
Water - 193.8/1000 gal. at $4.50	872.10
Total cost of processed surface	$20,494.35

Cost per square yard surface - 51 cents

INTRODUCTION

Road stabilization is the process of giving natural soils enough abrasive resistance and shear strength to accomodate traffic or loads under prevalent weather conditions, without detrimental deformation. The methods employed include the use of admixtures, compaction and densification by specific technical theory and laboratory control. Optimum water content is fundamental with gradation. Admixtures may be soil materials, deliquescent chemicals, solutions of eletrolytes, soluble cementitious chemicals, primes and neutralizers, and insoluble binders.

Many types of stabilized roads are being developed and it is important to the Michigan State Highway Department to know which are the best suited for Michigan conditions. This project would be the first of its type to be constructed in Michigan in which old surface material is used to a certain extent.

The purpose of this experimental project is, to determine the feasibility of constructing a soil-cement stabilized road base with existing surfacing materials, or with suitable local materials and to develop specifications for the use of the Michigan State Highway Department in constructing such types of roads.

This type of road construction is familiar to the Michigan State Highway Department in that one project 1.3 miles in length was constructed with virgin soil. It was among the first projects constructed of this type and served to assist in the development of construction methods. Sinch then, 111 projects consisting of 227.2 miles have been constructed in the United States and many new developments have been introduced. It is proposed to use the best of these methods in the construction of this project.

The project was awarded to Ray Sablain, of Lansing, Michigan, July 15, 1941, with instructions to start work in ten days. Because of the customary contractorial delays incidental to the starting of any new project and because of the heavy grading operations specified by the design division, the contractor did not start actual processing of the road surface until September 24th. The final processing was completed October 21st, after an unusually large number of days lost because of unfavorable weather conditions. The actual processing required only fifteen working days.

The soil material encountered during construction was quite uniform since approximately two-thirds of the grading material came from a single borrow pit. The remaining portion of the grade consisted of the naturally-occurring soil which differed from the borrow material chiefly by the presence of slightly more fine material.

As is customary, in the construction of this type of roadway, considerable laboratory work was done preliminary to actual construction. This work which was done by the Research Division of the Michigan State Highway Department consisted of a study of the physical properties of the soil materials encountered, and a study of the durability properties of specimens molded from these materials with appropriate amounts of cement. From the results of the laboratory work a cement content of 8% by volume was chosen as being economical and yet high enough to provide sufficient durability and strength.

The contractor was required to maintain the percentage of water in the mixture within 1/10 of the optimum percentage of moisture. The approximate density of the compacted mixture was specified from 120 to 135 pounds per cubic foot.

The total cost of the project was $56,485.85. The total cost of processing the soil-cement stabilized surface was $20,494.35. The cost per square yard of road surface is 51¢ based on a width of 22 feet and 164.23 stations in length.

Notwithstanding unfavorable weather, the construction was quite satisfactory. The soil material was uniformly and readily mixed with the cement in the road by means of a combination of a plow, cultivator and rotary tiller. The removal of some of the larger rock present in the borrow would have reduced the damage to the mixing equipment and a better appearing final surface would have been obtained. Finally, the processed material was readily compacted into what appeared to be a stable, dense roadway capable of withstanding considerable traffic wear even without a protective seal-coat.

The report consists of three parts; the first presents the laboratory investigation prior to construction of the project. The second gives the construction procedure and factual data pertaining to daily operations. The third contains the results of several condition surveys of the project after one winter season.

PART I

LABORATORY INVESTIGATION

The laboratory investigation pertains to all preliminary studies prior to construction of the stabilized surface, such as the soil survey and sampling of existent materials, the physical tests on soil samples, and the control tests on soil-cement samples to determine proper cement content.

LABORATORY INVESTIGATION

The laboratory investigation necessary to the construction of any type of soil stabilization project consists, essentially, of four parts:

1. The visual reconnaissance of roadway by soil engineers to identify the general soil types, the condition of the present surface and composition of underlying soil and to make recommendations.

2. The sampling of the project to obtain representative materials for laboratory analysis.

3. Testing in the laboratory for physical constants of the soil.

4. Special control tests for determining the correct proportion of binder to use with each soil type.

Soil Survey

The soil-cement stabilized project at Stockbridge, as originally planned, consisted of stabilizing the existent road surface making use of as much of the present road material as possible. This plan was changed by the Design Division who raised the elevation of the grade line to such an extent that practically two-thirds of the road surface consisted of borrow material. This change in plans limited the scope of the soil survey to sampling of the borrow pit material and the balance of the naturally-occurring soil which was very similar to the borrow material. Sufficient soil samples were obtained to carry on the required number of control tests.

Soil Characteristics

In the laboratory, investigations were carried on to determine the physical characteristics of four samples of soil material present in the graded roadbed. Sample 1 was a natural blend of the A, B, and C horizons of Fox Sandy Loam as taken from the borrow pit after the removal of the top six inches of the A horizon. Samples 2, 4 and 6 were soil samples taken from the naturally-occurring material in the roadbed at stations 246, 234 and 207, respectively. Since the results obtained from tests on all four of these soil samples were very similar, the results of tests on Sample 1, which comprised the major part of the roadway, will be discussed most fully with discussion of the other samples inserted when they differ widely.

Table I summarized the physical properties of the four soil materials. Soil No. 1 falls within the textural classification of a sandy soil and within U.S.P.R.A. soil group, A-3. It has physical test constants typical of sand soils. The liquid limit is low, the shrinkage limit is relatively low, and since the material does not become plastic at any water content it has no plasticity index. As would be expected, the organic content is also very low in view of the fact that the top six inches of "A" horizon was removed from the borrow pit. Plate I shows the similarity between the gradation curves of the four soils. Soils 2, 4 and 6 differ from No. 1 mainly by having a slightly higher silt and clay content. Also, these three soils have organic matter contents about four times that of No. 1. The higher content of fine material in the nautral soil would be expected since the roadway would

TABLE I

RESULTS OF TESTS ON SOIL MATERIAL

Soil No.	Gradation-Per Cent of Total: Gravel: Retained on No. 4 Sieve	Gravel: No. 4 to No. 10 (2.0 mm)	Sand: 2.0 to 0.25 mm	Sand: 0.25 to 0.05 mm	Silt: 0.05 to 0.005 mm	Clay: 0.005 to 0.000 mm	Physical Test Constants: Liquid Limit	Plasticity Index	Shrinkage Limit	pH	Organic Content p.p.m.	Textural Class	Specific Gravity Material Passing No. 4	Material Retained on No. 4: Sp. Gravity	Material Retained on No. 4: Absorption	Color of Moist Soil
1*	11.8	11.0	44.0	27.2	3.9	2.1	20	0	20	8.0	4,000	Sand	2.70	2.66	1.61	Yellow
SOIL MORTAR ONLY			57	35	5	3										
2*	18.6	6.1	36.8	24.4	8.9	5.2	11	0	18	7.4	16,000	Sand	2.70	2.68	1.22	Brown
SOIL MORTAR ONLY			48	33	12	7										
4*	11.5	14.5	35.5	21.5	11.8	5.2	11	0	24	7.7	15,700	Sandy Loam	2.68	2.66	1.07	Dark Brown
SOIL MORTAR ONLY			48	29	16	7										
6*	16.3	8.4	41.4	22.9	6.0	5	15.5	0	23	7.7	17,300	Sand	2.69	2.59	1.02	Brown
SOIL MORTAR ONLY			55	30	8	7										

* U.S.P.R.A. Soil Group (Soil Mortar) A-3.

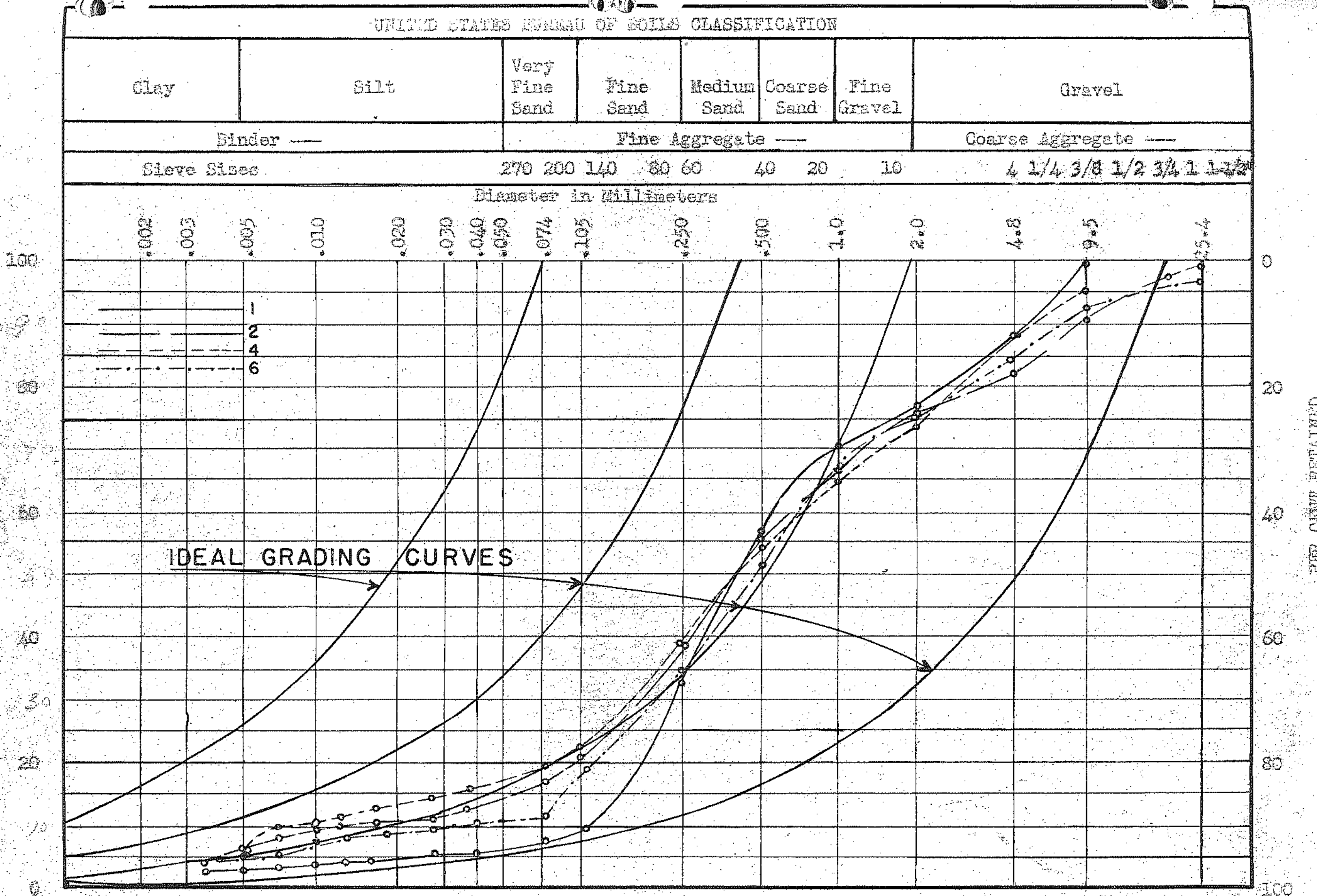

UNITED STATES BUREAU OF SOILS CLASSIFICATION
Clay
Silt
Very Fine Sand
Fine Sand
Medium Sand
Coarse Sand
Fine Gravel
Gravel
Binder
Fine Aggregate
Coarse Aggregate
Sieve Sizes
270 200 140 80 60 40 20 10 4 1/4 3/8 1/2 3/4 1
Diameter in Millimeters
.002 .003 .005 .010 .020 .030 .040 .050 .074 .105 .250 .500 1.0 2.0 4.8 9.5 25.4
PER CENT PASSING
PER CENT RETAINED
100 80 60 40 20 0
0 20 40 60 80 100
1
2
4
6
IDEAL GRADING CURVES

PLATE I

naturally contain a higher percentage of the "A" and "B" horizons, rich in organic matter and fine material, wherever surface grading was done. The specific gravity of material passing the No. 4 screen and that retained were quite uniform for all four samples tested. Although the absorption of the plus No. 4 material was quite low for all four samples the material from the borrow pit had a higher absorption than any of the soils used in place.

Soil-Cement Control Tests

After the soil survey and soil studies, it is possible to select soil samples for use in making soil-cement tests and for determining the job control factors. The soil-cement tests consist of the determination of the moisture-density relations of the roadway soil and the roadway soil mixed with various percentages of Portland cement. This is followed by a determination of the durability of the soil-cement mixtures compacted at optimum moisture to maximum density by subjecting them to repeated wetting and drying tests and repeated freezing and thawing tests.

Moisture-Density Relationships: In order to determine the moisture content at which a soil material or a soil-cement mixture could be compacted to its maximum density moisture-density curves were plotted from data obtained in the laboratory using the Proctor compaction method. Table II gives the results obtained from this test on the minus No. 4 material from each of the four samples. It is interesting to note that the soil samples 2 and 4 which contain a considerably higher percentage

TABLE II

MOISTURE-DENSITY RELATIONSHIPS
OF MINUS NO. 4 MATERIAL

Sample Number	Cement Control % by volume	Optimum Moisture Content	Maximum Density lbs. per cu.ft.
1	0 6.1 10.1	9.1 9.1 8.7	118.3 122.8 122.3
2	0 6.9 11.0	8.3 7.9 8.3	129.9 130.4 130.6
4	0 6.8 10.0	8.9 8.2 8.5	129.0 128.1 127.0
6	0 7.1 11.1	9.0 9.8 9.4	124.4 127.4 127.8

of fines than No. 1 have higher maximum density values and slightly lower values of optimum moisture, while sample No. 6 which has medium content of fines has maximum density values in between No. 1 and Nos. 2 and 4.

<u>Compression Tests:</u> Knowing the optimum moisture required for maximum density, compression test specimens were molded from the minus No. 4 material in the Proctor mold for breaking at two, seven and twenty-eight days. The compressive strengths of the various specimens are tabulated in Table III. Each of the four samples meet the requirements of the field control factors for both the 6 and 10 percent cement content. This requirement is that the compression strengths shall increase with age and with increase in cement content in the ranges of cement content producing results meeting other requirements.

<u>Durability Tests:</u> The most important tests used to determine the correct cement content for a given type of soil were the wet-dry and freeze-thaw tests. For each soil sample to be investigated four wet-dry tests and four freeze-thaw test specimens were molded at appropriate moisture and cement content. Three specimens in each set were brushed and weighed for soil losses; the other specimen was used as a control to check volume and moisture changes throughout the twelve cycles. These specimens were molded from a combination of the plus and minus No. 4 material in the proportions occurring naturally. Tables IV and V show the final results of these durability tests. Plates II to V inclusive show graphically the progressive losses by cycles, and Plates VI and VII show the final condition of the specimens after 12 cycles. The requirements for satisfactory durability are that the losses during twelve cycles

TABLE III

COMPRESSION TESTS ON MINUS NO. 4 MATERIAL

Sample Number	Cement Content % by volume	Compressive Strengths - lbs. per sq. in. Age when tested - days		
		2	7	28
1	6	108	218	304
	10	245	492	873
2	6	190	278	403
	10	346	706	1072
4	6	147	276	387
	10	387	682	1069
6	6	241	301	442
	10	279	570	750

TABLE IV

WET-DRY SOIL LOSSES IN TWELVE CYCLES

Sample Number	Cement Content % by volume	Moisture Content % by O.D. Wt.	Dry Density lbs.per cu.ft.	Total Soil Loss %
1	5.0 8.2 10.5	8.1 9.1 8.7	126.0 125.5 124.9	20.3 11.5 2.4
2	5.3 7.5 9.6	6.2 6.7 6.3	136.1 136.7 138.0	5.5 2.2 0.7
4	5.7 8.0 10.0	7.4 8.2 7.5	132.9 131.9 132.2	4.5 1.4 0.7
6	5.6 7.9 10.0	8.9 9.1 9.1	132.0 131.8 131.8	13.4 3.6 1.1

TABLE V

FREEZE-THAW SOIL LOSSES IN TWELVE CYCLES

Sample Number	Cement Content % by volume	Moisture Content % by O.D. Wt.	Dry Density lbs.per cu.ft.	Total Soil Loss %
1	6.5 8.2 10.5	8.7 8.9 9.1	124.5 124.4 126.1	16.1 6.3 3.1
2.	5.3 7.5 9.5	6.4 6.6 7.2	137.0 136.8 137.1	9.6 4.8 0.9
4	5.7 8.0 10.0	7.5 7.7 8.2	132.7 133.1 131.8	10.6 3.4 1.1
6	5.6 7.9 10.1	8.2 9.1 8.8	132.2 131.8 133.2	11.3 4.1 1.6

PLATE II

PROGRESSIVE SOIL LOSSES FROM LABORATORY DURABILITY

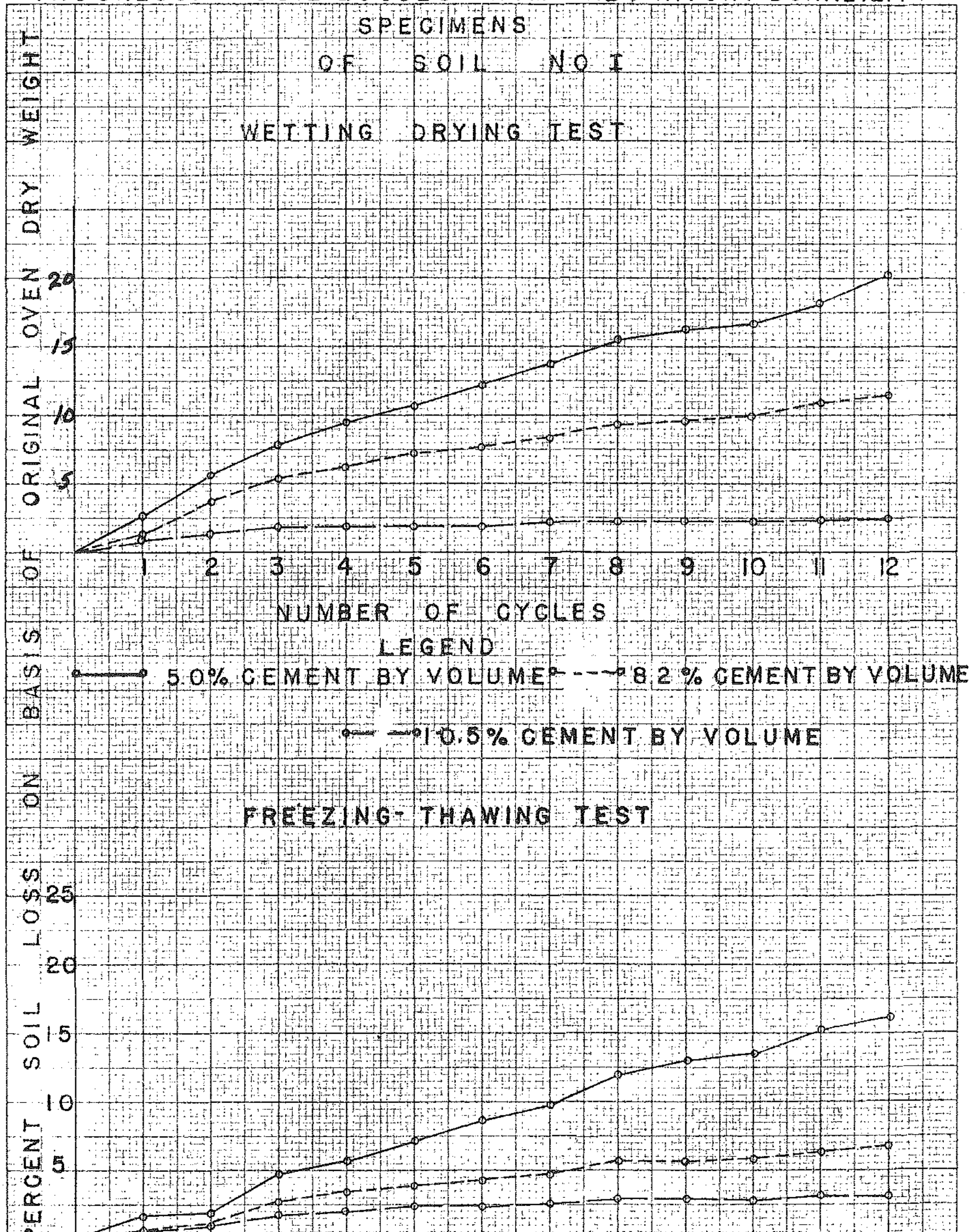


PLATE III

PROGRESSIVE SOIL LOSSES FROM LABORATORY DURABILITY SPECIMENS OF SOIL NO 2

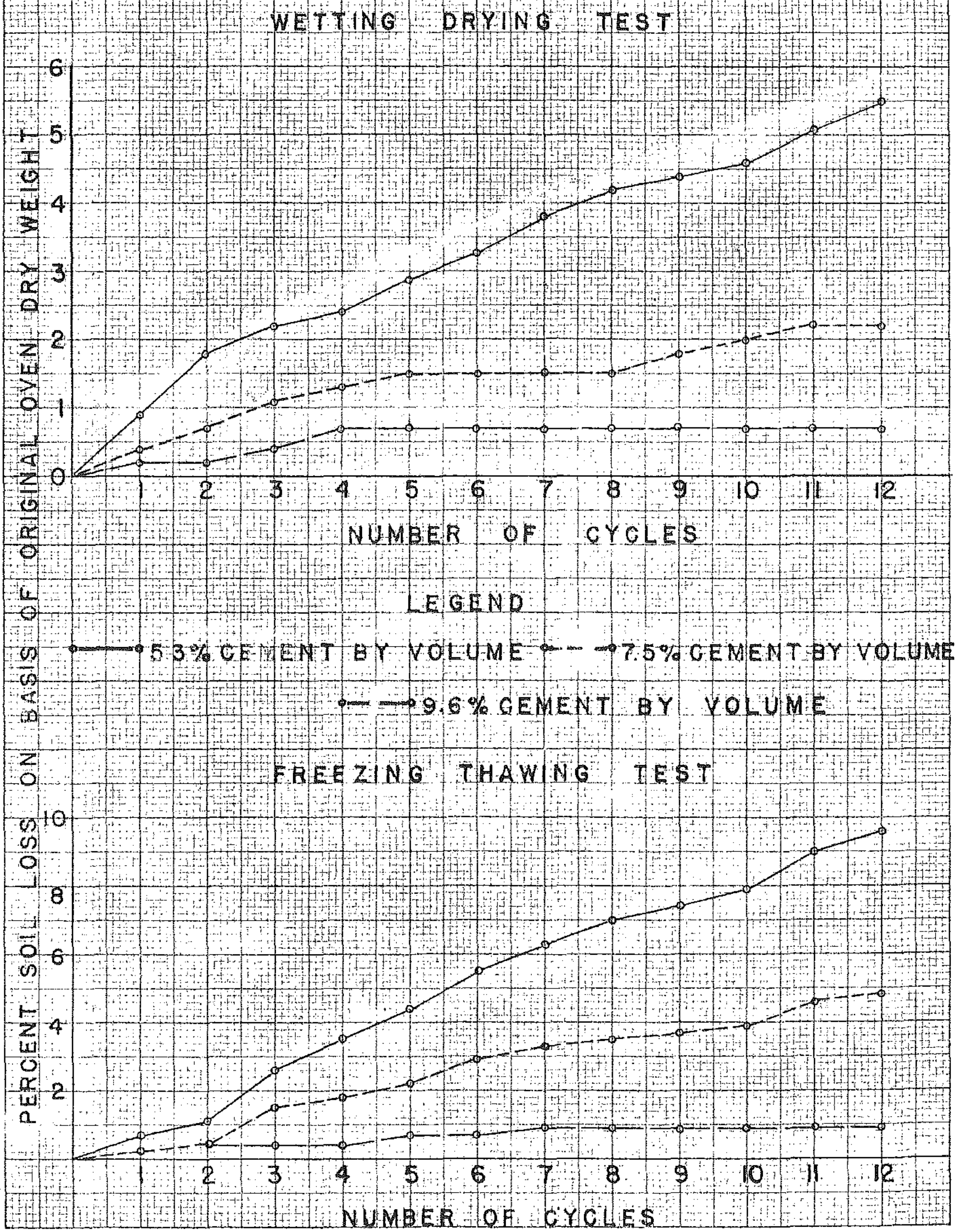
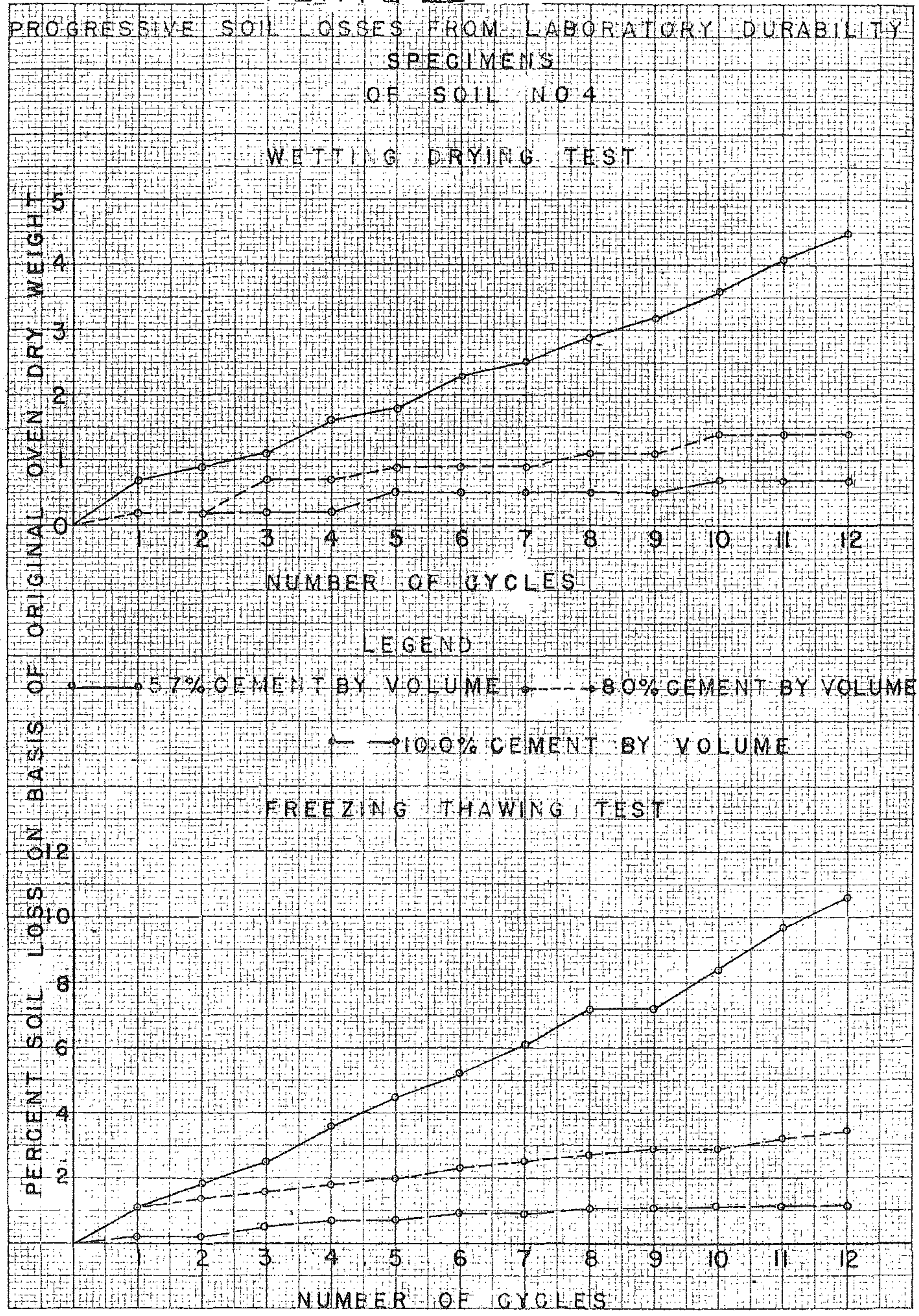
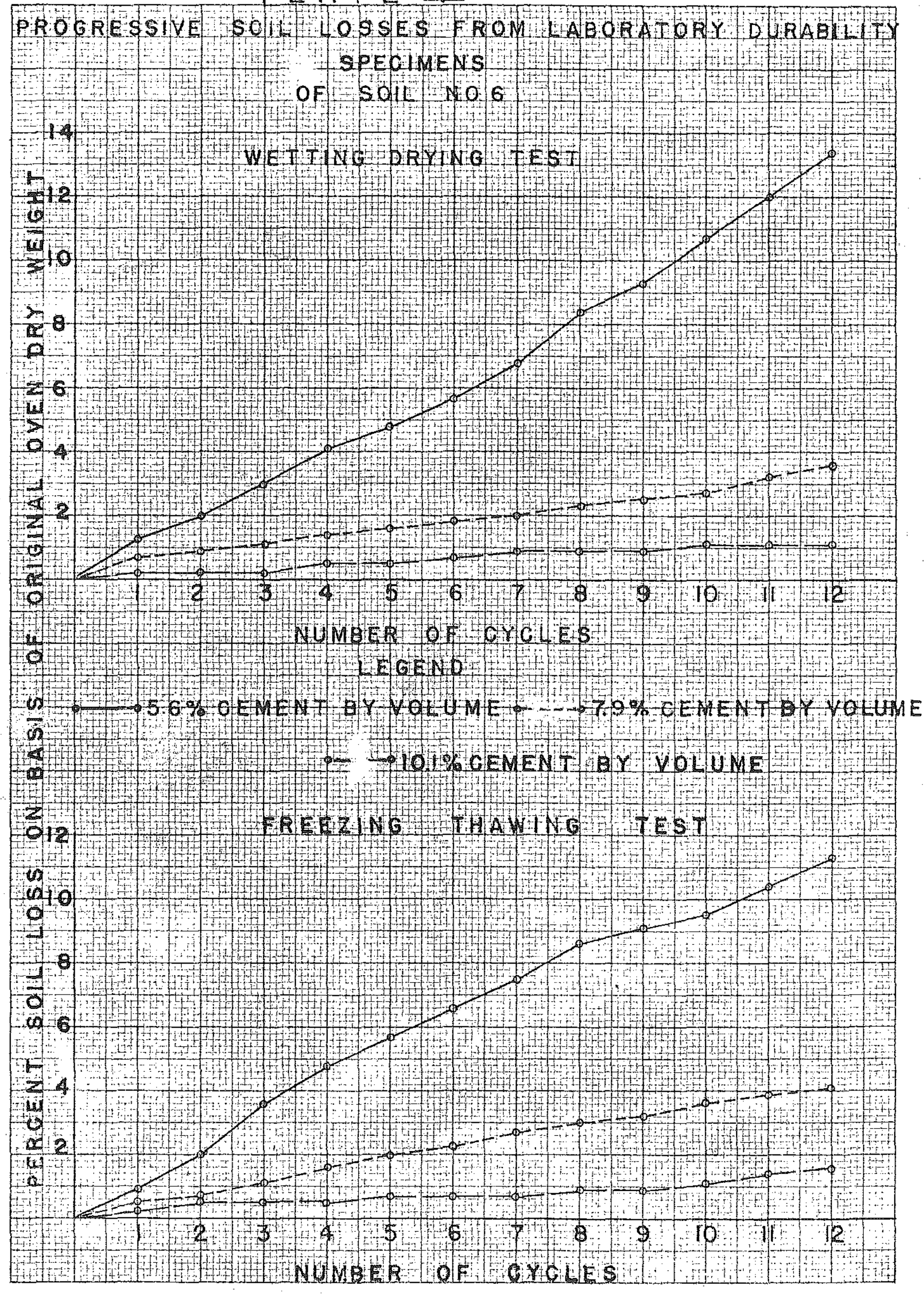


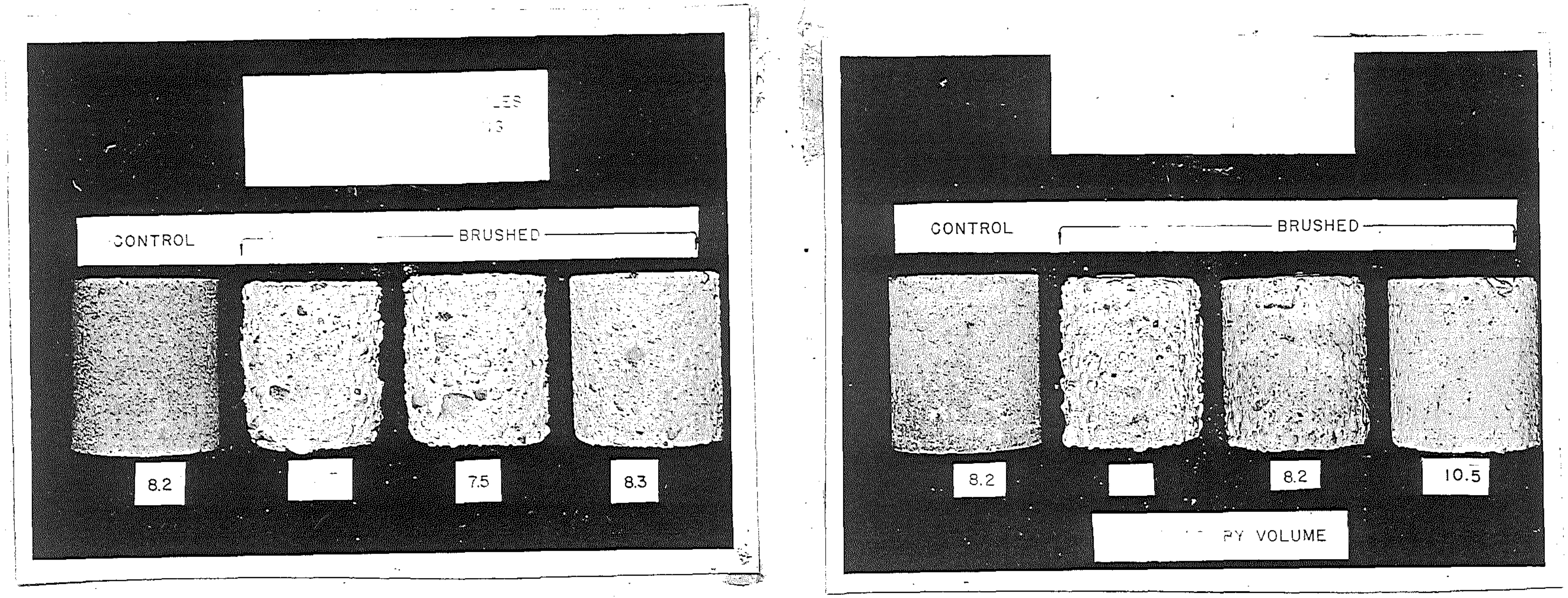
PLATE IV



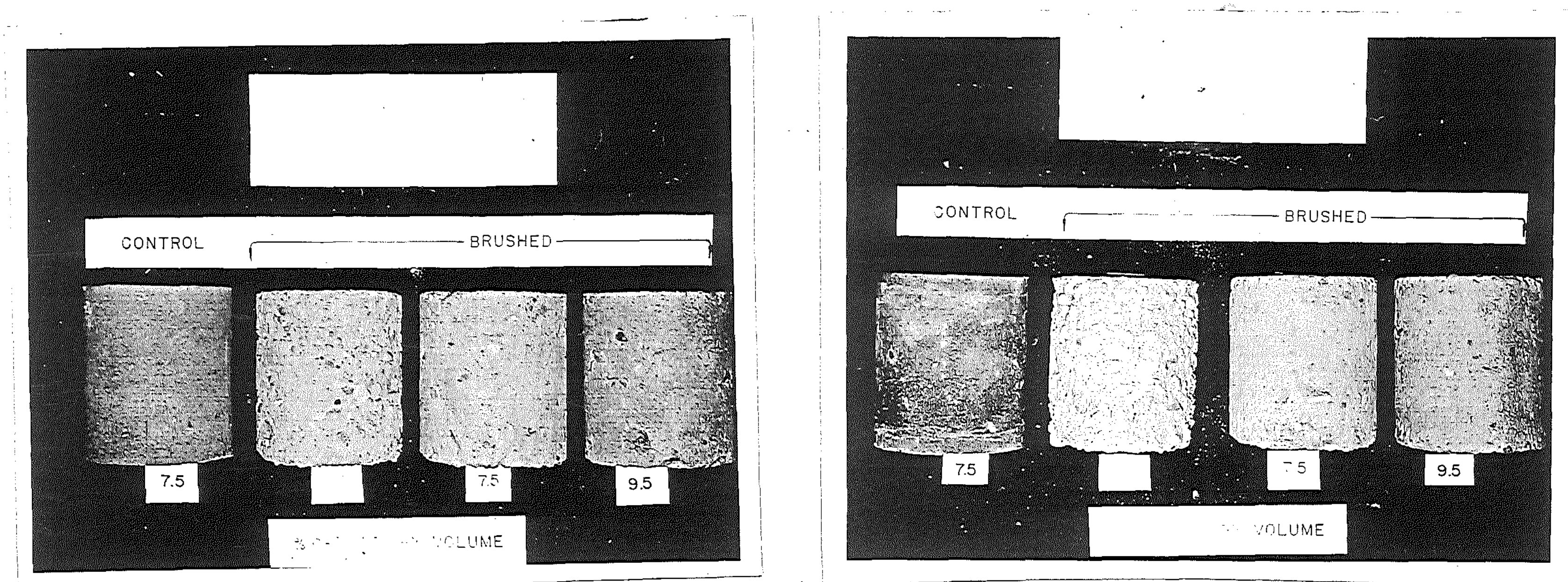
PROGRESSIVE SOIL LOSSES FROM LABORATORY DURABILITY SPECIMENS OF SOIL NO 4
WETTING DRYING TEST
PERCENT SOIL LOSS ON BASIS OF ORIGINAL OVEN DRY WEIGHT
0
1
2
3
4
5
1
2
3
4
5
6
7
8
9
10
11
12
NUMBER OF CYCLES
LEGEND
5.7% CEMENT BY VOLUME
8.0% CEMENT BY VOLUME
10.0% CEMENT BY VOLUME
FREEZING THAWING TEST
2
4
6
8
10
12
1
2
3
4
5
6
7
8
9
10
11
12
NUMBER OF CYCLES

PLATE V

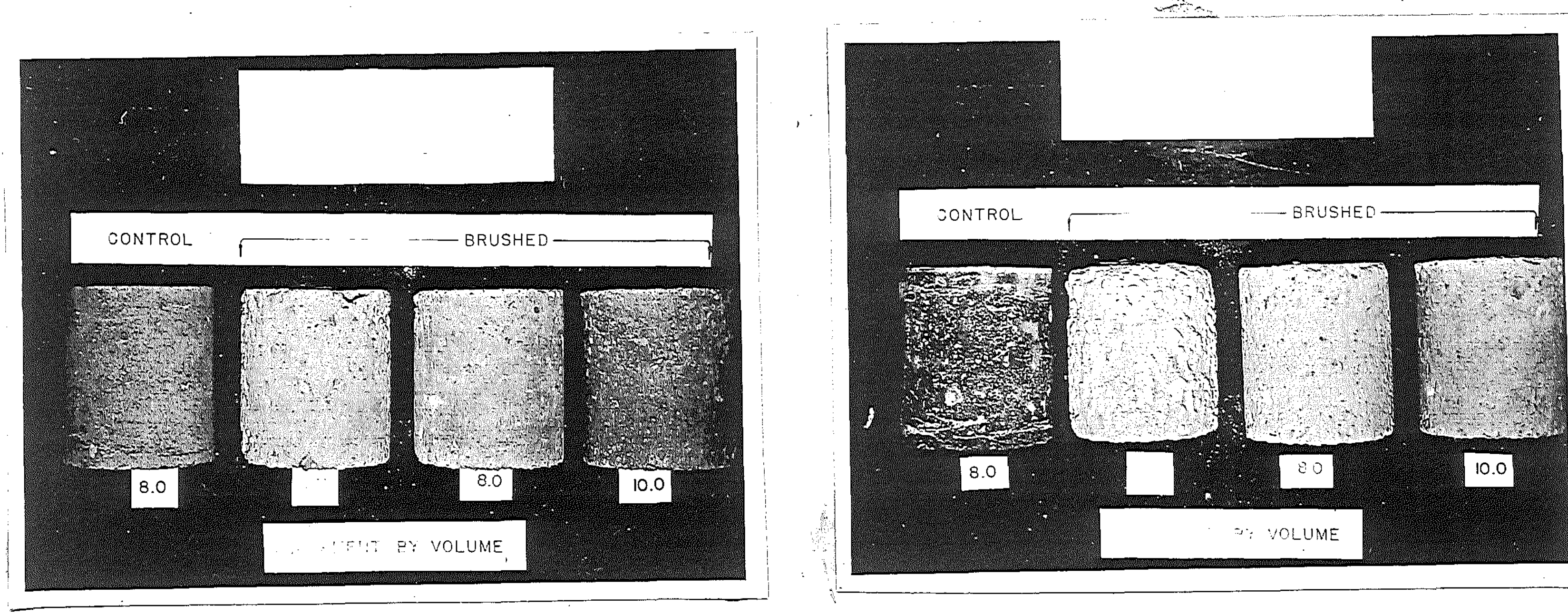

PROGRESSIVE SOIL LOSSES FROM LABORATORY DURABILITY SPECIMENS OF SOIL NO 6
WETTING DRYING TEST
PERCENT SOIL LOSS ON BASIS OF ORIGINAL OVEN DRY WEIGHT
14
12
10
8
6
4
2
1
2
3
4
5
6
7
8
9
10
11
12
NUMBER OF CYCLES
LEGEND
5.6% CEMENT BY VOLUME
7.9% CEMENT BY VOLUME
10.1% CEMENT BY VOLUME
FREEZING THAWING TEST
12
10
8
6
4
2
1
2
3
4
5
6
7
8
9
10
11
12
NUMBER OF CYCLES



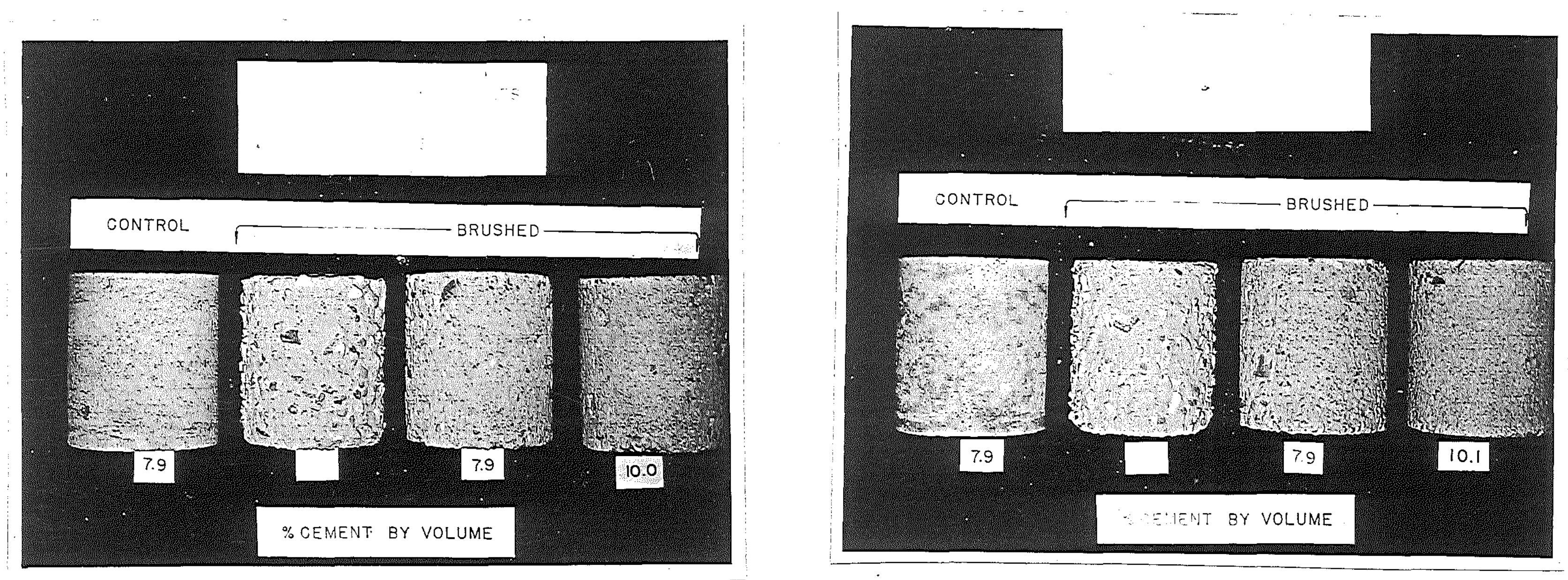
Soil No. 1-Durability Specimens after 12 cycles of (a) wetting and drying, and (b) freezing and thawing



Soil No. 2-Durability Specimens after 12 cycles of (a) wetting and drying, and (b) freezing and thawing



Soil No. 4-Durability Specimens after 12 cycles of (a) wetting and drying, and (b) freezing and thawing



Soil No. 6-Durability Specimens after 12 cycles of (a) wetting and drying, and (b) freezing and thawing of either the wet-dry test or freeze-thaw test shall not exceed 14 percent for soils with U.S.P.R.A. classification A-3. It is evident that a cement content of 6 percent did not meet these requirements for soil No. 1 and soil No. 5 was dangerously close to the allowable maximum. However, a cement content of 8 percent did meet the requirements for all four soil samples. It seemed inadvisable to specify a cement content below 8 percent since soil No. 1 showed a total loss of 11.5 percent during the freeze-thaw test even at this content.

Cement Content

Taking into consideration that soil No. 1 comprised the major portion of the roadway and that the other soils occurred for the most part in short strips interspersed with No. 1 a cement content of 8 percent by volume was specified for the full length of the project.

That the selected cement content met the other two requirements recommended for durability and serviceability is shown by the data in Table VI. In no case did the maximum volume change during the tests to exceed two percent and in no case did the moisture content exceed the quantity required for saturation, when based on the voids present in the specimen as molded.

Having established a cement content which on the basis of the laboratory test data would assure satisfactory hardness, durability and serviceability of a roadway built from the materials investigated, it became possible to formulate specifications for field control. As soon as these specifications were set up it was possible to begin construction.

TABLE VI

DATA FROM DURABILITY CONTROL
SPECIMENS CONTAINING 8% CEMENT

Sample Number	Test Type	Maximum Volume Change % of molded volume		Maximum Moisture Percentage Above or Below Saturation
		Plus	Minus	
1	Wet-Dry	1.5	0.0	-3.9
	Freeze-Thaw	2.0	0.0	-3.3
2	Wet-Dry	1.1	0.0	-1.7
	Freeze-Thaw	1.5	0.0	-1.6
4	Wet-Dry	1.1	0.0	-2.4
	Freeze-Thaw	1.5	0.4	-1.6
6	Wet-Dry	1.4	0.3	-1.6
	Freeze-Thaw	1.3	1.1	-0.8

PART II

CONSTRUCTION OF PROJECT

Part II explains all of the various operations incidental to the construction of this soil-cement stabilization project.

CONSTRUCTION PROCEDURE

The construction procedure which is used in building a cement stabilized road consists of the following operations; preparation of the fine grade and preliminary pulverization, spotting and emptying the required number of cement bags, spreading the cement uniformly, uniformly mixing the cement and soil to the specified depth, adding the amount of water necessary to bring the mixture to its optimum moisture content, uniformly mixing the water with the soil-cement, compacting the soil-cement-water mixture to maximum density, shaping the compacted roadway, finishing the surface and curing. These operations as they were applied to the Stockbridge project are discussed in the above order.

Preliminary Pulverization

With the sandy soil which was stabilized on this project preliminary pulverization was not necessary. After fine grading operations had been completed the grader operator loosened the top five inches of the soil with the scarifying teeth of the patrol grader. It is doubted whether this operation was necessary although it may have saved some time in the dry mixing. At one point where some surface grading had been done and the sand borrow not used, a clay pocket about 50 feet long and 10 feet wide was encountered. It was not possible to discover whether the grader operator had failed to scarify this spot or not since it was covered by about three inches of sandy material. This clay was in a saturated condition due to the rainy weather and could not be satisfactorily pulverized during mixing operations. Consequently, it was necessary to remove this material with a scraper. Possibly preliminary scarification and pulverization on the preceding day would have remedied this situation but because of the heavy nature of the clay this seems improbable.

Cement Spotting

To obtain a cement concentration of 8 percent by volume in a roadway 22 feet wide to a depth of 6 inches required 88 bags of cement per station. These were spotted in rows of four, 4.55 feet apart along the roadway. The two outside sacks were 2.5 feet from the edge of the treatment and 5.7 feet from the two inside sacks. Plate VIII (a) shows how the bags were unloaded and spotted from the trucks. After spotting, the bags were opened and spread in windrows across the roadway.

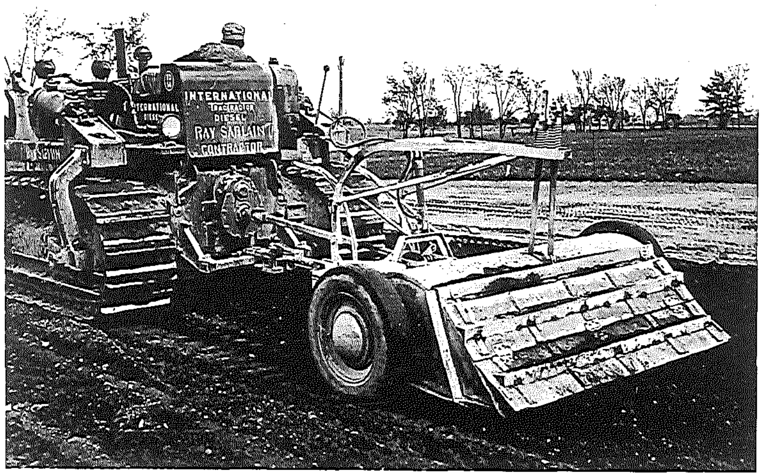
Cement Spreading

Uniform spreading of the cement was completed by dragging the length of the treatment with a spike tooth drag. For this procedure the teeth on the drag were set almost flat and it was found that two complete passes of the drag produced a layer of cement of uniform thickness. Table VII lists the construction operations with the average time consumed by each. Although this table indicates that cement could be spread over a 1500 foot length in the same time that it could be spread for 1000 feet, it should be remembered that this does not take into account the improvement in organization by the contractor. As the men become more familiar with their jobs, it was no longer necessary to limit construction to 1000 feet. The time consumed during cement spread was also increased if the cement was spread from stockpiles alongside the road instead of directly

PLATE VIII

a. Spotting cement bags.

b. Mixing with the cultivator.



c. Mixing with the rotary tiller.

d. Mixing with the three-gang plow.

TABLE VII

AVERAGE TIME CONSUMED IN CONSTRUCTION OPERATIONS

Construction Operation	1000 ft. Section Time - Hours	1500 ft. Section Time - Hours
Cement spread	2	2
Dry Mixing	2-1/2	3
Addition of Water	1-1/2	1-3/4
Wet Mixing	1-3/4	2
Compaction	1-3/4	1-3/4
Shaping	2	2
Final Rolling	1-3/4	2
TOTAL TIME	13-1/4	14-1/2

from the cement trucks. The average time for this operation would very likely be lowered if weather permitted unloading directly from trucks to a road surface instead of requiring occasional stockpiling. Several days of construction were lost because rain the previous day or night had saturated the soil to the extent that it would have been impossible to uniformly mix the dry cement with it.

Table VIII gives the stations processed, with the dates and amount of cement used for each. An equivalent of 163.17 stations, which were processed, would require only 3,589-3/4 barrels of cement which in comparison with the 3,677-3/4 barrels used, indicates an overrun of 88 barrels. However, no account was taken for the extra cement required in the intersection at the south end which amounted to over 2200 square feet of surface. The remainder of the extra cement was consumed by "sweetening" at the joints and cutting back which was sometimes necessary, particularly at the start of construction. Notwithstanding, an overrun of approximately 2.4 percent is not out of line for this type of construction.

<u>Dry Mixing Operations</u>

As soon as cement spreading was completed dry mixing operations were begun. Three pieces of equipment were necessary to satisfactorily mix the soil and cement; a field cultivator, a rotary tiller and a three gang plow. The operation of these three pieces of equipment is illustrated in Plate VIII (b), (c) and (d). The cultivator was set to scarify the soil to a depth of about 5-1/2 inches and was useful in cutting the cement

TABLE VIII

RECORD OF CONSTRUCTION AND CEMENT USED

Date of Construction	Stations Processed	Cement Used
9-24-41	99+00 - 94+00	120 bbls.
9-29-41	94+00 - 99+18	120 "
10-1-31	99+18 - 108+88	215 "
10-2-41	108+88 - 118+82	220 "
10-4-41	118+82 - 129+08	226 "
10-6-41	129+08 - 144+00	340 "
10-8-41	144+00 - 160+89	371-1/4 "
10-9-41	160+89 - 165+39	100 "
10-10-41	165+39 - 179+04	300 "
10-11-41	179+04 - 193+47	340 "
10-15-41	193+47 - 208+33	325 "
10-16-41	208+33 - 223+25	340 "
10-17-41	223+25 - 233+46	225 "
	Patch (11 feet wide)	
10-20-41	(218+53 - 219+64	13-1/2 "
	(Approach to 246+50 - (317 ft.)	70 "
10-21-41	233+46 - 249+44	352 "
TOTAL	163.17 Stations	3677-3/4 "

into the soil. Because of the distance between teeth such an implement could not adequately mix soil and cement, however, when followed by a rotary tiller operated by power takeoff, a thorough job of mixing could be done in this soil. At the start of the project considerable delay was caused by lack of sufficient power to operate the tiller (35 h.p.). However, when a power takeoff was obtained for the 55 h.p. tractor, good mixing was obtained at a more uniform and more rapid rate of speed. Because of the very stony nature of this soil it was necessary to reinforce the back board of the tiller and to check regularly for broken teeth. If some of the larger stones had been removed at the borrow pit, damage to the tiller would have been reduced considerably. Since the mixing unit of the tiller used on this job was only 5 feet wide, it was necessary to make five passes to cover the full 22 feet of roadway, however, one pass over a given spot was sufficient to mix the top five inches.

After the tiller had completely covered the full width of treatment once, being run simultaneously with the cultivator, the three gang plow was used. This implement is specified for accurate control of depth of treatment and served to turn up any unmixed soil down to the six inch level. With the good type of grading of the soil material on this project, very accurate control of depth was possible because of the stability of the base. Data from the 55 test holes showed the average depth of treatment to be 6.2 inches. Plowing was begun at the center line and continued until furrows were left along the edge of treatment.

As soon as plowing was completed the cultivator and tiller continued dry mixing and the patrol grader with tilted blade trimmed the edge of the treatment and shaped the mixture to the general outlines of the finished roadway. This operation is illustrated in Plate IX (a). A uniform dry mix to a depth of six inches was usually obtained by the time the tiller had completely covered the treatment. At this time the character of the mix was checked by the trench method. In this manner streaks of cement or soil indicative of insufficient mixing were readily observed and mixing was continued until these were eliminated. When dry mixing had been completed, a composite sample of about 15 pounds was taken for determination of moisture, percentage of plus No. 4 material, and field moisture density curve.

Adding Water

Field moisture-density tests, like the laboratory tests, were run on the minus No. 4 soil-cement mixture and the optimum moisture required for maximum density was determined for the section of road being processed. By knowing the percentage moisture in the minus No. 4 soil-cement dry mix, the additional water required to bring this mixture to optimum was readily calculated. However, it should be remembered that the percentage of plus No. 4 material in the soil must be taken into account. Since the larger material is relatively inactive in absorbing moisture a correction must be made in the amount of water to be added to the total roadway soil which eliminates the weight of that part of soil which is plus No. 4 material. It was found by field experience that water added only on the basis of

a. Trimming edges with the patrol grader.

b. Adding water with the distributor.

c. Compacting with the sheepsfoot roller.

d. Final shaping with the patrol grader.

weight of minus No. 4 soil cement was insufficient whereas that added considering the total soil to be minus No. 4 was in excess. For field practice a value about half way between the two was selected and final moisture checks made on specimens indicated that the moisture content was within 1 percent of the optimum in almost every case.

Water was added to the dry mix by the use of two pressure distributors with 11 foot spray bars. Plate IX (b) shows the distributor in operation. One distributor held 2600 gallons, the other 2900 gallons. With these it was possible to add the required water at quite a rapid rate and still maintain uniform distribution. For the first days run the spray bars were not exactly 11 feet and overlapping caused a wet streak down the center of the road. This was corrected by plugging some of the outside holes in the bars. The contractor had a 5000 gallon storage tank so arranged as to fill the distributors by gravity feed. This enabled the saving of considerable time in water distribution. In referring to Table VII it should be noted that rainy weather kept the roadway soil at a fairly high moisture content during most of the construction period and that higher temperatures and dryer weather would have considerably increased the time required for water distribution.

Wet Mixing Operations

Wet mixing started immediately after the first pass of the water distributor. During the time that the water was being added the field cultivator was in operation continuously to cut the water into the soil, remove compacted tracks of the distributors, and mix the water with the soil as evenly as possible to a depth of 6 inches. The cultivator alone looked to be adequate for mixing the water into the soil, so the tiller was not used before the plow in the wet mix. Thus, a half hour to an hours time was saved and an even distribution of the water was obtained in the final wet mix.

The remaining operations involved in wet mixing were exactly the same as the dry mixing. After the cultivator came the plow to turn the mix over and bring to the top any dry soil-cement mix. Once again, the patrol grader trimmed the edges and shaped the grade; and then the tiller and cultivator completed the mixing operations. As in the dry mixing operations, a uniform mixture of soil, cement and water was usually obtained by the time the rotary tiller had completely covered the treated roadway.

One of the most difficult problems encountered in the road mix method is that of mixing adjacent to completed work, removal of header boards, and finishing of joints. At the end of each days run, the processed roadway was squared off and 6" x 6" header boards were placed to prevent breakdown of the treatment. To obtain a uniform mixture in front of the header and still provide an adequate turnaround for equipment required some experimentation. The Portland Cement Association recommended wasting the top 6 inches of fill material for 50 feet at the beginning of the first days run, using this space for an equipment turnaround, and hauling back with scraper from the end of processed section completely mixed material to fill this area prior to compaction. This procedure was adopted for the first two days of processing and then discarded for a much simpler method. Hauling back the mixed material in the scraper was not only a very time-consuming operation, but also was found to be very wasteful of material. The trips of the tractor and scraper over the grade caused surface compaction of some of the processed soil requiring additional time to loosen it before sheeps-foot compaction.

The procedure of mixing next to the header was changed on the third day of construction. For this, the turnaround was built on the completed roadway with a platform of 2" x 12" planks covered with 2-3 inches of soil. This prevented any damage to the surface of the previous construction. A raw soil strip about 2 feet wide was left against the header board until the final stages of the mixing operation, but next to this a trench about 2 feet wide and 6 inches deep was dug which permitted the mixing equipment to get down to specified depth as close to the header as possible. This trench was kept open by one man whose job it was to handle all construction at the joints. When wet mixing was nearly completed the raw soil next to the header was removed with shovels and thrown out with the mixed soil. To this raw soil was added 3 sacks of cement which had been saved for this purpose and mixing was accomplished by transverse movement of the cultivator and tiller. The patrol grader was used to return the material to the adjacent end of the preceding section, the header boards and cover platforms having been removed. As soon as the cultivator had loosened all compaction planes caused by the grader, compaction could be started on the whole section.

Compaction of Soil-Cement-Water Mixture

On this project compaction was obtained by the use of one double drum sheeps-foot roller with feet having an area of 6 square inches. Plate IX

(c) shows the method of compaction with the sheeps-foot roller. At first it was thought that the unit pressures exerted by this roller were too great when filled with water and the water was removed to the half-way mark giving unit pressures of about 160 pounds per square inch. During the first few days processing the roller did not pack out satisfactorily, but it should be considered that the time for packing was sometimes necessarily reduced because of a desire to finish the processed section before dark and often by the necessity of sealing the surface before too much rain entered into the mixture. Later, when a better organization was realized and clear days permitted more attention to be directed to compaction procedure, the roller drums were completely filled with water to give unit pressures of about 200 pounds per square inch, and the roller packed out very satisfactorily. Table IX shows that actual roadway densities were just as good at the beginning of the project as near the end. This indicates that insufficient rolling is not wholly responsible for low test hole densities as compared with specimen densities and maximum density from field test curves.

Both rubber-tired and caterpillar type tractors were tested for use in pulling the sheeps-foot roller. It was found that when the rubber-tired tractor was used alone the roller packed out much too fast because of surface compaction by the tires and good compaction was not obtained at the base of the treatment. On the other hand, the caterpillar tractor enabled good compaction at the base, but the roller would pack out only to a depth of about 2 inches from the surface since the track cleats prevented compaction of the surface. On several days runs the caterpillar

TABLE IX

COMPARISON OF MINUS NO. 4 SOIL-CEMENT DENSITIES

Station No.	Field Moisture Density Test	Specimen Densities		Test Hole Densities	
		Lowest	Highest	Lowest	Highest
94-99	130.2			120.7	130.3
99-109	127.5			114.7	133.8
109-119	131.3	124.1	127.3	118.2	130.3
119-129				115.8	132.4
129-144	127.9	116.6	124.4	119.0	124.0
144-161	127.3*	123.6	124.0	117.2	122.2
161-165		124.4	125.6	125.7	129.0
165-179		121.6	126.1	117.3	126.0
179-193		123.9	125.1	115.8	120.0
193-208	126.1	122.0	126.2	112.0	122.2
208-223		120.8	124.1	106.6	112.6
223-233				119.0	123.8

* Corrected density from moisture-density curve of total soil

tractor was used for preliminary packing and the rubber-tired tractor for final packing, but this proved to be of no particular advantage since the patrol grader compacted the surface 2 inches as well as the tractor and sheeps-foot roller. Such complete packing out was not particularly desirable for the grader required a mulch to build his final grade, and at least one inch of mulch was essential to obtain a good surface after final rolling.

Table IX compares the road densities and control densities. The determination of maximum density of the minus No. 4 soil-cement has been previously described, the field specimens were molded in the Proctor cylinder from the total wet mix material immediately preceding compaction, and the test holes were dug in the roadway the day following processing. Thus, both the specimens and the test holes involved plus No. 4 material and the densities had to be corrected for the percentage of plus No. 4 material for comparison with optimum moisture-maximum density determinations. It was found that only in a very few cases were the test hole corrected densities within the specified 5 pounds of the field maximum density determinations. Even when compared with the lowest specimen density for the same days run the difference was often greater than 5 pounds. It was also noticed that the lowest specimen densities were always lower than the field maximum densities and sometimes more than 5 pounds lower. Disregarding the fact that insufficient sheeps-foot compaction might have been given to the roadway soil there are several other reasons for these discrepancies. If the moisture in the wet mix was not exactly at optimum both specimen and test hole densities would be lower, however, in several cases, moisture determinations showed the wet mix to contain exactly optimum moisture and densities were still low. In correcting both field and specimen total densities to minus No. 4 soil-cement density, the laboratory determination of specific gravity of the plus No. 4 material was assumed to hold true while the percentage of plus No. 4 material in the specimens was determined by a representative sample. Variations in either one of these factors could considerably change the corrected density, and such variations undoubtedly occured. Another factor worthy of consideration is the difference in density caused by the hydration of cement. Even though several of the field moisture-density curves were run delayed, that is by allowing one-half hour (to an hour) interval between each density determination at an increased water content, the total elapsed time during the test did not exceed four hours, while the time after field dry mixing until completion of compaction averaged five to six hours. The fundamental assumption that the density of the minus No. 4 soil-cement material when compacted alone should be compared with the density of the same material when compacted in the presence of a relatively large amount of plus No. 4 material is very likely not strictly true. The average percentage of plus No. 4 material was 20.5 as determined from test holes and in one section a percentage as high as 30 was not uncommon. The differences between specimen densities and field maximum densities would indicate that the fine material could not be as well compacted when mixed with the rock even in a Proctor cylinder. In the roadway where arching action of the rock was more likely to occur differences in density of the fine material would probably be even more pronounced.

Perhaps a more valid check on roadway densities is the comparison between total specimen densities and total test hole densities which is given in Table X. Of the thirteen stations at which specimens were molded and test holes bored, six showed differences in densities of over five pounds per cubic foot. For the nine stations at which the specimen densities were the greater, the average difference was only 6.3 pounds per cubic foot and in only one case was the difference as great as 10 pounds per cubic foot. This comparison is somewhat in error because the specimens molded from a composite sample taken at a given station would not necessarily contain the same amount of plus No. 4 material as a test hole bored at any given spot at the same station. Nevertheless, the two do agree quite well and the indication is that, for the most part, as good compaction as could be expected was obtained.

Shaping of Completed Roadway

As soon as the sheeps-foot roller had packed out a depth of about 4 inches the patrol grader started final shaping operations, including building the crown. Usually the grader and roller worked simultaneously for about three-quarters of an hour and then the grader completed final shaping of the roadway which is illustrated in Plate IX (d). The time required for grading operations as shown in Table VII includes shaping during both wet and dry mixing, which has been mentioned, as well as the final shaping which by itself averaged about one hours work.

When the final shaping operations had been completed, it was possible to prepare the road surface for final finishing. In order to prevent chipping or raveling due to compaction planes near the surface, caused

TABLE X

COMPARISON OF TOTAL DENSITIES

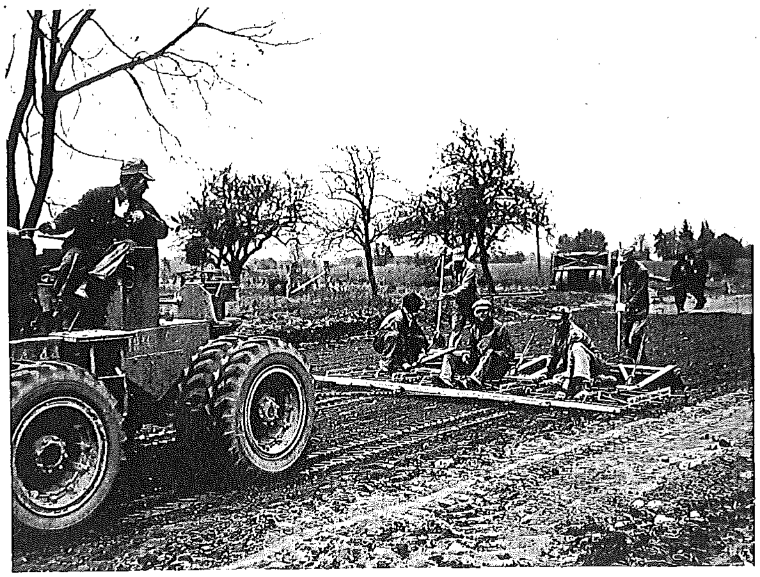
Station Number	Specimen Densities Average of 2	Test Hole Densities	Difference
133	129.2	131.8	-2.6
138	126.0	131.8	-5.8
149	132.3	125.8	6.5
155	129.2	124.8	4.4
162	131.3	132.3	-1.0
170+50	132.8	123.8	9.0
174+50	128.3	126.0	2.3
184	132.2	126.1	6.1
190	131.3	125.4	5.9
195	131.2	127.1	4.1
205	127.7	128.5	-0.8
212	127.7	116.2	7.8
218	129.0	118.5	10.5

by grader wheels or the sheeps-foot roller, a loose uniform mulch about 1-1/2 inches deep was built with a spike-tooth drag followed by a broom drag. See Plate X (a). During the first days run a nail drag was used but proved to be impractical on this project as the stones would lodge between the nails and leave ruts not filled in by the broom. The spike tooth drag worked very well except in some cut sections of the natural soil which were higher in clay content. In this heavier soil type an implement with the teeth closer together would have been more useful in forming the mulch.

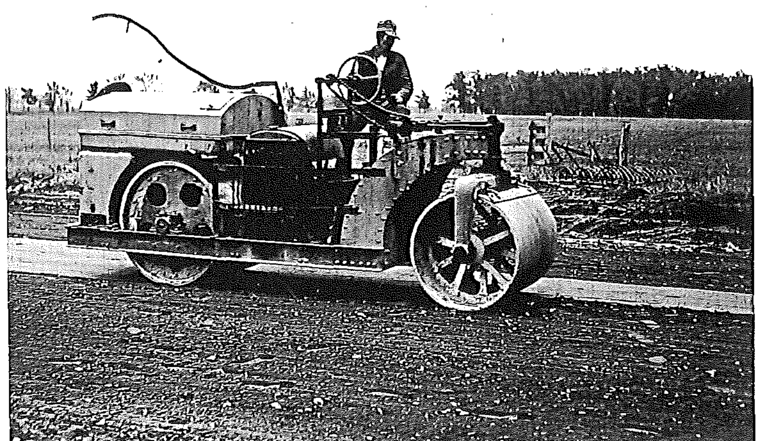
Finishing Surface

Four different procedures were tried out for finishing the surface of the processed section. Because of the large amount of stone which was present it was quite difficult to obtain a smooth surface, however, by experimentation a procedure was developed which produced a very acceptable surface. On the first day of processing the contractor had only a small steel roller which was an attachment to the patrol grader. It was not possible to use this roller at all because it did not cover the tracks left by the grader wheels and these could not be rolled out. Also, because of the small diameter of the roller, cracks were left in the road surface due to shoving. Consequently, on this first day the pneumatic roller was the only equipment used for rolling. Naturally, this roller would not press the stones into the surface completely and a very poor looking job was obtained. It was clear that before additional processing could be done a two wheeled tandem roller must be available.

PLATE X



a. Dragging to remove surface compaction planes and produce a mulch.



b. Rolling with steel tandem roller.

On the second day of processing the mulch surface was first covered once with the pneumatic roller* to knit the surface in order to prevent shoveling, and picking up on the steel roller; second, rolled once with the steel roller beginning at the edge and rolling to center to press in the stones and give a smooth riding quality; and finally, rolled several times with the pneumatic roller to remove any steel roller marks which might be present and to knit the fine material firmly around the stones. This method, however, was not entirely satisfactory as the steel roller did not completely eliminate the tire marks left by the pneumatic roller on the first pass. It was found while using this finishing procedure that steel rolling from the center of the road to the edge would eliminate to a great extent any roller creases and did not injure the crown. After that, all steel rolling was done in such a way.

On the eighth day of processing, because of dissatisfaction with previous surfaces, it was decided to use the smooth steel roller directly on the surface mulch, followed by the pneumatic roller. Such a procedure gave a smoother surface than any which had been obtained, although on this particular day some pickup did occur because the rolling was done in a light rain. Plate X (b) shows the use of the steel roller directly on the mulch. The final rolling procedure was simply an extension of this method to include a second application of the steel roller after the pneumatic roller had knit the surface stone in place. Using the steel roller last served to eliminate any small ridges which might have been left by the pneumatic roller and a very acceptable surface was obtained. When using the steel roller first, great care was necessary to have the surface mulch very nearly at optimum moisture content. If the surface was too dry, cracking and shoving would occur and if it was too wet the steel roller would pick up the material. It was sometimes necessary to give the roadway a light spray of water just before mulch-building operations, but this was only done when it was evident that the surface was much too dry. In general, it was found that less damage to the surface resulted if rolled slightly dry than if rolled slightly wet. The finished surfaces on this project would in general have been much better had it not been for the exceptional amount of rain falling during the construction period. On five of the fifteen days of processing, it was raining while final rolling was being done.

During final rolling operations certain conditions sometimes appeared which were not evident in mixing operations. These were all noticed in sections where surface grading had been done, thus introducing a larger percentage of top-soil into the roadway. In spots where the surface had a high proportion of silt or very fine sand the stability was low. This condition was evidenced by the fact that the steel roller had a tendency to shove and leave check cracks in these places. However, in most cases the pneumatic roller was able to seal these cracks and, furthermore, visual inspection the following day indicated that the cement had hardened normally in these spots. Only exposure to weather conditions will show whether failure will occur sooner at these silty spots. Silty topsoil was also responsible for another condition which appeared during final rolling. In this case a layer of topsoil had been buried at a depth of 8 to 12 inches and subsequently became saturated by the rains. When the steel roller passed over this section deep ruts and cracks were left in the road surface. Upon inspection it was found that these cracks extended completely through the processed soil into the spongy material below. Here it was necessary to remove all material down through the saturated topsoil, refill with borrow material and reprocess the section which was about 100 feet long and 11 feet wide.

Curing of Completed Surface

The final stage of construction of the soil-cement roadway is curing. On this project the completed roadway was covered with a protective layer of straw on the day following processing. Throughout the seven day curing period the straw was kept damp by wetting down with the water distributor. As soon as the soil-cement had cured, the straw cover was removed and the road was opened to traffic. The time required for covering is not listed in Table VII since it varied a great deal depending upon the distance of haul from the straw stack to the project. However, the time to cover 1500 feet on favorable days was estimated at about three hours including the loading of the truck and the hauling. It was noticed that straw was a poor type of covering to use during the fall season since it was impossible to load and evenly distribute the straw on very windy days. For this reason, it was sometimes late afternoon before the processed roadway was covered whereas it should have been completely covered before noon.

Summary and Suggestions

A complete summary of construction irregularities is presented in Table X located at the end of Part II.

Table VII shows that the total time required for processing 1000 to 1500 feet was from 13 to 14 hours. In this time the cement was in contact with water over 7 hours before soil and cement were compacted. A question should be raised about the setting and hardening properties of the cement after being worked in the presence of water for such a time. Unquestionably the cement loses some of its strength during mixing operations and direct correlation with laboratory durability specimen seems very dubious. Some study should be made of the effect of time of mixing soil and cement with the durability of the specimens.

Of the operations required in the road mix method of soil-cement construction it seems that only one might be eliminated. Although the plow is often a valuable implement in controlling depth of treatment, it may also be responsible for extending the treatment too deep. This was particularly true with the type of material encountered on the Grayling project, where it was almost impossible to keep the depth of treatment within the specified limits. Even on this project it is conceivable that plowing might be eliminated if heavy duty rotary tillers were available. Without the plow, in some cases, such a uniform depth of treatment might not be obtained but there would not be the danger of going too deep and the elimination of this one operation would save at least two hours and probably more in a 1500 foot section.

A procedure which is specified by the Portland Cement Association and which seems to be superflous is that of covering or rolling the processed roadway before construction is completed in the event of a rain. This is true particularly in a rainy season such as was encountered on this project. However, it is necessary to finish construction within 12 to 15 hours after the cement is mixed with the soil, consequently if processing is not completed within this time the whole section is ruined. It may be said that rain will usually fall only for a short time or continue for such a time that once construction is stopped it is impossible to start again and complete operations within the allotted time. In the majority of cases not enough rain will fall to injure the soil-cement mix during a short shower. If the rain continues for some time it is better to continue construction, shortening procedures wherever possible, in an attempt to complete processing rather than stop and lose the section by not being able to get back on it in time.

TABLE X

SUMMARY OF CONSTRUCTION IRREGULARITIES

Date	Stationing	Weather	Construction Irregularities	Soil Irregularities	Test Hole Densities		
					Station	Total	-4SC
9-24-41	90 to 94	Clear - a.m. Cloudy - p.m.	No smooth rolling to punch in rock due to lack of proper type of steel roller. Material at Sta. 90 to 90+50 mixed ahead and hauled back by scraper. Premature packing of East side of road by tractor and scraper. Sheepsfoot roller did not pack lower part of treatment.	None. Soil of Fox sandy borrow.	90+50 92+00 95+50	116.5 110.8 138.3	108.0 105.8 131.6
9-29-41	94 to 99+18	Partly cloudy a.m. Partly cloudy p.m.	Center of the road received too much water due to overlapping of spray bar on distributor. Some pickup occurred when rolled. Material at Sta. 94 to 94+40 was mixed ahead and hauled back by tractor and scraper. Finishing: pneumatic, steel, the pneumatic roller.	None. Soil of Fox sandy borrow.	94+50 96+50 98+00	138.5 126.9 128.0	130.3 120.7 123.0
10-1-41	99+18 to 108+88	Partly cloudy a.m. Cloudy - p.m.	None. Finishing: Pneumatic, steel, then pneumatic roller.	None. Soil of Fox sandy borrow.	99+50 101+50 103+50 105+50 108+00	117.8 134.1 140.7 130.2 130.4	114.7 126.4 133.8 124.0 120.9
10-2-41	108+88 to 118+82	Fair - a.m. Partly cloudy slight rain during rolling p.m.	None. Finishing: Pneumatic, steel, then pneumatic roller.	Soil of Fox sandy borrow. High in +4 material. 25 to 30% +4	108+95 110+50 112+50 114+50 117+00	133.0 131.2 128.6 128.6 137.5	123.0 122.2 120.0 118.2 130.3

Date	Stationing	Weather	Construction Irregularities	Soil Irregularities	Test Hole Densities		
					Station	Total	-4SC
10-4-41	118+82 to 129+8	Partly cloudy a.m. Showers - p.m.	Rain began during wet mixing raising moisture content about 2% above optimum. Compaction time was considerably shortened. Pneumatic rolling was done in heavy rain and the road surface was soupy. Steel roller removed tire marks but left some creases. Final pneumatic rolling not done. It is estimated that the cement was washed out of 1/4 to 1/2" of the surface.	Soil of Fox sandy borrow. Very high in +4 material. 25 to 30% +4.	119+00 121+00 123+00 126+00 128+50	132.0 127.3 139.5 126.0 133.1	121.0 118.7 132.4 115.8 121.3
10-6-41	129+8 to 144+00	Fair - a.m. Cloudy to rain - p.m.	Compaction time shortened because of impending rain. Both pneumatic and steel rolling was done in heavy rain leaving deep roller creases in the surface. Final pneumatic rolling was not done. Rain lasted most of the night and on the next morning the surface was not yet hard. Steel roller was used again in the morning to remove the deep roller marks.	Soil of Fox sandy borrow. 20 to 25% +4.	129+28 133+00 136+50 138+00 142+00	127.0 131.8 130.1 131.8 130.7	119.9 123.9 124.0 119.0 121.2
10-8-41	144+00 to 160+89	Cloudy - a.m. Fair - p.m.	None	Soil of Fox sandy borrow.	144+50 149+00 152+00 155+00 159+00	130.2 125.8 129.3 124.8 128.4	117.2 118.5 121.5 118.6 122.2

Date	Stationing	Weather	Construction Irregularities	Soil Irregularities	Test Hole Densities		
					Station	Total	-4SC
10-9-41	160+89 to 165+39	Cloudy - a.m. Rain - p.m.	Sheeps-foot roller packed out completely. Finishing: Steel roller used directly on mulch followed by pneumatic to knit in the stones. Rain prevented finishing with steel roller.	Soil of Fox sandy borrow.	161+00 162+00 164+00	132.2 132.3 133.0	129.0 126.6 125.7
10-10-41	165+39 to 179+04	Partly cloudy a.m. Cloudy - p.m.	Finishing: steel roller followed by pneumatic roller.	Soil of Fox sandy borrow.	165+50 167+50 170+50 174+50 177+50	133.1 129.5 123.8 126.0 126.8	125.8 126.0 117.3 123.8 119.2
10-11-41	179+04 to 193+47	Fair - a.m. Partly cloudy p.m.	Rubber tired tractor used to pull sheeps-foot. This seemed to cause premature packing and may have been partially responsible for low densities. Finishing: steel roller, then pneumatic, followed by steel for final finishing.	Strip of sandy clay about 10 ft. wide removed from center of road at sta. 192+10 to 192+80. From sta. 192 to 193+50 the roadbed was quite rich in topsoil which apparently had been pulled in from the shoulders and did not come from borrow pit This material had a silty texture, did not pack out well, and formed surface cracks under the weight of the steel roller.	179+50 182+00 185+00 190+00 192+50	124.3 172.8 126.1 125.4 118.5	118.0 116.2 120.0 118.7 115.8

Date	Stationing	Weather	Construction Irregularities	Soil Irregularities	Test Hole Densities		
					Station	Total	-4SC
11-15-41	193+47 to 208+33	Fair - a.m. Fair - p.m.	None. Finishing: steel roller, then pneumatic, then steel.	Soil of Fox sandy borrow.	195+00 200+00 205+00	127.1 121.3 128.5	122.2 112.0 118.8
11-16-41	208+33 to 223+25	Fair - a.m. Fair - p.m.	None. Sheeps-foot seemed to pack out in good shape. Finishing: steel roller, then pneumatic, then steel.	This soil was low in +4 material and in general had a siltier texture. On the left side of the road between sta. 218+53 and 219+64 it was found that the road had been laid on a subgrade of saturated topsoil. This prevented packing or rolling of the surface and was therefore removed and patched later.	209+00 212+00 218+00 219+30	114.1 116.2 118.5 115.6	106.6 112.6 110.5 111.3
11-17-41	223+25 to 233+46	Cloudy - a.m. Cloudy to showers - p.m.	Sheeps-foot compaction appeared to be good. Finishing: steel rolling followed by pneumatic. Final steel rolling could not be done since roller began to pick up the surface which was wet by the rain.	During steel rolling it was noticed that several silty spots existed. A strip about 5 ft. wide in the center of the road from sta. 223+30 to 224+00 cracked considerably under the weight of the roller.	223+50 228+00 232+00	125.5 131.0 125.9	120.0 123.8 119.0

Date	Stationing	Weather	Construction Irregularities	Soil Irregularities	Test Hole Densities		
					Station	Total	-4SC
10-20-41	Patch 218+53 to 219+64	Fair - a.m. Fair - p.m.	None.	Fox sandy borrow.	Not tested.		
10-20-41	Approach to sta. 246+50	Fair	None.	Fox sandy borrow.	246+50	126.4	117.8
10-21-41	233+46 to 249+44	Cloudy - a.m. Fair - p.m.	None.	Fox sandy borrow.	Not tested.		

PART III

CONDITION SURVEYS

Part III contains a graphical presentation of the road surface after one winter of service, as well as a station to station description of the road surface as it appeared upon visual observation.

CONDITION SURVEYS

Under normal conditions a soil-cement stabilized road surface will abrade under weathering and traffic. Consequently, it is necessary to treat the surface with some kind of a bituminous wearing coarse to preserve the surface. The surface treatment is usually applied within a specified time after completion of the project. The Stockbridge project was completed so late in the year that it was considered inadvisable to treat the surface with any kind of a bituminous seal. Consequently, the project has gone through one winter season without a seal coat and with the exception of a few areas, has come through in fair condition considering the conditions under which it was constructed.

Condition surveys have been made to ascertain the general condition of the project. The surveys consist of a detailed crack and surface condition examination which has been plotted on specially prepared graph paper, and visual examination by the personnel of the Testing Division and by representatives of the Portland Cement Association.

Crack and Surface Condition Survey

A detailed crack and surface condition survey was made on March 24, 1942 by T. H. Thornburn and G. A. Ryan of the Research Division. The survey included the location by stations of all cracks, joints, and of rutted, pitted and raveled areas as well as other defects which were apparent. The condition survey will be found at the end of this report. The defects are designated by the following legend. Surface rutting (SR), surface rutted and rough (SR-R), surface badly rutted

(SBR), surface badly rutted and rough (SBR-R), and edge raveling (ER).

Condition Survey by Testing Division

At the request of Mr. W. W. McLaughlin, Testing Engineer, Messrs. Rathfoot, Olmstead and Stokstad made a visual examination of the Stockbridge project on March 17, 1942. A report covering their findings was submitted by Mr. O. L. Stokstad on March 18th. The report in full is as follows:

Sta. 90 (P.O.B.) to Sta. 120 -

> Structurally the slab is in excellent condition. Some of the joints between daily runs need patching. Traffic has caused some surface abrasion.
>
> Fill settlement over the culvert at Sta. 114 is causing some slab weakening.

Sta. 120 to Sta. 190 -

> This section is in good condition showing some local pitting and some raveling along the edge. General surface abrasion caused by traffic. Fill settlement at the culvert Sta. 130 and peat swamp Sta. 131, has also caused some weakening of the soil cement. Some patching will be necessary.

Sta. 190 to Sta. 198 -

> This is the poorest section of the entire project. Chuck holes are forming in the slab which causes it to look like a gravel road without maintenance. The slab lacks the cracking characteristic of the best sections.

Sta. 198 to Sta. 207 -

> This section is in good condition with some pitting and slight raveling. Some patching will be necessary before applying a surface treatment.

Sta. 207 to Sta. 211 -

A poor section showing a tendency toward chuck hole formation. The resulting poor surface drainage probably has a tendency to accelerate the destructive action of traffic.

Sta. 211 to Sta. 223 -

Extensive pitting was observed in this section resulting in a poor to fair surface condition as compared to the balance of the project. Considerable patching will be necessary before applying the bituminous surface treatment.

Sta. 223 to Sta. 230 -

In good condition with slight tendency toward pitting and edge raveling.

Sta. 230 to Sta. 237 -

Edge failures and pitting is common requiring considerable patching before applying a wearing course.

Sta. 237 to Sta. 249 (P.O.E.) -

The surface is in fair to good condition with some pitting which will require patching.

Conclusions -

1. Of the 3 miles involved in this project 1/4 mile is definitely bad.

2. There is no obvious evidence of foundation weakness.

3. The soil-cement has the appearance of being on the lean side with respect to cement content.

4. Less failure would have resulted if this project could have been sealed last fall. On the other hand this is a research project and as such should be subjected to a severe test in order to uncover information useful in the design and construction of future soil-cement projects.

Recommendations -

1. Obtain cores for -

    a. Cement content tests.
    b. Freezing and thawing tests.
    c. Density tests.

2. Make condition survey in order to have a map of the present slab with which to compare the construction record. The map to show -

    a. cracks
    b. pits
    c. joints and thin condition
    d. disintegration
    e. raveling
    f. chuck hole sections
    g. culvert fill settlements
    h. swamp fill settlements
    i. edge failures

3. Patch and seal as soon as weather permits.

<u>Condition Survey by Portland Cement Association:</u>

At the request of the Research Division the Portland Cement Association made an examination of the Stockbridge project since their representative was present during construction operations. Their inspection was made by Messrs. J. O. Granum and K. W. Shell on March 25, 1942. The report of their examination is presented in full as follows -

> <u>Section #1</u> Sta. 90+00 to 94+00 and intersection widening (9/25). Top surface has uniform shallow ravel. S-C in intersection wings medium hard. Ravelled fines accumulated along section edges. End joint ravelled 1" to 1-1/2". West edge S-C medium hard.
>
> <u>Section #2</u> Sta. 94+00 to 99+18 (9/29) Take off joint very good with a few shallow ruts ravelled and general light surface ravel. End joint ravelled back 30' east side and 50' west side - depth 1/2" to 1".

Section #3 Sta. 99+18 to 108+88 (10/1)
Take off joint very good. General section improvement over #2. Spike tooth harrow grooves show up. West side smoother - more rubber tired rolling. Stony end joint - low, ravelled, max. 2" on east.

Section #4 - Sta. 108+88 to 118+88 (10/2)
Whole section good. West 1/2 very good - steel rolled before rubber tired rolled. Center 1/3 shows spike tooth scars and has some shallow surface ravel. Culvert Sta. 114 - fill on both sides has settled - S-C shattered and depressed. S-C bridging shown. Sta. 114+50 - low density area - ravel and short ruts. End joint fairly good but low edges. Back of end joint for 150' + fill over swamp drawn slab edges show grade settlement.

Section #5 Sta. 118+82 to 129+08 (10/4)
Rain during finishing operations. General surface shallow ravel. Soil very stony. End joint better but low edges and east 1/4 point. Applied straw cover two days after processing. West edge Sta. 121 shows side borrow soil in place for treatment instead of pit borrow.

Section #6 Sta. 129+08 to 144+00 (10/6)
Rain during finishing. Sheepfooted 1 hr. 5 min. Rubber tire rolled before spike tooth and broom. Settlement at Culvert Sta. 130 - broken S-C. Section built 6th, rain 7th, covered 8th October. South hill slope shows somewhat inferior S-C with about 1" accumulated loose material on surface. Edges appear to be depressed just outside 1/4 line. Apparently some existing soil in treatment. Hill top portion good. Balance of section like hill slope with some maximum 2" ruts and pocket ravel. End joint slightly low.

Section #7 Sta. 144+00 to 160+89 (10/8)
Sheepsfooted 1 hr. 15 min. Take off joint very good. Sta. 144+50 to 147+50 surface ravel - spike tooth scars. Balance of section light surface ravel with a few 2" to 3" ravelled ruts. Section not bad, not good.

Section #8 Sta. 160+89 to 165+39 (10/9)
Section best on project. Only section where all densities met specs.

<u>Section #9</u> Sta. 165+39 to 179+05 (10/10)
Generally fair section. Millner Road intersection shows side borrow soil. Sta. 176 to 178 many longitudinal cracks between edge and 4' to 6' in accompanied by small transverse crack pattern. End joint low - east edge 3" low.

<u>Section #10</u> Sta. 179+04 to 193+50 (10/11)
<u>Section #11</u> Sta. 193+50 to 208+33 (10/15)
Station 179+04 to 190+10 fairly good surface - few shallow ruts. Sta. 190+10 to 198+00 rough and rutted section. Denter roadway S-C is very hard but spotty surface. Sheepsfoot marks show where scaling has occurred. Construction notes show clay excavated during processing Sta. 192+10 to 192+80 also that this section is natural roadway having no sand cushion or pit borrow. In general S-C is less than medium hard. Areas of clay treatment show. Sta. 207-zero cut point west side. Soil to end joint dark, light on cement for good hardening. Sta. 198 to 207 - S-C fairly good.

<u>Section #12</u> Sta. 208+33 to 223+27 (10/16)
Entire section heavy spike tooth scaling with practically no mulch developed. Edges show existing dark soil. Densities 15# to 20# low. Construction patch west half 218+53 to 219+64 O.K. S-C failed account saturated "B" silt loam subgrade. Patched 10/20.

<u>Section #13</u> Sta. 223+27 to 233+46 (10/17)
Generally good section. Sta. 231 - dark natural soil east edge 5'. Low end joint - east edge shows corner cracks.

<u>Section #14</u> East approach to Sta. 246+50, 317' (10/20)
Very good section. Rubber roller marks near east end. Good joints.

<u>Section #15</u> Sta. 233+46 to 249+44 (E.O.P.) (10/21)
Station 233+46 to 234+50 - S-C shows numerous longitudinal cracks - 4 or 5 in a group on 4" centers. Soft subgrade indicated - noted by Treadwell, State Insp. East edge poor along east farm yard. S-C good to road cut and then some spotted ravelling on to north end with ravelling across north end joint.

Conclusions:

It is our conclusion that about ninety per cent of the soil-cement needs a 50 to 60 pound bituminous surfacing. The shattered soil-cement at culverts where grade settlement has caused disruptions should be removed; the subgrade repaired and new soil-cement installed before surfacing. The balance of the soil-cement will require a good leveling course, followed by the surfacing course.

Before application of the bituminous prime, the soil-cement should be thoroughly cleaned. This will require the use of a blade, a power sweeper, hand shovels and push brooms.

In our opinion the causes of the existing defects are as follows:

1. New grade settlement a contributing factor.
2. No variation in cement control to meet the needs of a poorer soil type.
3. Contractor not properly equipped for length of sections constructed.
4. Allowing less than specification densities.
5. Not following proven surface finishing methods.

CONCLUSIONS

Since the purpose of this research project was to construct an experimental soil-cement stabilized road surface under regular contract procedure to determine the feasibility and economics of such type of road construction in Michigan and to develop specifications for such construction, we feel that on the basis of the facts set forth herein, we have accomplished that purpose quite satisfactorily. The fact that the road surface was not sealed soon after construction has proven to be helpful in that it has revealed certain weaknesses in this type of construction which otherwise might have been overlooked.

It is apparent that the contractor started the processing operation at a time when he should have been through and also that the contractor lacked sufficient equipment to properly handle the length of roadway processed per day within the proper time limitations. These conditions were contributory to a great degree for the unsatisfactory condition of the finished surface as witnessed this spring.

Furthermore, it must be conceded that there was a certain amount of laxity on the part of the highway personnel in charge of the project in permitting the contractor to continue operations and permitting conditions to exist which were not conducive to the production of a good soil-cement stabilized surface. However, this laxity may be expected throughout the state, especially on certain projects where weather, the time element and season of the year have a great bearing on the completion time of the project. Therefore it is not a surprise to expect that such conditions existed on this project.

Soil stabilization is not a stereotype construction process in which standards practiced will necessarily work for all soil types and conditions. Therefore, experience derived from other projects can only be used to a certain degree; from there on, it is purely experimental depending to a certain extent upon soil conditions, contractor's equipment, personnel and organization.

It is evident that soil-cement stabilized surfaces must receive a suitable surface treatment soon after completion in order to be satisfactory.

From a construction standpoint it has been proven that under proper control and construction procedure it is possible to construct soil-cement stabilization road surfaces in Michigan. However, before final conclusions can be established it will be necessary to build many miles of such surfaces in Michigan in order to determine their ultimate reaction to traffic and weather conditions over a period of years. Otherwise, our present research activities in this field will be of little value.

The problem is one of economics in road construction, and the merits of soil-stabilization construction should be compared with other types of road surfaces in the same category. For example, let us compare the relative costs of this soil-cement project with a comparable oil aggregate project. Current prices for oil aggregate construction are as follows: 5" clay gravel base course 33¢ per square yard, 4¢ per square yard for prime coat and 41¢ for oil aggregate surface, or a total of 78¢ per square yard for a finished oil aggregate surface. The ultimate cost of the Stockbridge soil-cement project, exclusive of repairs which would not have been necessary last fall, will be 51¢ per square yard for the base course plus 17¢ per square yard for a double seal bituminous treatment making a total cost of 68¢ per square yard of completed road surfaces.

A saving in this case of 10¢ per square yard. Unit prices naturally will vary to a certain extent in certain localities and with different contractors.

Final conclusions cannot be based on the fact that the two types of surfaces can be constructed for approximately the same cost per square yard. It is necessary to consider the relative economic life of the two surfaces. The economic life is the period during which they must be kept in service for their annual cost to reach the minimum. The annual cost includes such factors as annual return on the value invested, annual routine maintenance, annual administrative and operating costs, annual depreciation and annual cost of periodic repairs.

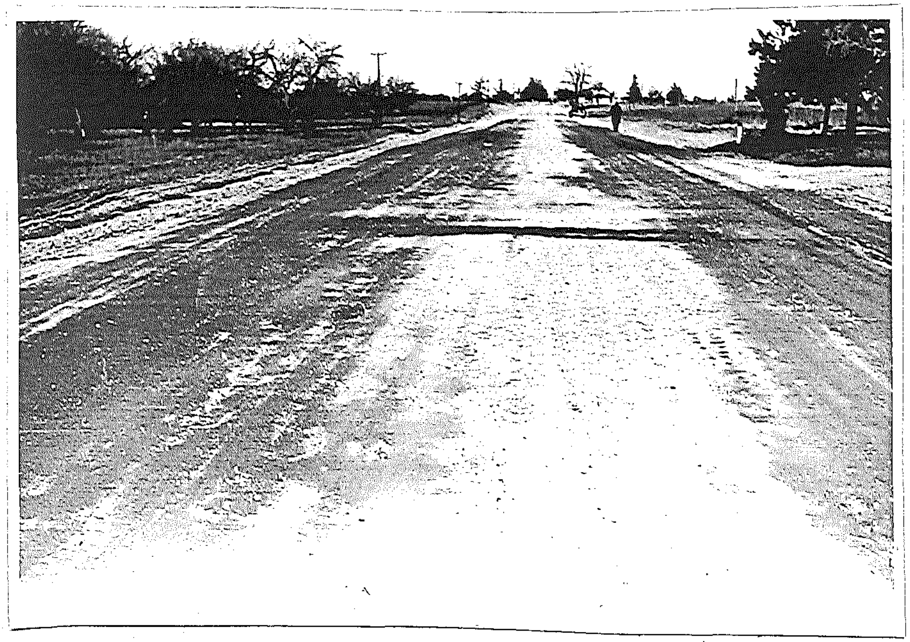
It would seem then that the future of soil stabilized surface construction in Michigan is a matter of policy to be defined by the administration. Two alternatives are suggested, either discourage this type of construction entirely or put on a suitable construction program involving other types of construction in conjunction with soil stabilized surfaces on the same projects for comparative study. The program should be of such scope that the many irregularities which usually exist on the small experimental project will be eliminated.

The three experimental projects which have been constructed in Michigan are of no value only in so far that they have proven that Michigan soils are adaptable to stabilization by employing Portland cements or bituminous binders. Whether or not these stabilized surfaces will resist the effects of Michigan's climatic conditions is another matter which can be determined only by actual experience over a period of years.

APPENDIX

Appendix contains several views of the Stockbridge soil-cement stabilization project illustrating the typical surface characteristics prevalent throughout the project.

PLATE XI



a. General surface condition Station 193+00
Dark areas badly rutted.

b. General surface condition Station 191+00
Dark areas badly rutted.

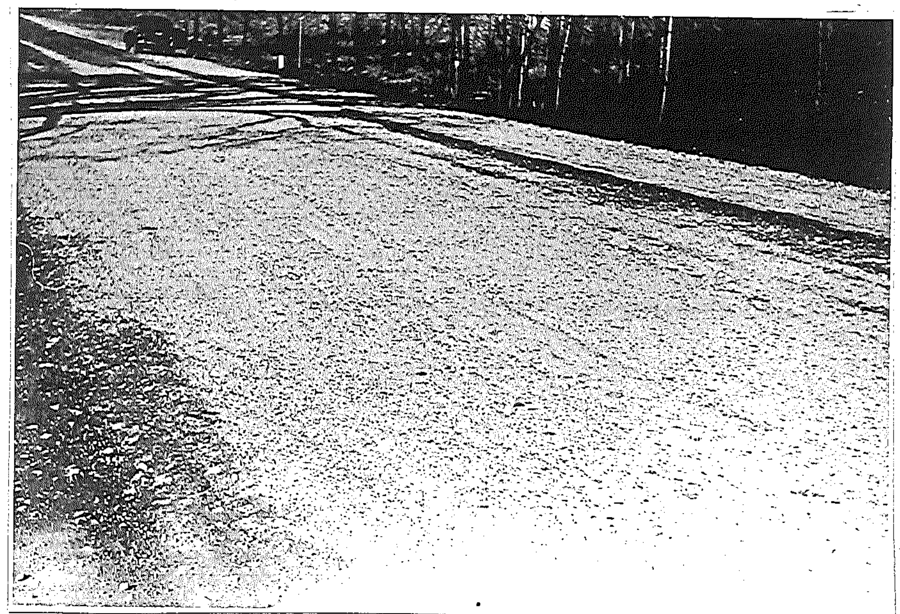
c. General surface condition Station 95+00
Surface in good condition.

d. General suffface condition at Station248+00
Dark areas slightly rutted.

a. Surface texture Station 90+25

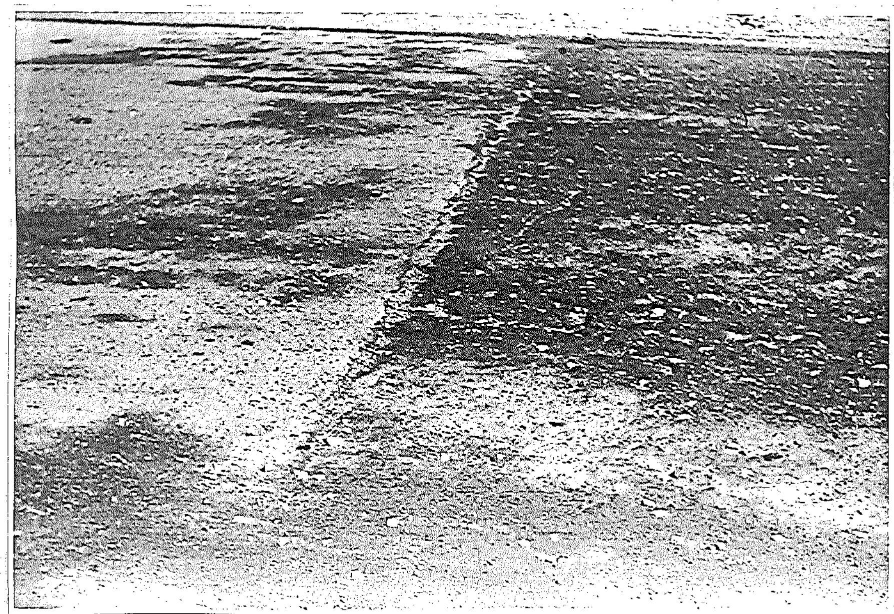
b. Surface Texture Station 135

c. Surface texture Station 109+00



d. Surface texture Station 128+50

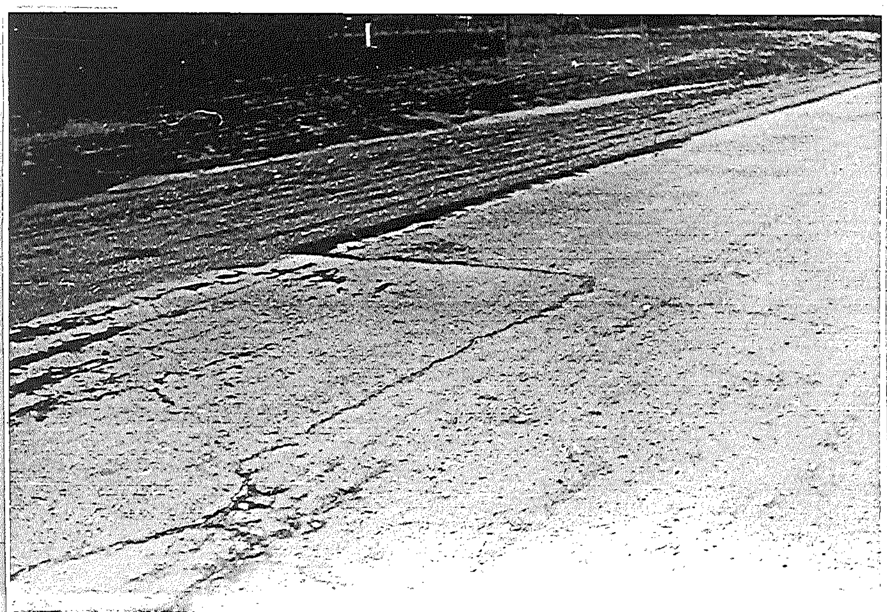
PLATE XIII



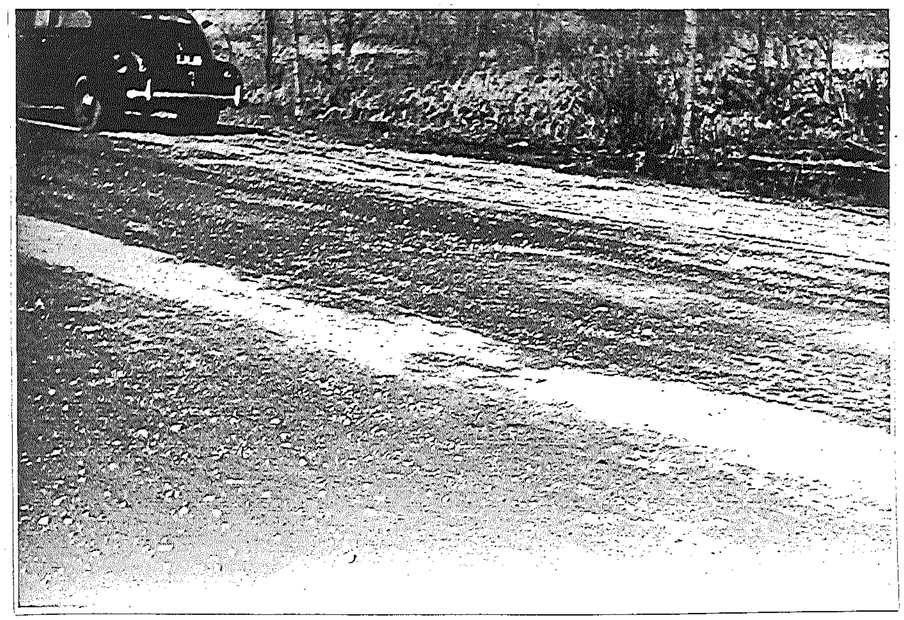
a. Station 94+00

b. Station 144+00

Typical Joint Condition



c. Patch at Station 219+50



d. Subbase failure at culvert, Station 130+00

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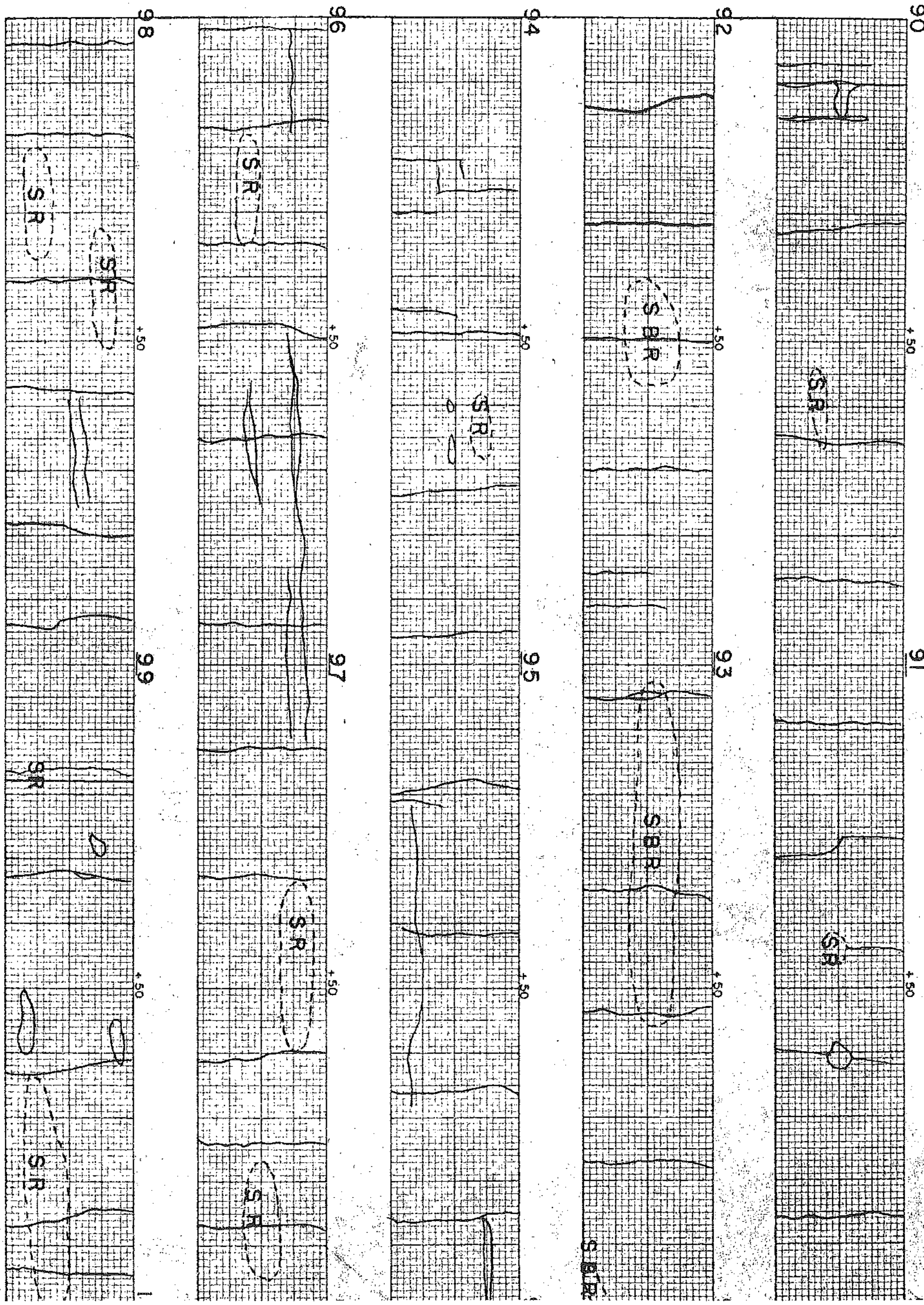
SURVEYED BY THORNBURN



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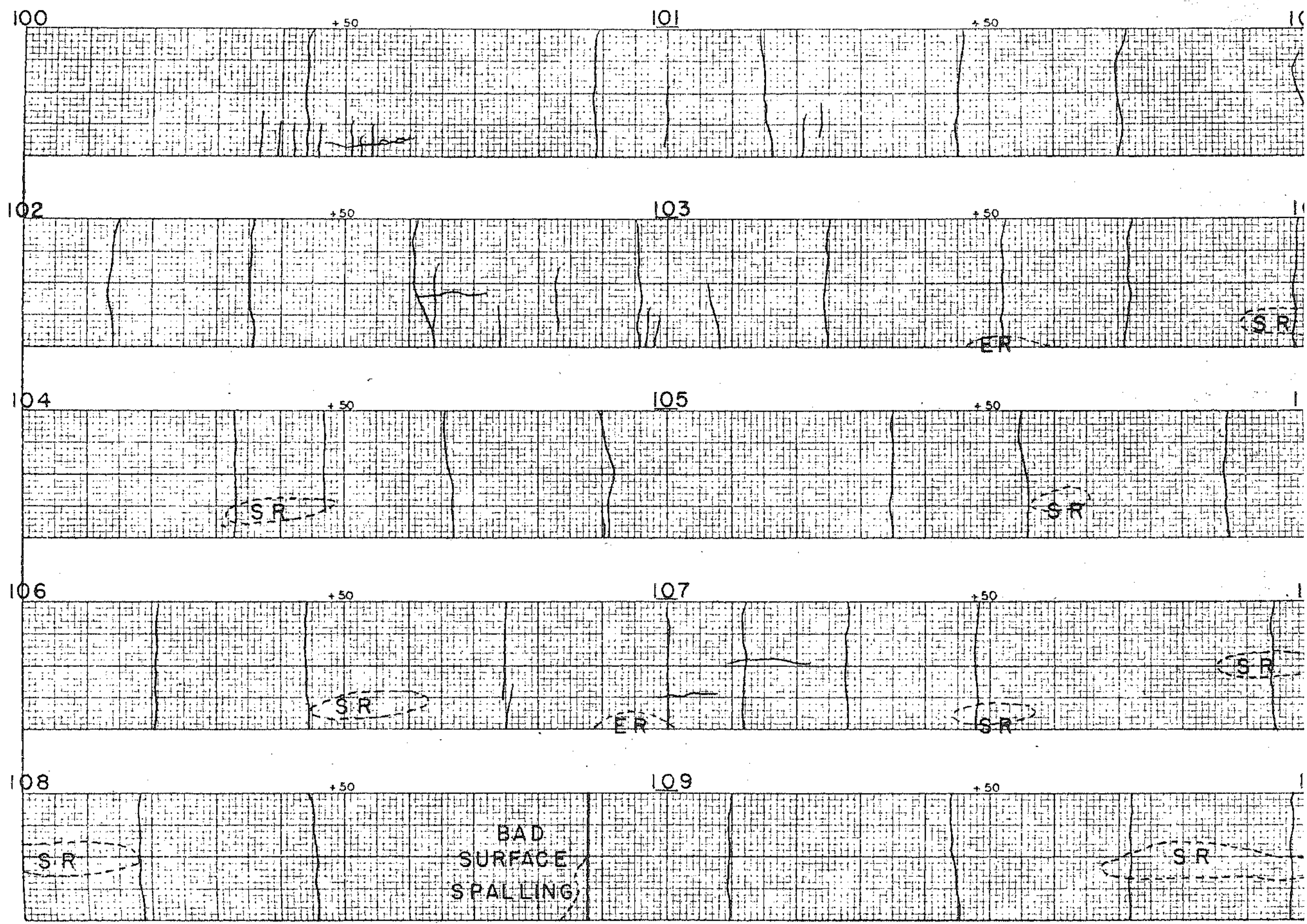

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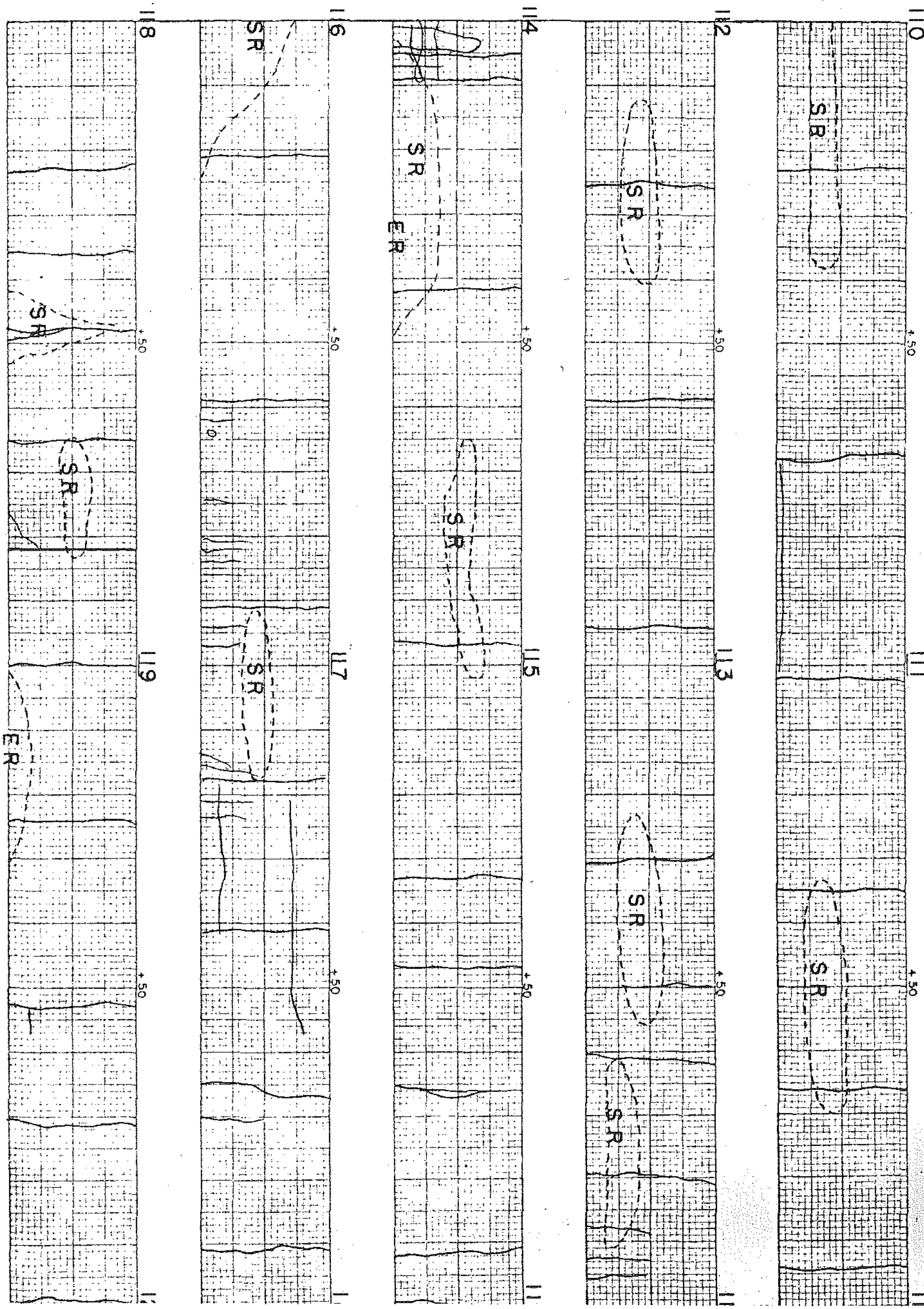

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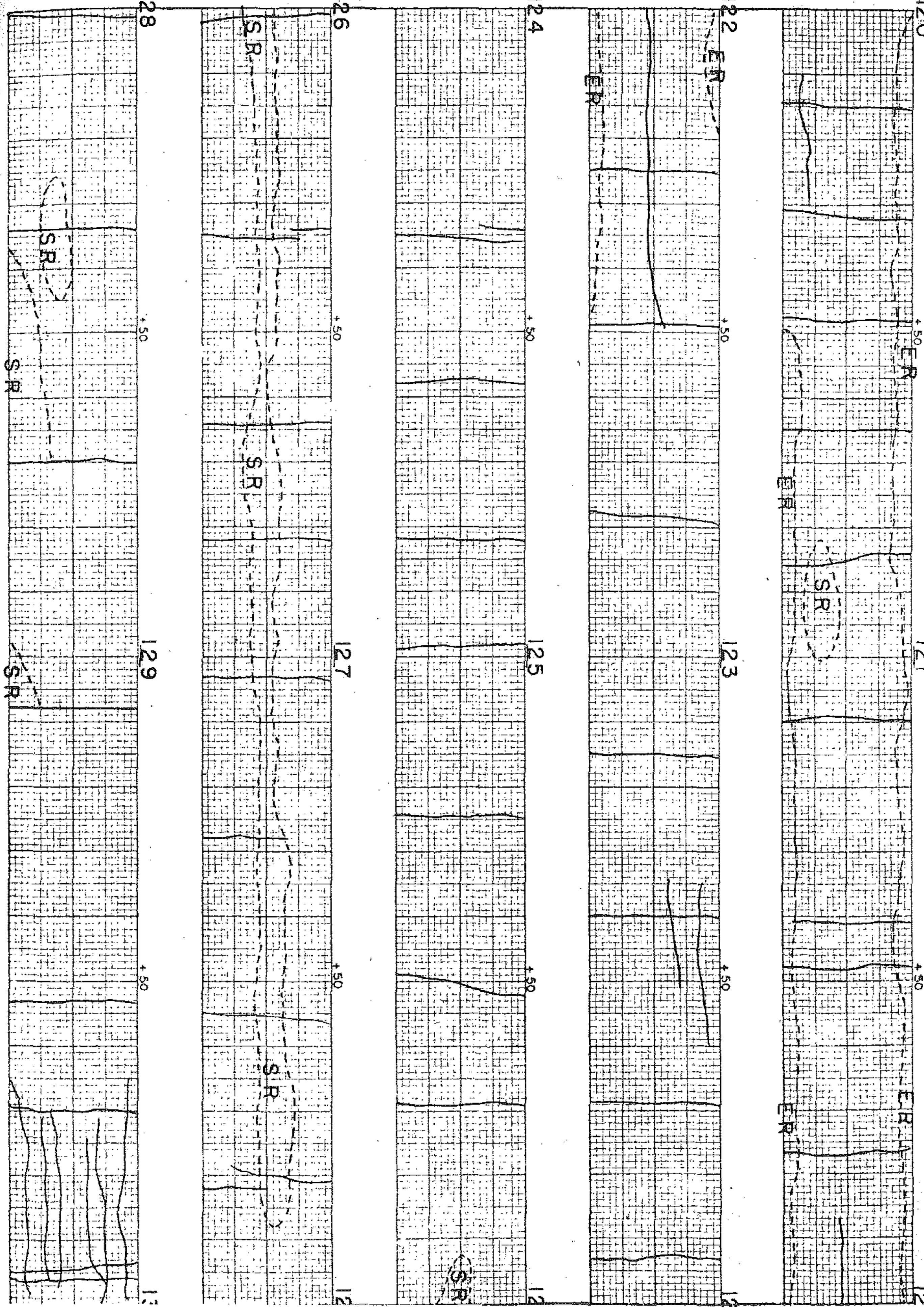

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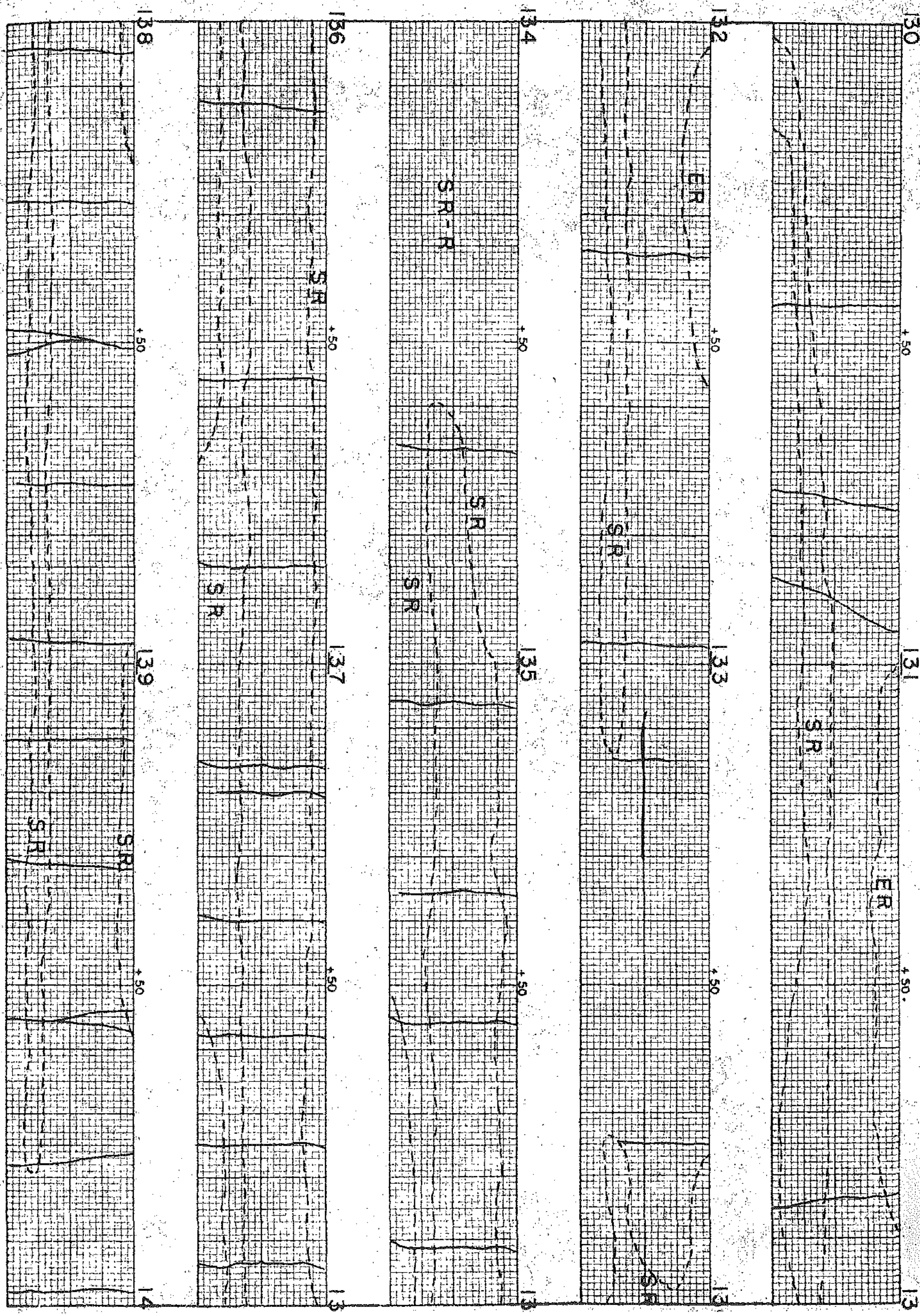

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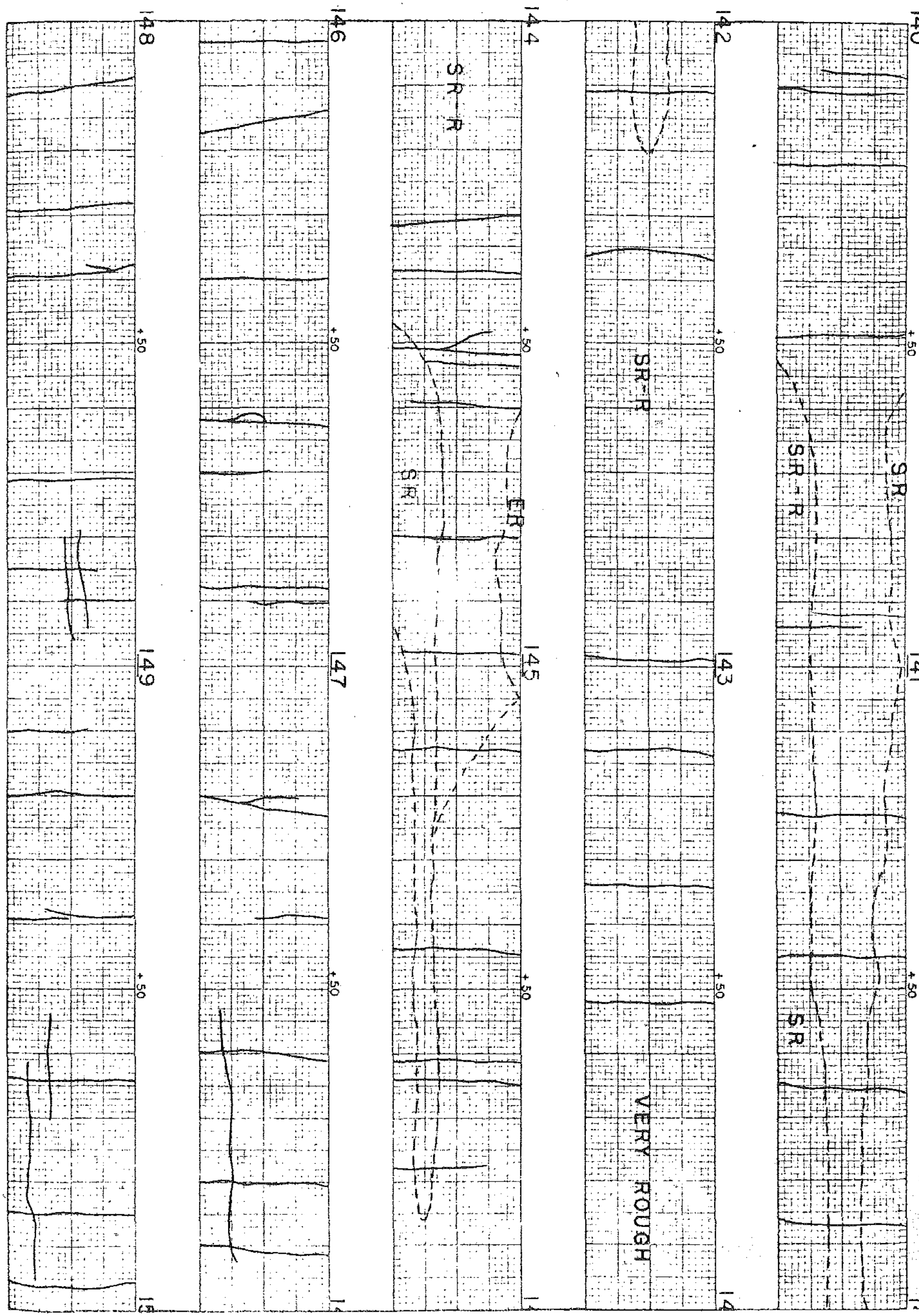

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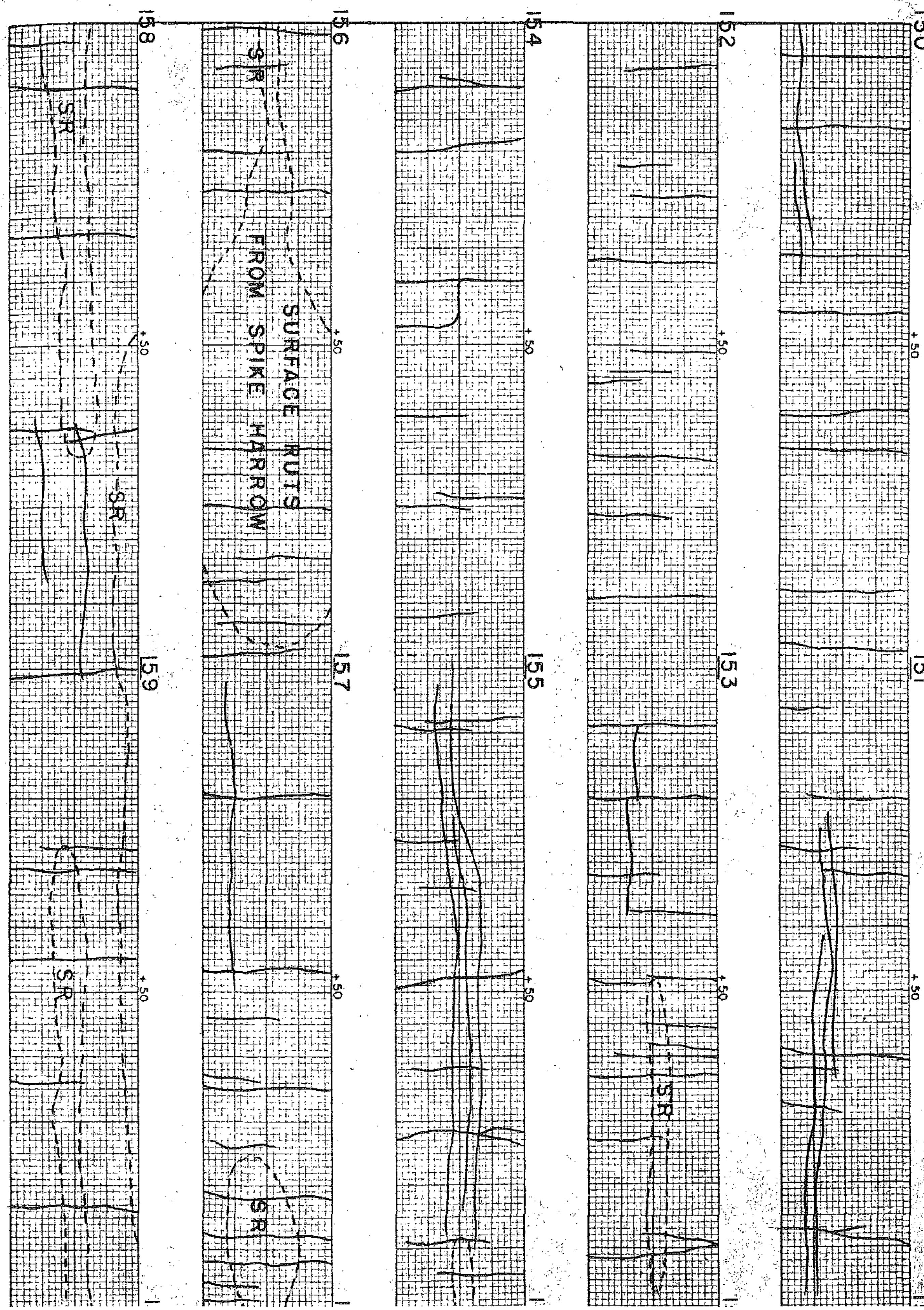

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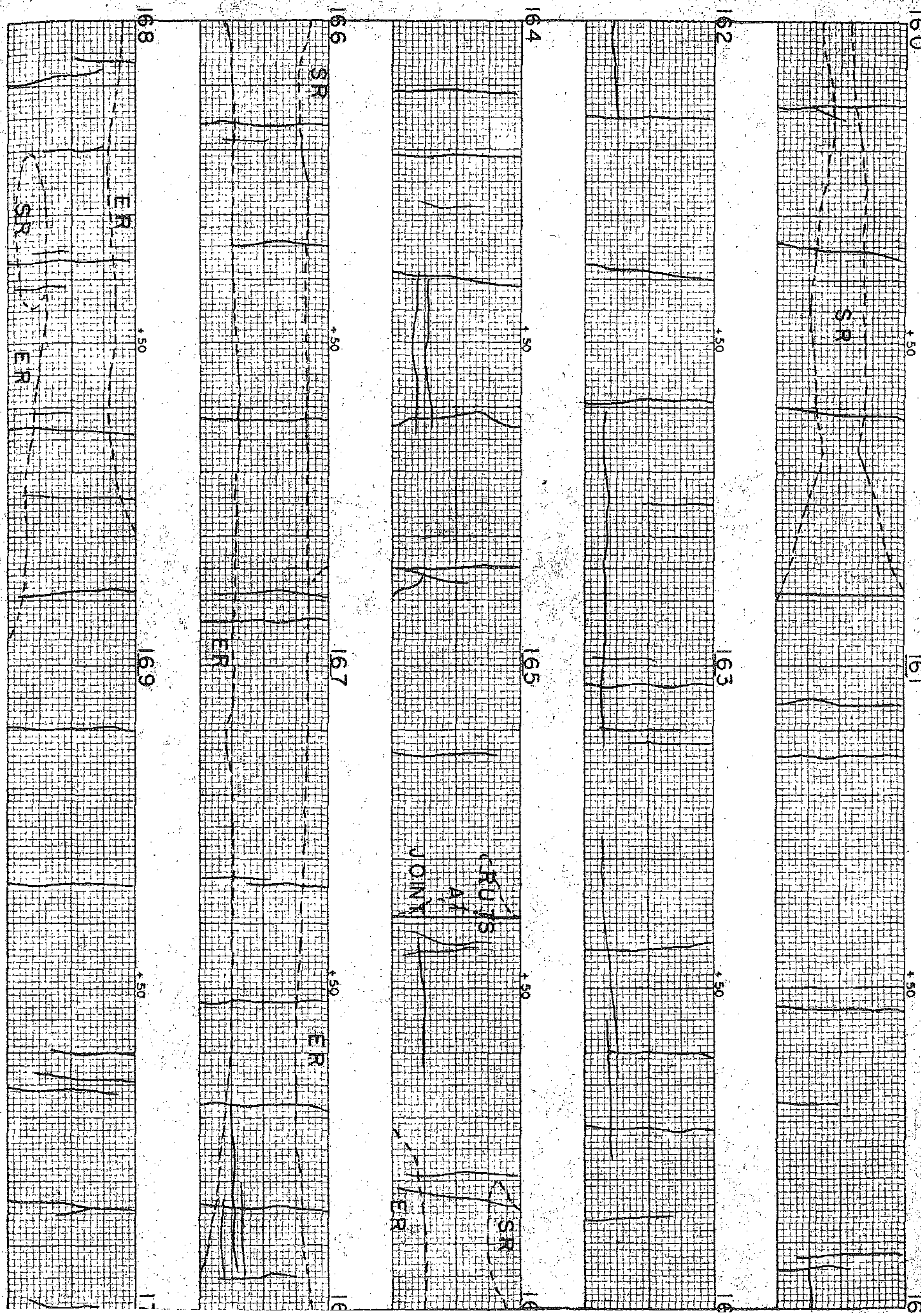

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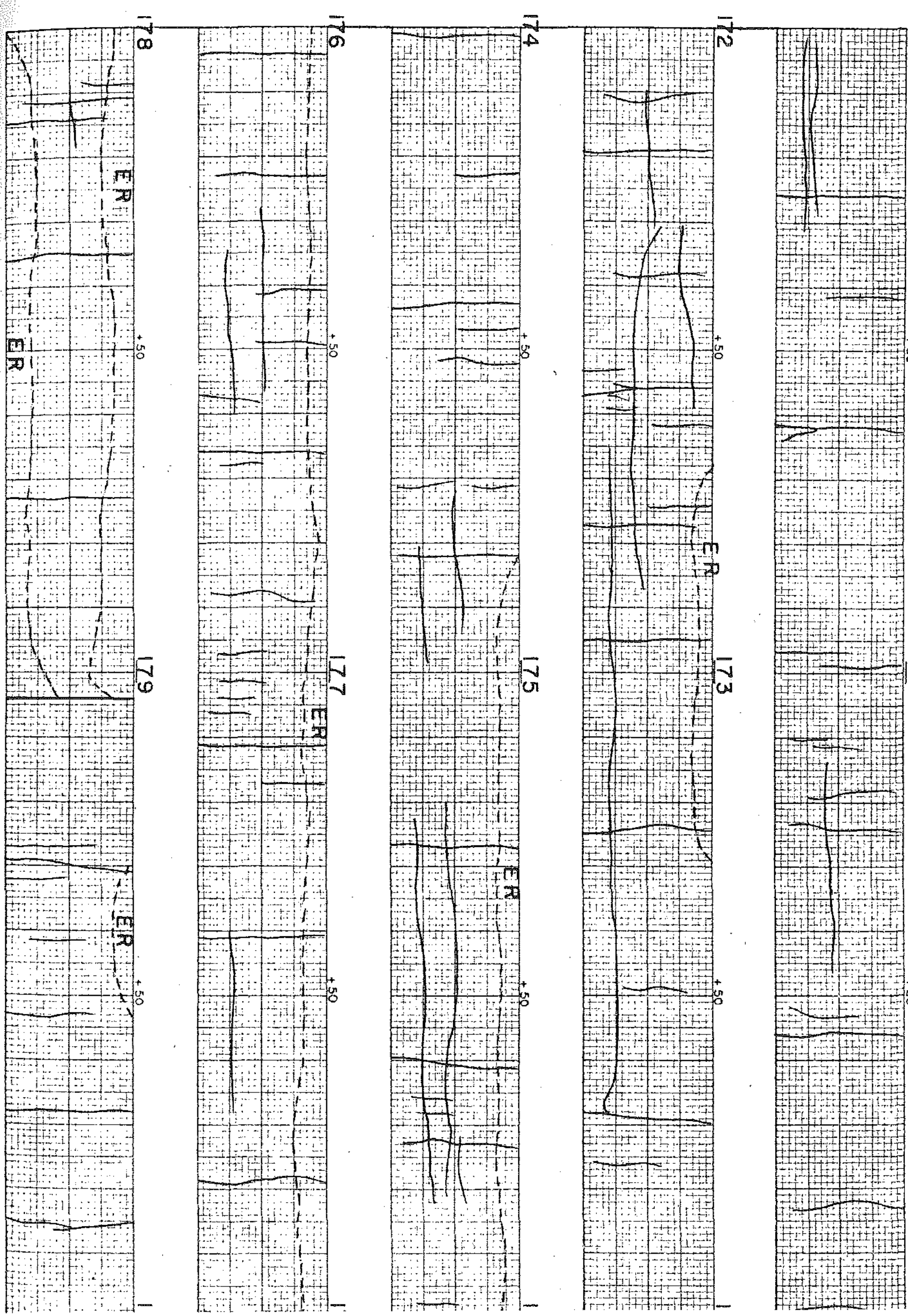

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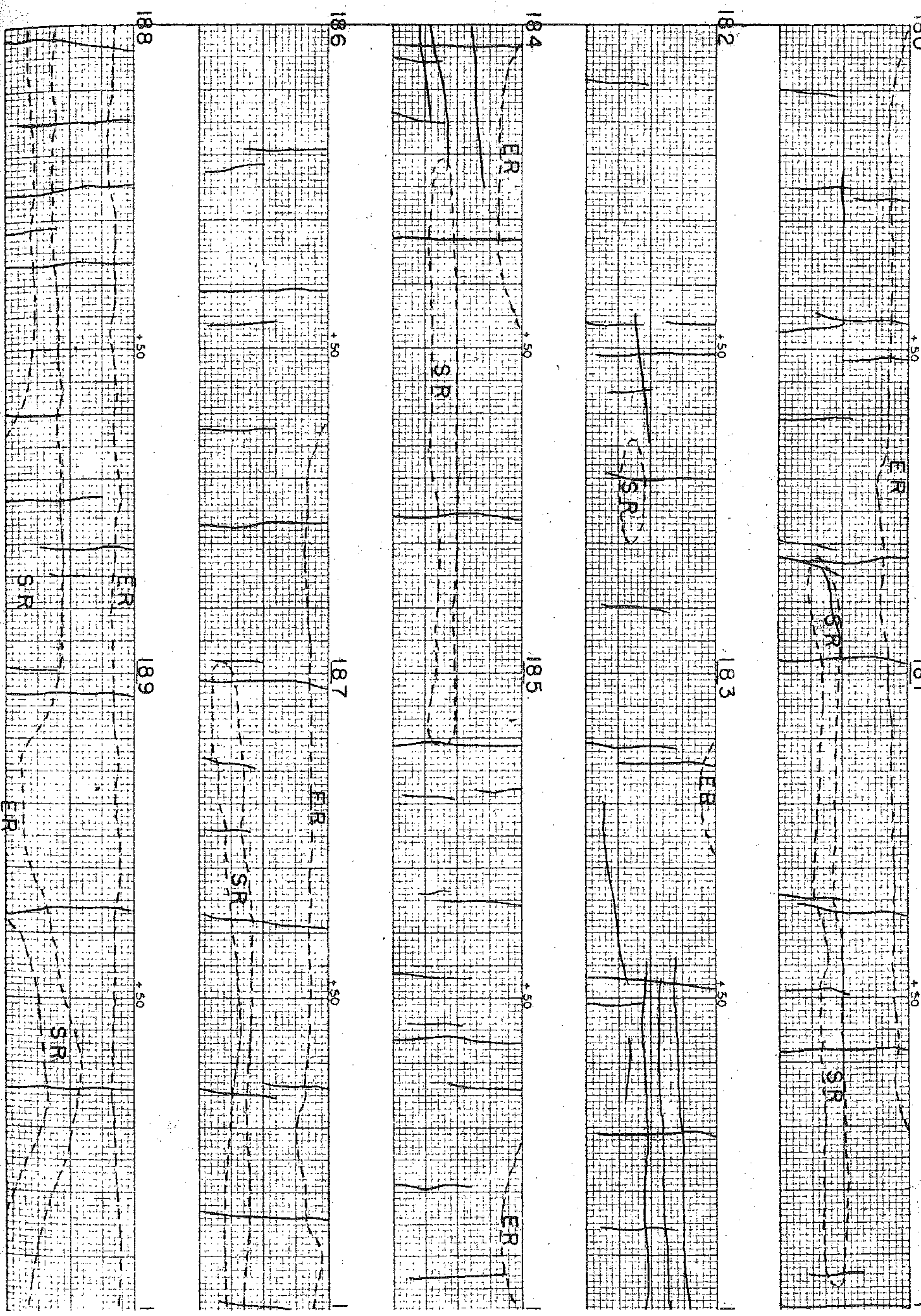

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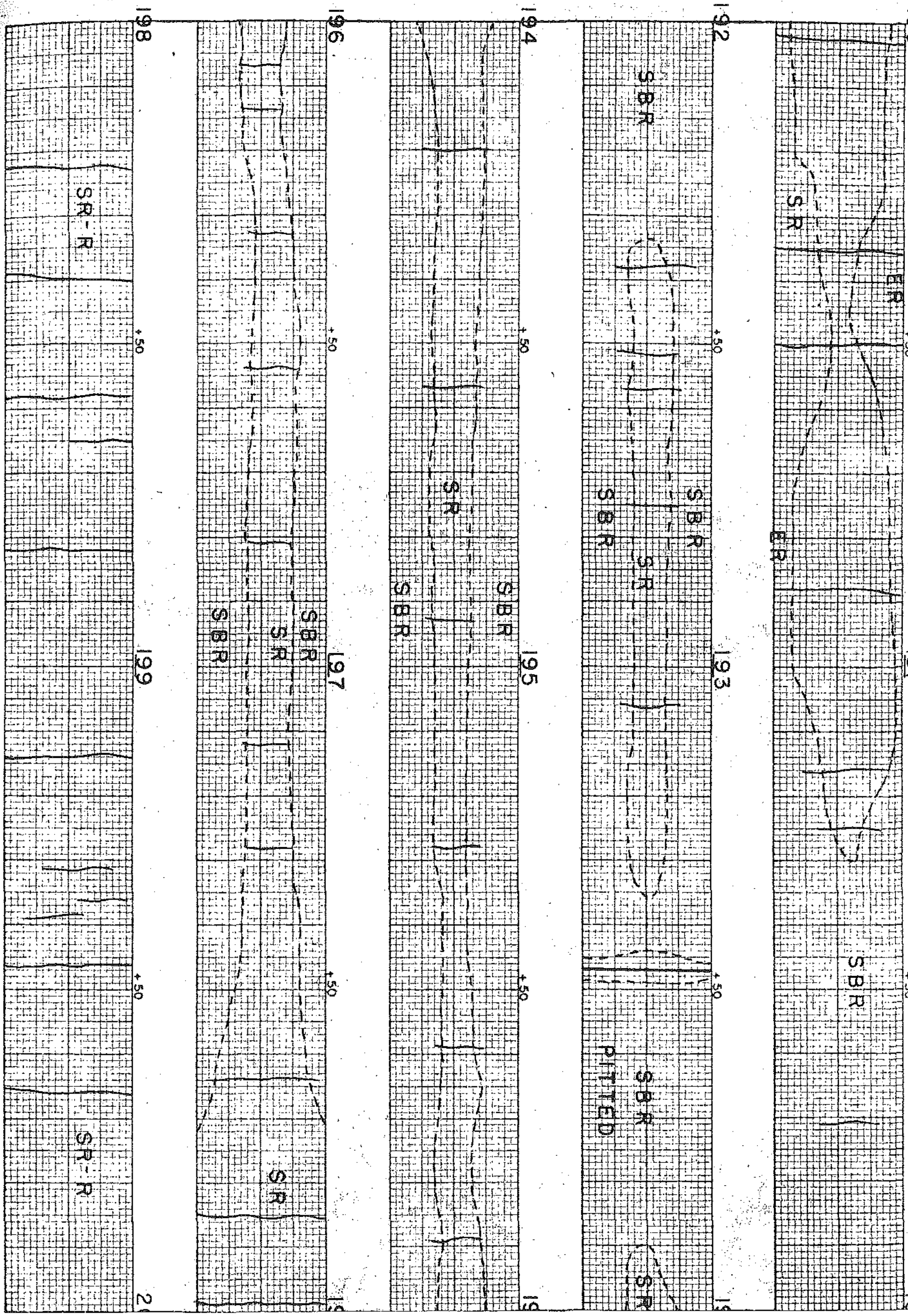

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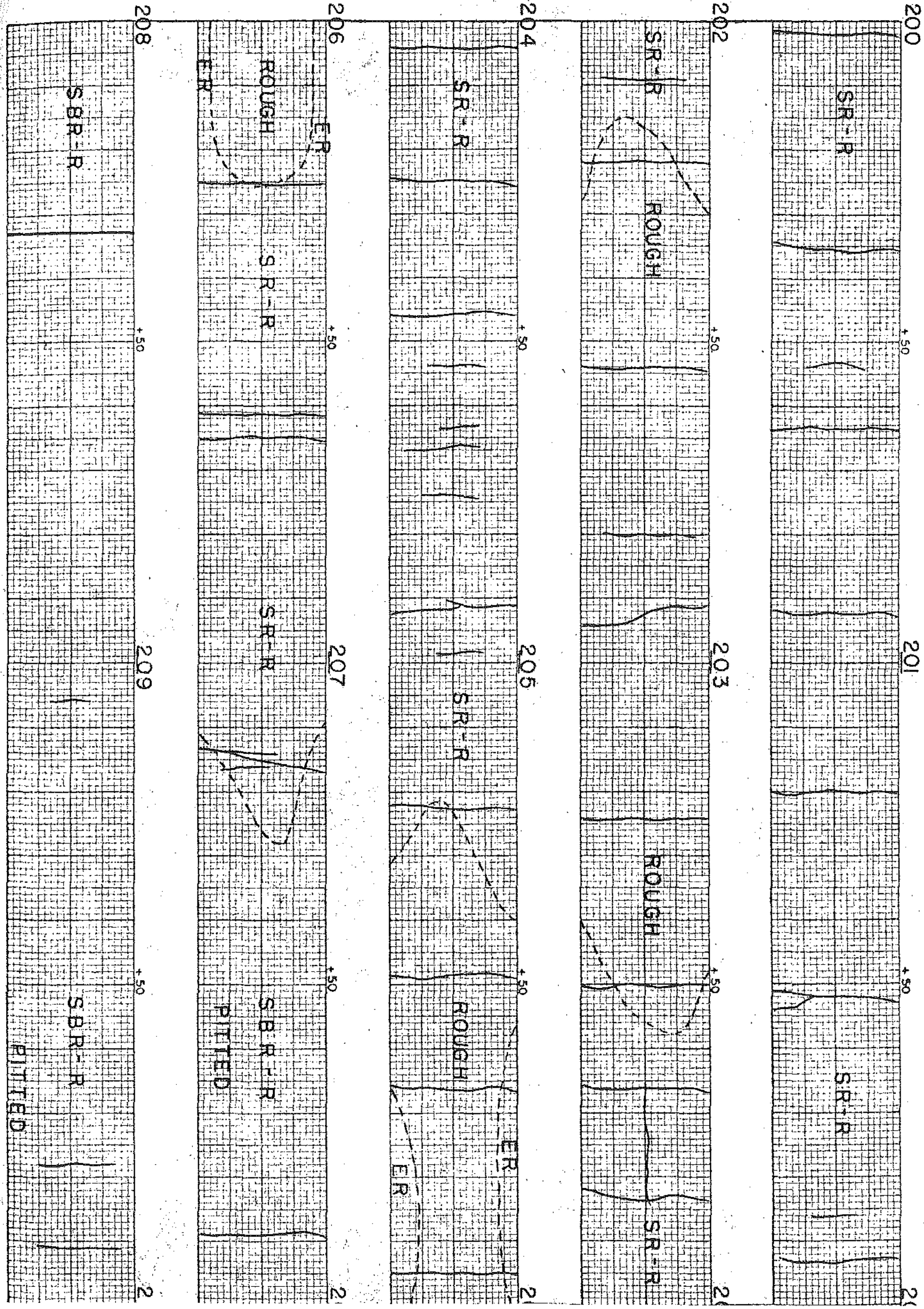

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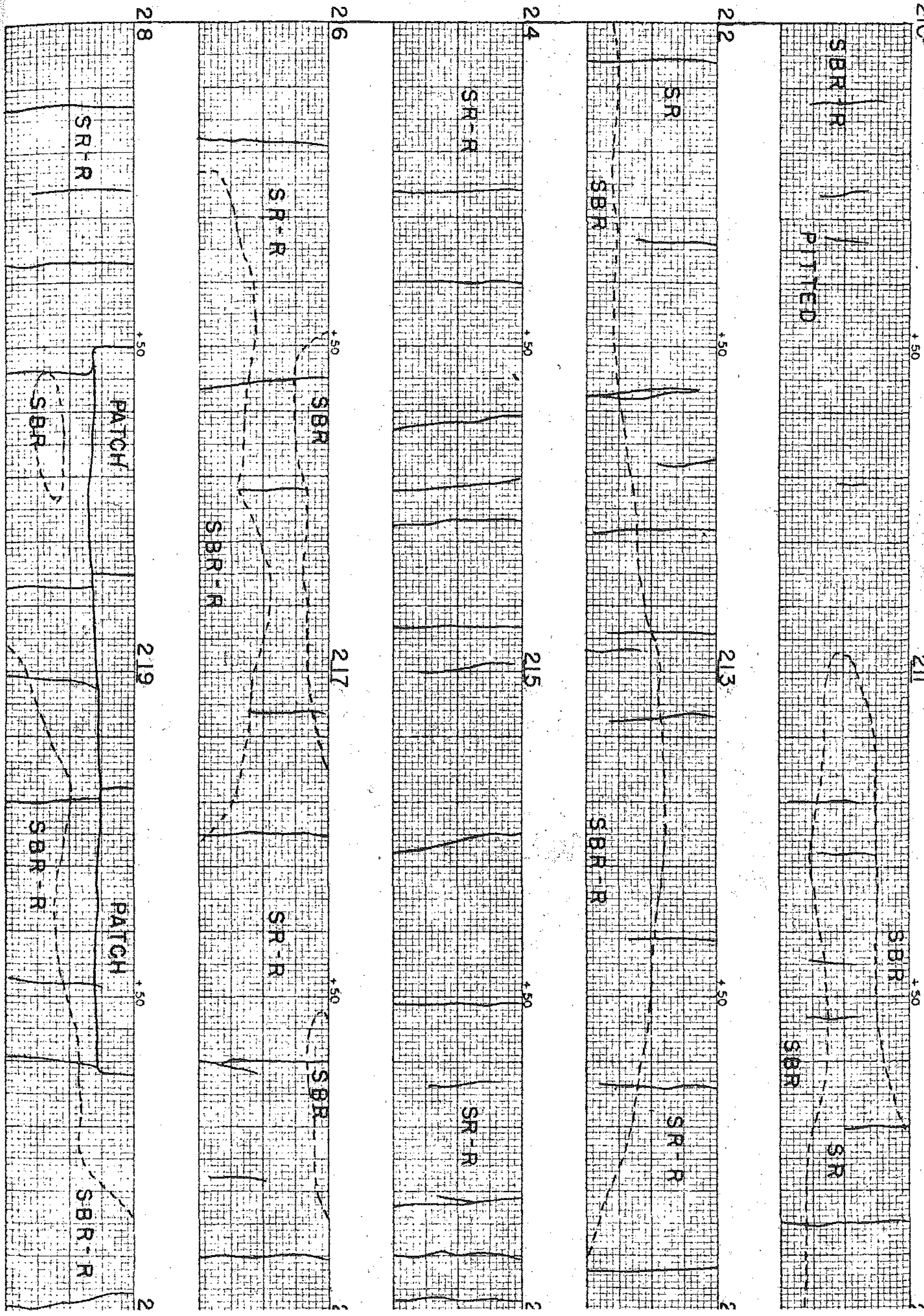

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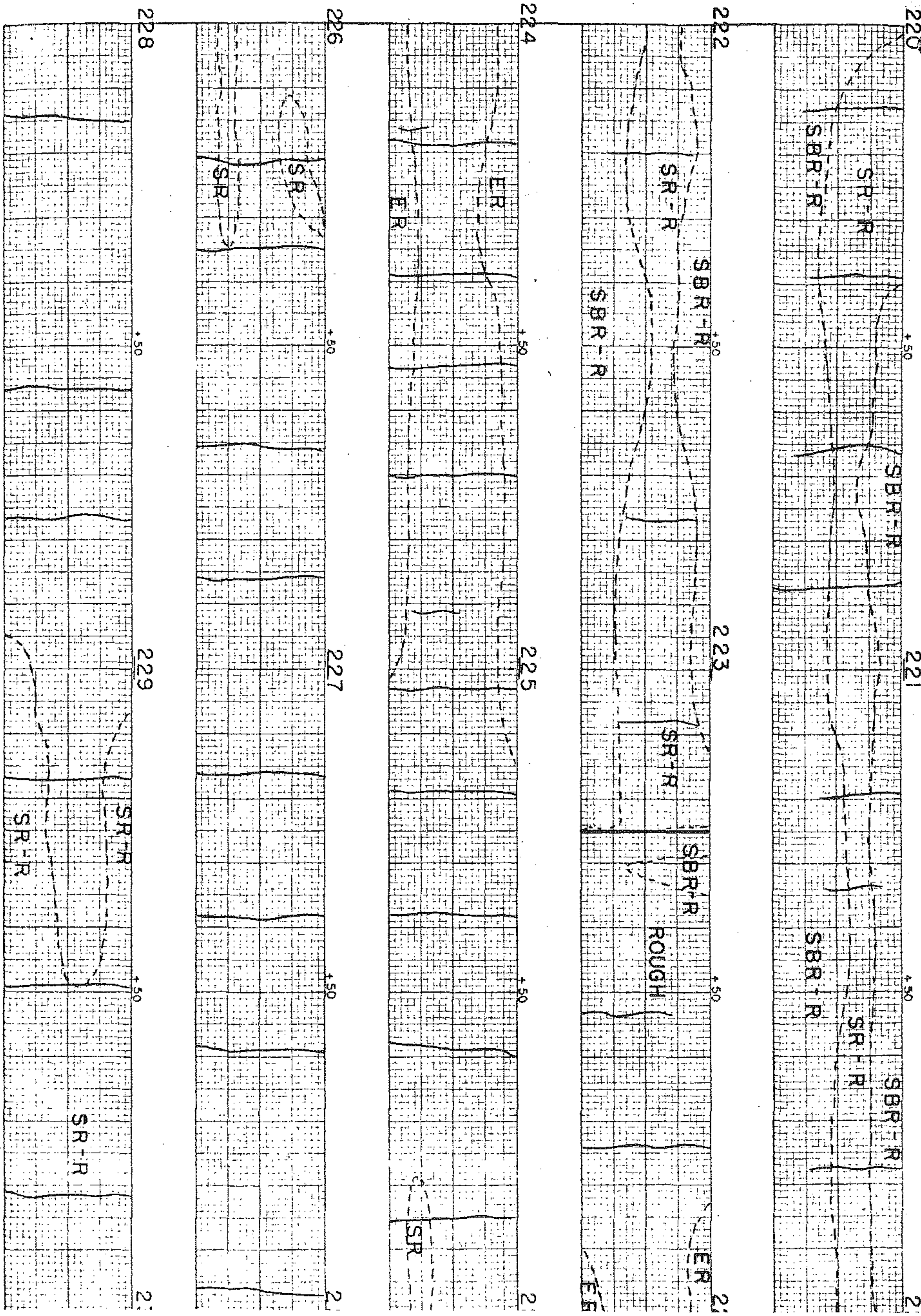

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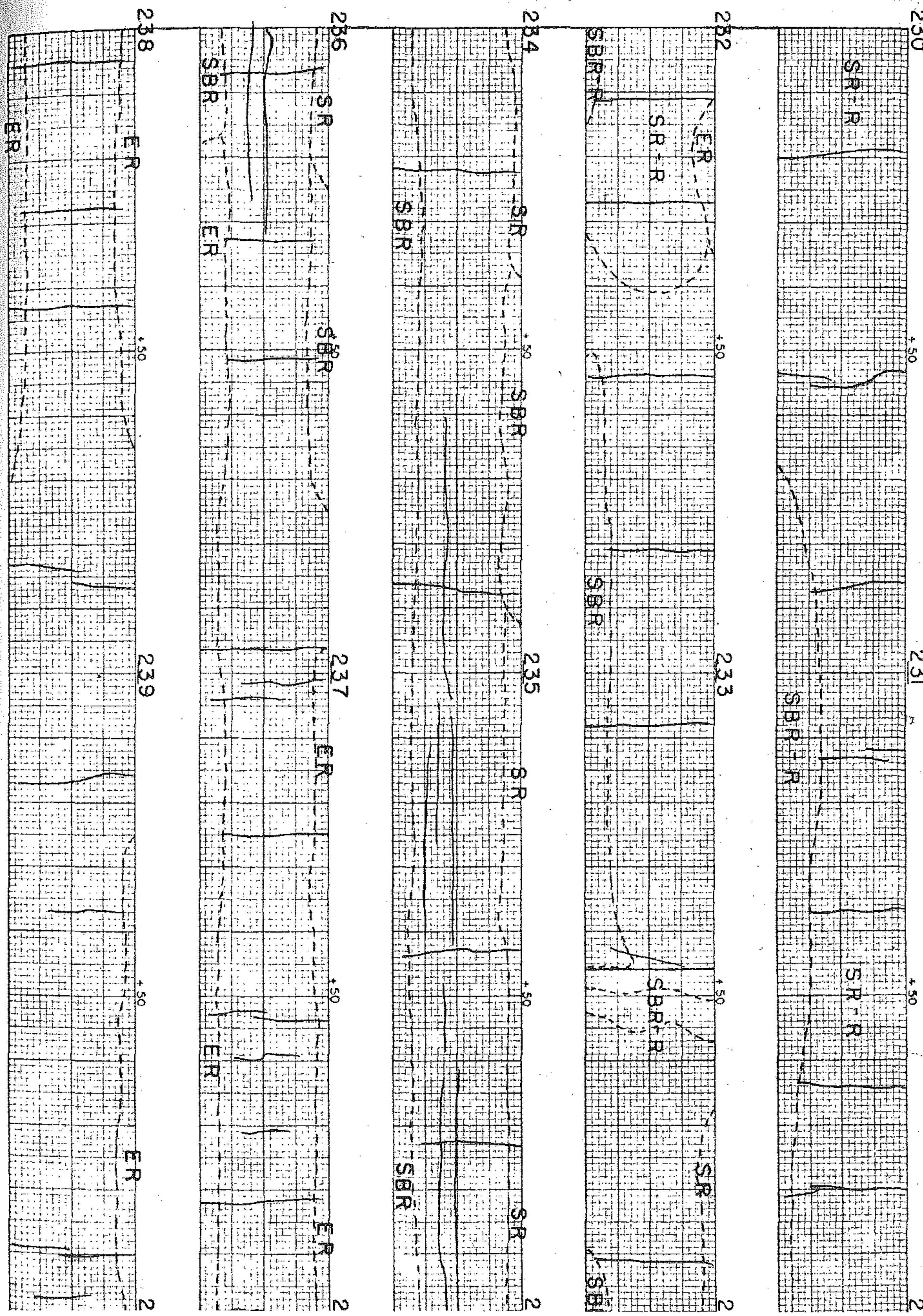

PROJECT No. M-33-50-GI
YEAR OF SURVEY 3-24-42
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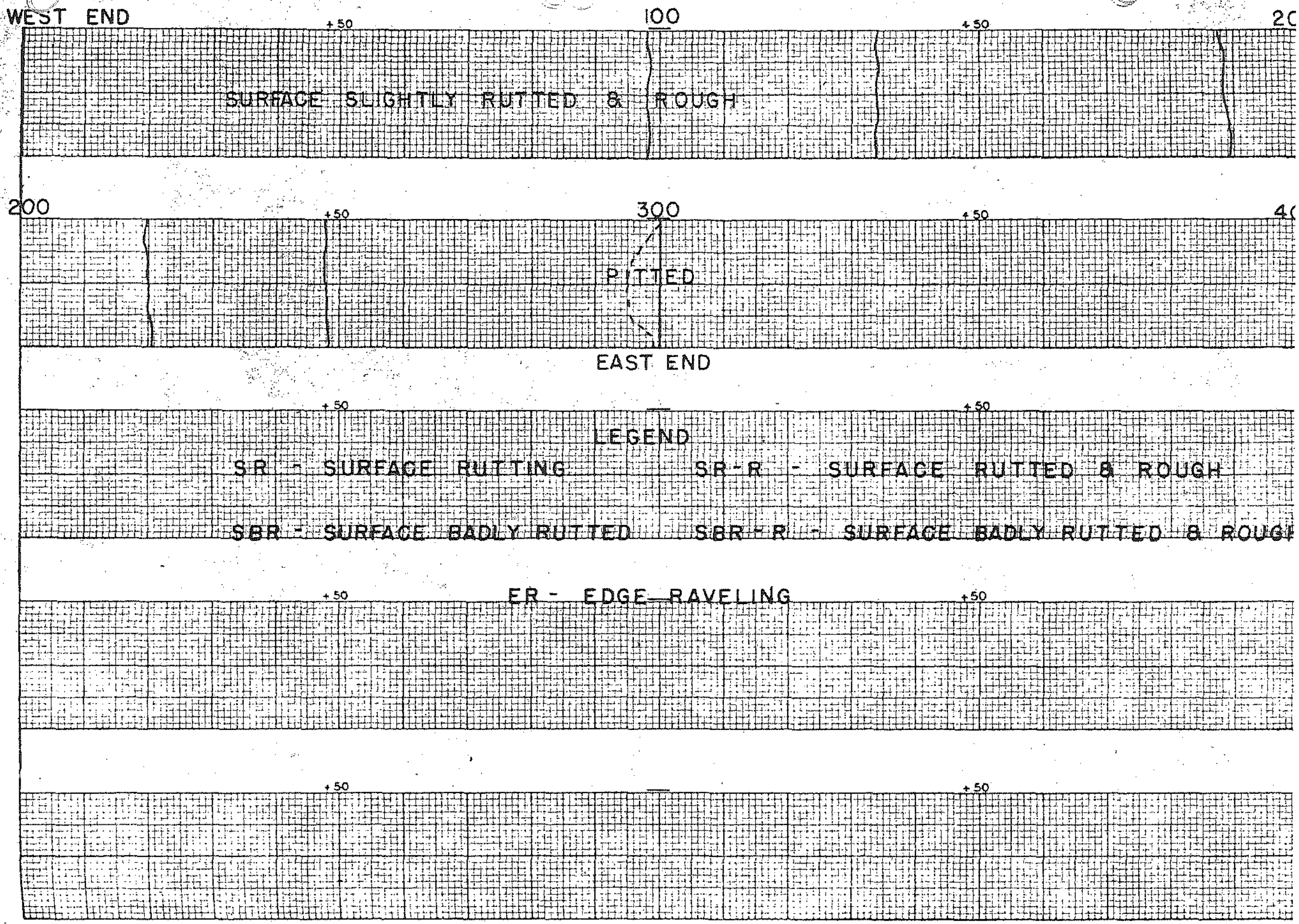
INTERSECTION STRIP FROM EAST AT STATION 246 & 33



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