COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

July 7, 1958

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

C.2.4.
D.1.7.

MEMO TO: D. V. Terrell
Director of Research

The attached report, "An Evaluation and Summary of the 16-Year Performance of a Concrete Test Pavement" by Milton Evans, Jr., was prepared at the request of the State Highway Engineer's office. A memo inspection report was submitted in June, 1957, and the present report is the record of field observation and measurements along with laboratory testing and analysis.

The conclusions presented on pages 11 through 15 seem to substantiate the June 1957 visual inspection report, but, of course, are the result of a more involved analysis.

Using the evaluation procedures outlined in this report for this specific project, the limestone coarse aggregate sections on the average had a better performance rating than the pit gravel coarse aggregate.

The air entrainment item produced some significant results but, because of the present standard of 3 to 6% or practically twice the amount of air entrained, they should not be considered conclusive.

Respectfully submitted,

W. B. Drake

W. B. Drake
Associate Director of Research

WBD:dl
Enc.
cc: Research Committee Members
Bureau of Public Roads (3)

Commonwealth of Kentucky
Department of Highways

AN EVALUATION AND SUMMARY OF THE 16-YEAR PERFORMANCE OF A CONCRETE TEST PAVEMENT

(Project F. A. 366, C1 and C2, Harrison- Pendleton Counties)

by

Milton Evans, Jr.
Research Engineer

Highway Materials Research Laboratory
Lexington, Kentucky
June, 1958

INTRODUCTION

Presented herein are a summary and evaluation of the performance of a reinforced concrete section of U S 27 in north central Kentucky which has been in existence since the summer of 1941. The pavement, totaling 7.89 miles, was constructed in 10 experimental test sections, as shown on the layout map in Figure 1. Five blends of cement, containing normal portland, natural, and two additives, were used with two types of coarse aggregate, limestone and gravel. Since the construction of the pavement in the summer of 1941, several reports and memoranda have been released dealing with various aspects of the over-all study:

1. Test results on cores taken in 1941, KDH, April, 1942.
2. Results of freezing and thawing beams made in 1941, KDH, August, 1943.
3. Supplement to August, 1943, freeze and thaw report, KDH, November, 1944.
4. Summary Report of Concrete Investigations in Research Projects, HMRL, December, 1945.
5. Experiments with Air-Entrainment in Cement Concrete, Engineering Experiment Station, Bulletin No. 5, Sept. 1947. (The test sections are referred to as Project C-1 in this bulletin.)
6. Inspection Report, HMRL, June, 1953.
7. Inspection Report, HMRL, June, 1957.

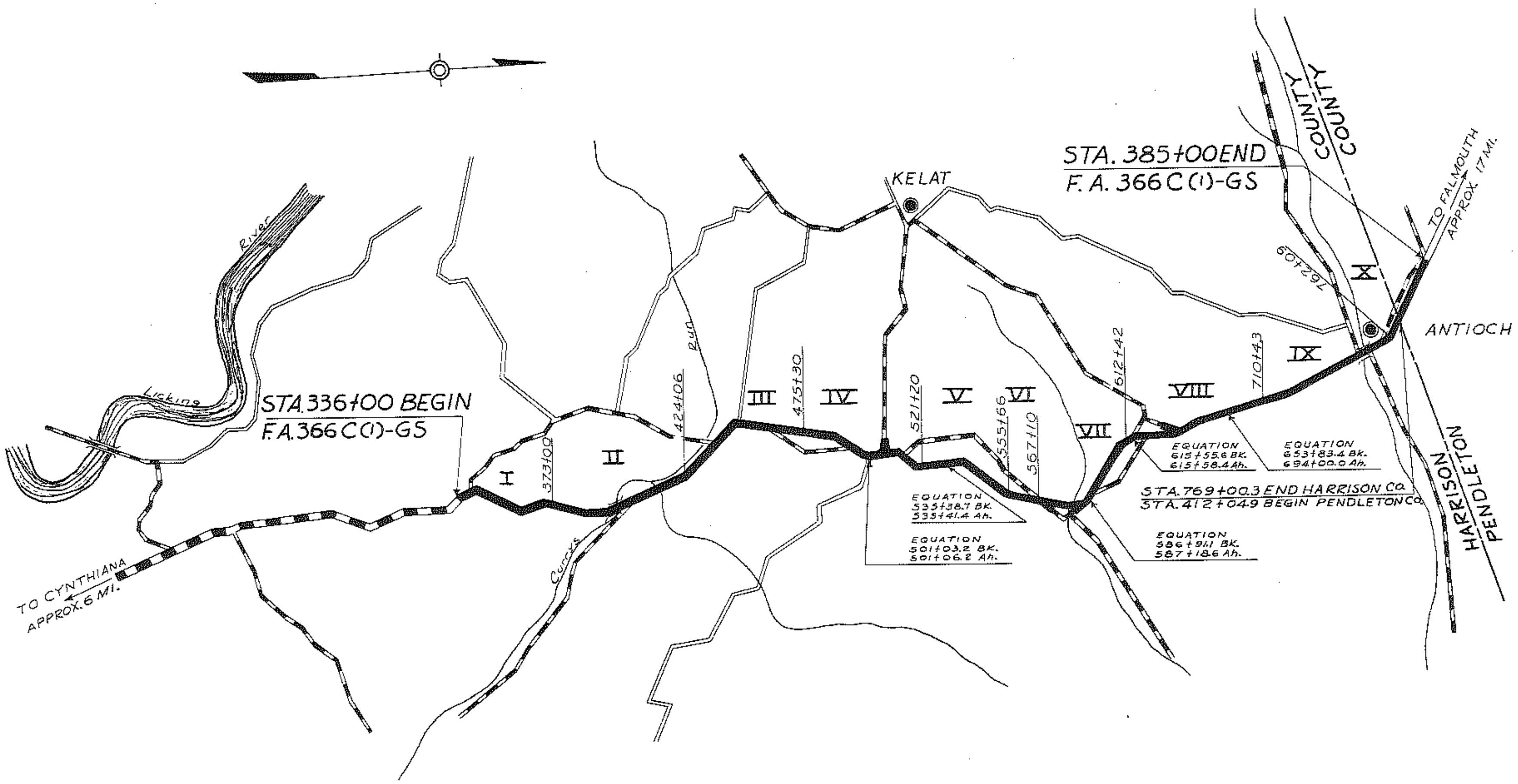

FIG. 1: Layout Map Showing Location of Test Pavement

During the summer of 1957, an extensive crack survey was made, pictures were taken, and levels were run. Also, cores from each section were tested for comparison with cores tested in the past.

The information presented has been arranged to permit comparison of the test sections with consideration for each section's basic design factors and performance data after 16 years of service. Table 5 is intended as a summary sheet for the performance data, so that by taking material, design, and construction differences (provided in Tables 1, 2, and 3, respectively) into account a comparative evaluation can be made of each section. The information and discussion which follow Table 5 are presented chiefly to compare the effects of Cleves Pit gravel with those of surface quarried Lexington* Series limestone on the performance of concrete pavement made with different blends of portland and natural cement, and containing different amounts of entrained air. Further data, taken from records of previous studies of the pavement, are given for the purpose of comparison and for a more complete record of the history and performance of the over-all project.

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*This limestone was taken from a quarry composed of the uppermost six feet of the Jessamine limestone and the lowermost forty feet of the Benson limestone, both members of the Lexington limestone series. By lithology, the formations are undifferentiated; the division is paleontological. The material has been roughly classified as "Fair" for highway construction.

More detailed information concerning this limestone is available in an earlier report on the study: Young, James L.; <u>A Study of the Properties of Coarse Aggregates</u>; Lexington, Highway Materials Research Laboratory, March, 1947. p. 11 and ff.

PERFORMANCE FACTORS

The actual condition of the 10 sections of the project as of July and August, 1957 (referred to hereinafter as "present condition") is presented graphically in plan and profile by section in the Appendix of this report; but before checking the crack survey in detail, certain material, design and construction variables should be considered.

Material sources and types along with methods of blending cements are presented in Table 1. Item 1 is very significant, as it apparently affected the durability of the sections considerably. First, it must be noted that the limestone used as coarse aggregate was from the Lexington Series in Lexington, Kentucky. Although it was in wide use at the time of the project's construction, this stone's ability to pass specifications for concrete aggregates is questionable. Second, the gravel used as coarse aggregate was a glacial outwash gravel and chiefly calcareous in nature. In this respect, it is technically different from dredged river gravels.

Design variables are presented in Table 2, and this table, used in conjunction with Table 1, provides a complete picture of the materials and design used in construction. In Table 2, section numbers and station limits are given for each section. Further, Table 2 shows that in Sections 1, 2, 3, 4 and 5 limestone coarse aggregate was used, while in Sections 6, 7, 8, 9 and 10 gravel coarse aggregate was used. The sections using the same cement conbinations but different coarse aggregates are paired. For example, sections 1 and 10 --- No. 1 using limestone coarse aggregate and No. 10 using gravel coarse aggregate --- were both made with cement combination E.

TABLE 1: MATERIALS AND SOURCES

1. Coarse Aggregate

Limestone - Central Rock Co., Lexington, Kentucky, Specific Gravity: 2.70

Sieve Analysis:

Passing 2½"	100.0%
Passing 2"	91.7%
Passing 1"	40.3%
Passing ½"	14.1%
Passing #4	0.5%

Gravel - Ohio River Gravel Co., Cleves, Ohio, Specific Gravity: 2.69

Sieve Analysis:

Passing 2½"	100.0%
Passing 2"	100.0%
Passing 1"	54.0%
Passing ½"	23.0%
Passing #4	1.5%

2. Fine Aggregate (pit sand)

Used with limestone - Carrollton Coal & Sand Co., Carrollton, Kentucky
Used with Gravel - Ohio River Gravel Co., Cleves, Ohio
Specific Gravity: 2.63

Sieve Analysis:

Passing 3/8"	100.0%
Passing #4	99.8%
Passing #16	93.5%
Passing #50	93.5%
Passing #100	1.3%

3. Cement

Natural with Grinding Aid - Louisville Cement Co.
Plain Natural - Louisville Cement Co.
Portland with Vinsol Resin - Alpha Portland Cement Co., Ironton, Ohio
Normal Portland - Alpha Portland Cement Co., Ironton, Ohio

4. Cement Blends

A. Normal portland cement.
B. Blend of five parts portland and one part natural cement.
C. Blend of five parts portland and one part natural cement, containing a grinding aid of beef tallow or petroleum distillate.
D. Blend of five parts portland cement with interground vinsol resin and one part natural cement.
E. Portland cement with vinsol resin interground.

TABLE 2: SUMMARY OF DESIGN CHARACTERISTICS OF TEST SECTIONS

Minimum Cement Factor:.. 1.500bbls/yd.
Maximum Free Water:... 5.75 gal/bag
Ratio of Fine and Coarse Aggregates:.......................... 38-62%
Pavement Section: 22 ft. width, 9" thickened edges, 6½" thick middle section, reinforced with wire mesh

Section	Stations	Coarse Aggregate	Cement Combination	Average Air %
1	336 + 00 to 373 + 00	Limestone	E	3.3
10	762 + 09 to 385 + 00*	Gravel	E	2.7
2	373 + 00 to 424 + 06	Limestone	D	2.5
8	612 + 42 to 710 + 43	Gravel	D	1.7
3	424 + 06 to 475 + 30	Limestone	C	2.7
9	710 + 43 to 762 + 09	Gravel	C	2.6
4	475 + 30 to 521 + 20	Limestone	B	1.4
7	567 + 10 to 612 + 42	Gravel	B	0.8
5	521 + 20 to 555 + 66	Limestone	A	0.8
6	555 + 66 to 567 + 10	Gravel	A	0.3

*385 + 00 is the end of section ten and the north end of these ten experimental sections. The north end of section ten is in Pendleton County, and stationing begins here at 385 + 00 and runs south to Harrison County line, where stations in Harrison County running from south to north also end.

The last column on the right in Table 2 shows air content for the various sections. It is necessary to recognize that the air contents shown here are much too low according to the limits of air entrainment now required by Kentucky Department of Highways Specifications. Present practice dictates that air entrainment should range between 3 and 6 percent, whereas in this project the highest air content, in cement combination E, is 3.3 percent, and the lowest, in cement combination A was only 0.3 percent. Section 1, using cement combination E, vinsol resin, and limestone coarse aggregate, is the only section which has enough air entrained to meet present day requirements. Even then, 3.3 percent is a bare minimum of air entrainment.

The subject of air entrainment with respect to these test sections was last discussed in the University of Kentucky College of Engineering Experiment Station Bulletin No. 5, Sept. 1947, and in the Highway Materials Research Laboratory Memorandum Report of June 11, 1953.

The 1953 report stated;

> "From the standpoint of air entrainment it should be noted that the percentage of air in this concrete was very low in comparison with current standards, and it averaged higher for the pavement with limestone than it did for pavement with gravel. Of course, none of the cements in this group (including portland, without an air entraining addition or without an air entraining admixture introduced in the concrete at the mixer) would be used in pavement construction now; and the air contents under current methods should average at least 4 percent with a permissible variation between 3 and 6 percent."

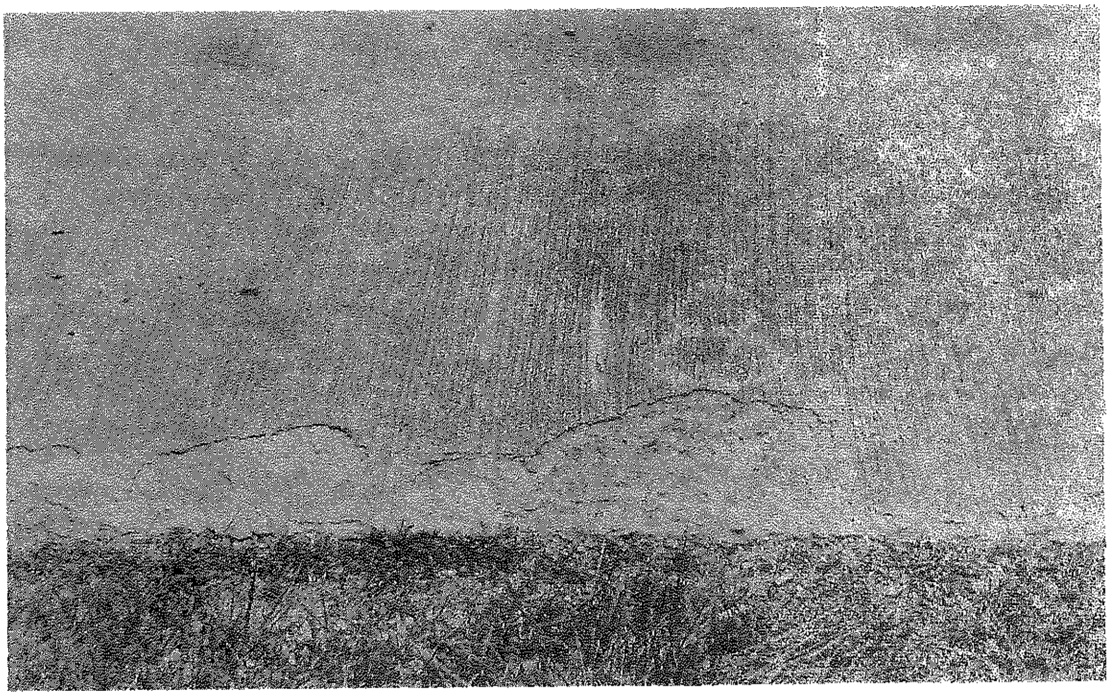
With these facts in mind, the importance of air contents in evaluating these test sections is greatly diminished. However, an apparent relationship does exist between air contents and surface spalling or scaling in some of the sections and this should be examined further.

From Tables 2 and 5 the lowest air content for any section is found to be 0.3 percent, in Section 6; and the most surface spalling in any section is found to be 11.87 percent, also in Section 6. By comparing air contents and spalling in these and the remaining sections a trend is established. As air content increases from 0.3 to 2.7 percent, surface spalling decreases from 11.87 to 0.15 percent. Where air contents are higher than 2.7 percent, no surface spalling or scaling has occurred. However, the data in Tables 2 and 5 do show certain exceptions to this trend. Section 7 has a low air content of 0.8 percent accompanied by only 0.25 percent surface spalling, whereas Section 5 has the same low air content of 0.8 percent but shows 4.51 percent surface spalling.

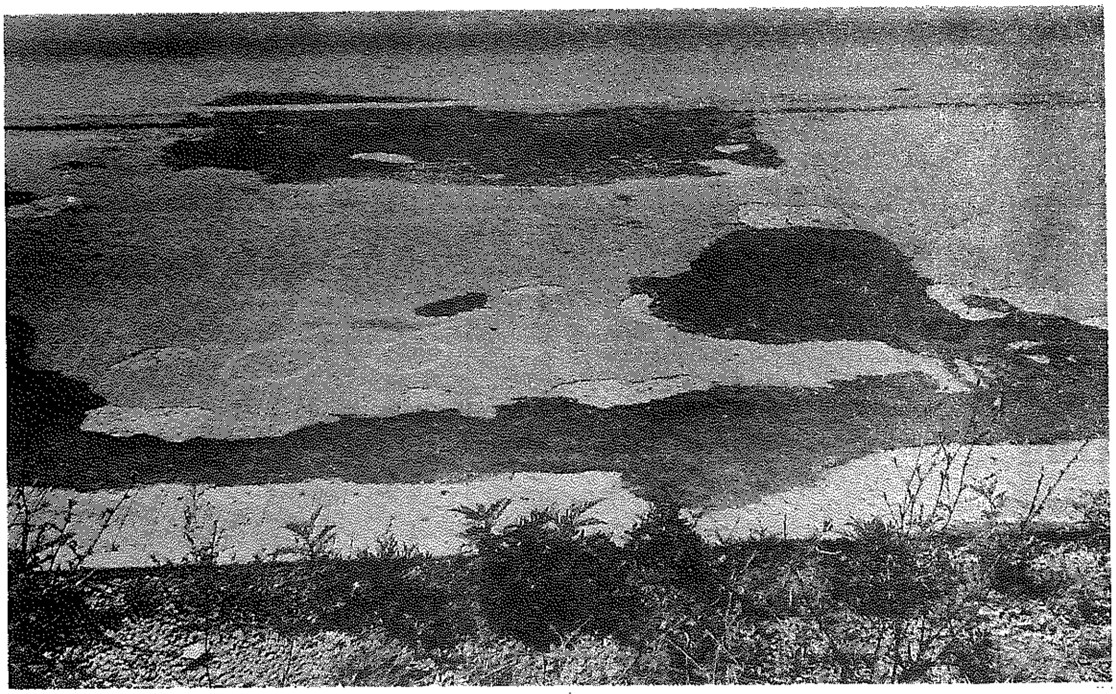
By discounting Sections 3, 7 and 8 as having negligible amounts of spalling, a trend for the remaining test sections does become apparent. The sections with air contents of 1.7 percent or more show no appreciable surface spalling, while with one exception those with air contents of 1.4 percent or less show more spalling as the air content decreases.

At present the surface spalling observed does not greatly impair the serviceability of any of the sections. In Fig. 2, part A shows the stage spalling has reached in most instances, while part B, shows the most advanced stage it has reached. At present this scaling occurs mainly in small patches and is rarely more than 1/8 inch in depth.

In this evaluation surface spalling or scaling seems to be a minor consideration. At present, the major performance features are condition of the joints and the number and condition of cracks occurring in the different sections.



A: Typical Surface Spalling



B: Extreme Surface Spalling

Fig. 2: Surface Spalling Encountered in Test Sections, as Indicated in Table 5.

Of no little importance in the performance of any pavement are the condition and type of sub-grade. This project was constructed on impervious clay (Highway Research Board Classification A-6, A-7) with a parent formation of Eden shale intermingled with thin ledges of limestone. This particular type soil has a rather poor performance record and is well recognized as a poor subgrade material. However, since each of the sections was constructed on this type of soil, comparisons among the various sections are permissible by an assumption of subgrade uniformity. The several failures which were obviously due to slides and excessive settlement have been excluded from the evaluation of the sections, since they were reflections of grade and drain characteristics and not pavement factors.

In order to determine the amount of pavement failure attributable to subgrade influences, levels were run in several representative sections. The intent was to find differential settlements of small magnitude, that might have produced cracking and subsequent deterioration in the pavement. The elevations determined were in nearly every case higher than the original elevations taken when the pavement was constructed. This could indicate that the subgrade has generally become swollen throughout the whole project, but since the differences in elevation were consistently small, never more than 2 or 3 inches, it seems more plausible that bench marks used for the survey were inaccurate.

The most significant fact determined by the recent elevations is that, except in obvious cases where a slide and settlement can be seen, the pavement has been uniformly supported throughout, even though it may have been raised by swelling of the underlying material.

The fact that the sections were reinforced did not influence the evaluation, because each was reinforced in the same manner. Reinforcement is significant equally in each section throughout the project in that it has prevented excessive faulting of joints and cracks. In very few instances was faulting more than 1/16 of an inch, which is normally tolerable. In the cases where faulting was greater than 1/16 of an inch, major deterioration had occurred. Hence, the whole project was assumed to be in better condition than it would have been if no reinforcing steel had been used.

There is still a possibility that some of the differences in performance among the sections can be traced to other factors such as salt de-icing treatments, varying maintenance practices, and varying conditions during construction.

Although de-icing salts have been used in a limited way on this project, their use has been general and not confined to any one section. If crack and joint cleaning and sealing had been omitted for any part of the project for an extended period of time this, no doubt, would have permitted more advanced deterioration of cracks and joints in that part of the project. The Highway Materials Research Laboratory Memorandum Report of June 11, 1953, records just such an omission existing at that date in test Section 10. At that time, deterioration of cracks and joints in Section 10 was proceeding at a more rapid rate than in the other sections. This condition was corrected shortly thereafter, however, and even though Section 10 is probably in worse condition than it might have been it does not seem to be very much out of line with the other sections. If maintenance has varied significantly among the different sections it is extremely difficult to determine the effects at this time. Most likely it has not varied in any section more than it did in Section 10 mentioned above. Apparently the effect in that section has not been severe enough to prevent its comparison with the other sections.

Construction data are presented in Table 3. Cement factors, curing times and curing methods are sufficiently alike for each section that no great significance can be attached to them in comparing sections. The water-cement ratios for the limestone sections average generally higher than for the gravel sections. This difference shows up later in this discussion, where compressive and flexural strengths of specimens taken from each section are discussed. As would be expected, the gravel sections, utilizing less water, have higher strength on the average.

From station 465+00 to station 495+00 an experimental Goodrich Preformed Rubber Joint Seal, or equal, was used. There are only a few pieces of these rubber sealers still in the joints and normal joint sealing maintenance has been necessary for some time. However, it appears that for an extended period after the seals had failed no conventional joint sealing was practiced to protect the exposed joints. As a result there is evidence in Section 4 that where these experimental joints were used a greater percentage of joints are in a more advanced stage of deterioration that joints in the rest of Section 4, where conventional joint sealing was used.

Compressive strengths of cores taken in 1942, 1947 and 1957 are shown in Table 4. These are plotted by section on the graph in Fig. 3. No appreciable differences in average compressive strengths between the limestone and gravel sections were evident in 1942 or 1947; but now, after 16 years, average compressive strengths for the sections containing

TABLE 3: SUMMARY OF CONSTRUCTION DATA BY SECTIONS

SECTION NO.	I	II	III	IV	V	AVG. FOR SECT I-V	AVG. FOR SECT VI-X	VI	VII	VIII	IX	X
Cement Combination	PCVR	PCVR,N	PC,NGA	PC,N	PC	—	—	PC	PC,N	PCVR,N	PC,NGA	PCVR
Coarse Aggregate	ls	ls	ls	ls	ls	—	—	gravel	gravel	gravel	gravel	gravel
Avg. Cement Factor	1.495	1.490	1.473	1.546	1.511	1.503	1.486	1.535	1.480	1.454	1.465	1.497
Avg. W/C Ratio	4.328	4.395	4.665	4.448	4.673	4.502	4.026	3.885	4.320	4.245	3.968	3.713
Avg. Slump	2.29	2.28	2.00	2.64	1.96	2.23	2.46	2.31	2.60	2.66	2.45	2.30
Avg. Air Content	3.3%	2.5%	2.7%	1.4%	0.8%	2.14%	1.62%	0.3%	0.8%	1.7%	2.6%	2.7%
Avg. Density (lb./cu. ft.)	150.3	151.2	151.3	153.6	154.4	152.2	154.3	156.8	155.2	154.3	152.5	152.7
Avg. Curing Time in Days: 1) Wet Burlap	1	1	1	1	1	1	1	1	1	1	1	1
2) Kraft Paper	3	3	3	3	3	3	3	3	3	3	3	3
No. of Joints Reworked in Finishing	0	3	2	3	1	—	—	6	9	1	1	0
Avg. % of Surface Sprinkled in Finishing	0	7	2	1	17	—	—	4	11	15	5	7

TABLE 4: SUMMARY OF TEST RESULTS BY SECTIONS

SECTION NO.	I	II	III	IV	V	AVG. FOR SECT I-V	AVG. FOR SECT VI-X	VI	VII	VIII	IX	X
Avg. Flex. Str. Before F & T: 1) Control Beams** (psi)	1085	968	862	1028	1083	1005	961	1113	1085	1002	818	788
2) Stock Beams***(psi)	775	777	715	788	850	781	959	968	1065	900	975	885
Avg. of Control and Stock Beams (psi)	987	928	823	904	982	925	967	1064	1080	958	896	836
Avg. No. of F & T Cycles Endured Before Failure	461	482	408	58	115	305	304	188	355	379	300*	300
Avg. % of Modulus of Elasticity Lost During F & T	33.6	33.3	37.4	47.5	45.4	39.4	28.8	26.1	47.7	14.7	3.0	52.5
Avg. % of Flex. Strength Lost During F & T	44.3	46.7	44.6	58.6	60.8	51.0	55.9	84.5	73.2	55.9	3.1	62.9
Avg. Comp. Strengths of Cores '42 (psi)	5200	6000	5143	5870	6770	5797	5527	—	--	—	5660	5393
Avg. Comp. Strengths of Cores '47 (psi)	6200	5760	5543	5730	7100	6067	6020	6510	6325	5880	5573	5813
Avg. Comp. Strengths of Cores '57 (psi)	4714	4250	4550	4888	6718	5024	6246	7365	6428	5330	6063	6045

*Underwent 300 cycles of freeze-and-thaw without failure.

**Control beams were immersed in water for seven days, reweighed, tested for sonic modulus while wet, and broken in flexure on the day freezing and thawing commenced.

***Stock beams were stored in the laboratory at room temperature, until the last frozen and thawed beams in the series had been broken. They were then immersed in water for seven days and broken to determine changes in strength caused by the additional age.
Averages were taken by eliminating all beams not within 15 percent of the average.

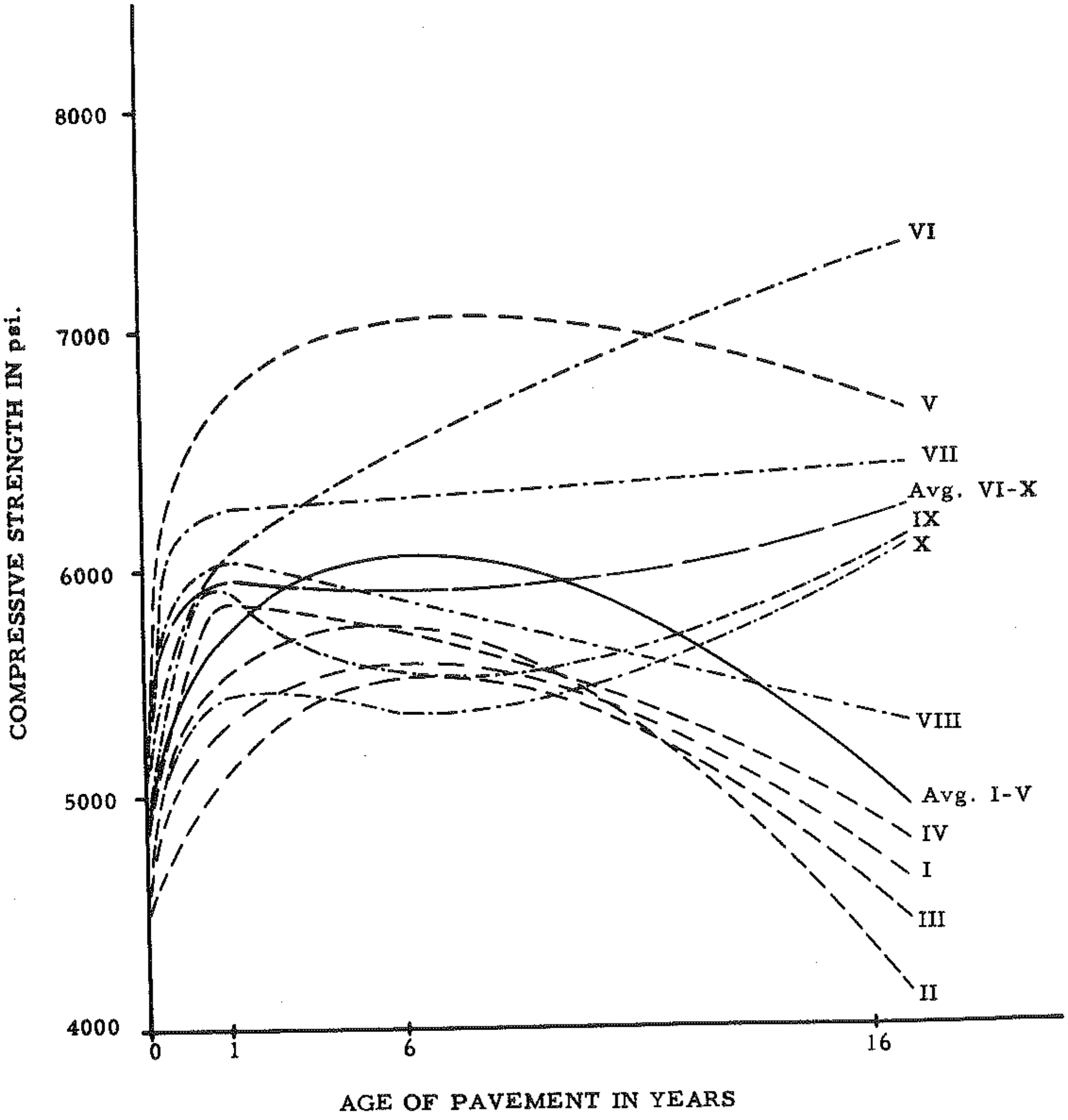
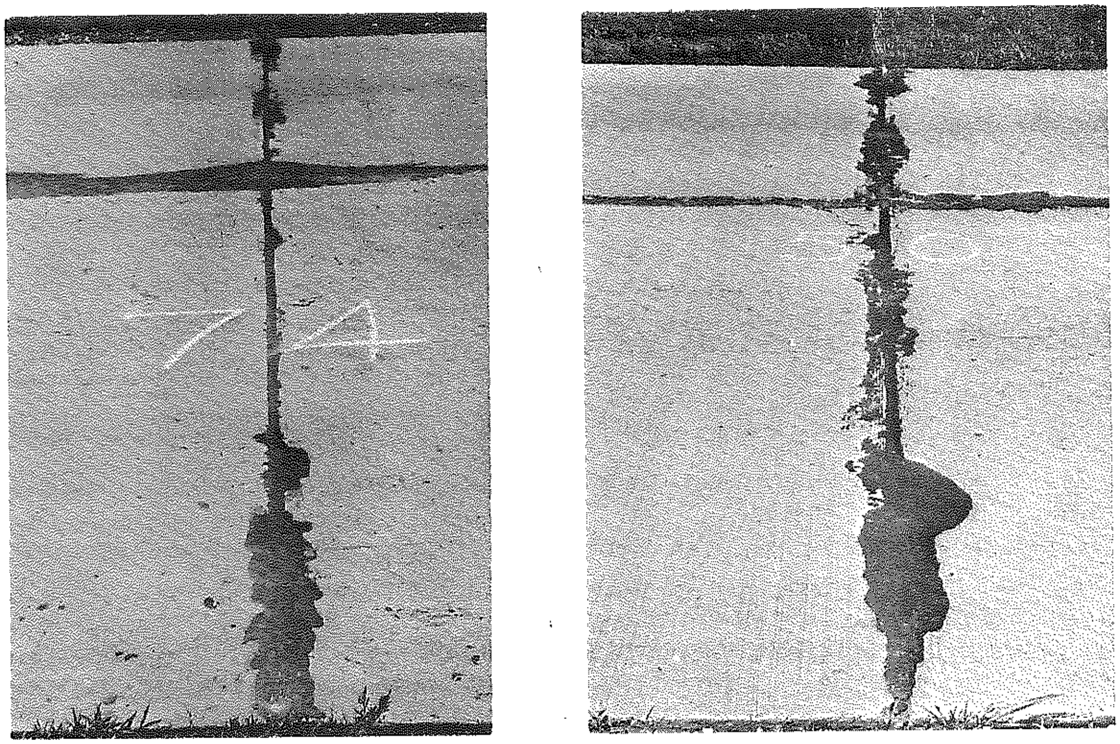


Fig. 3: Variation in Compressive Strength with Age, by Sections. Data were obtained from tests on cores taken in 1942, 1947, and 1957. Sections I through V contain limestone coarse aggregate; VI through X contain river gravel coarse aggregate.

limestone coarse aggregate are much lower than for those containing gravel coarse aggregate. Also, compressive strengths are not necessarily low for the sections which show the most deterioration. The best conclusion that can be reached by examining these compressive strengths and the condition of each section is that compressive strengths are not a very good indicator of durability.

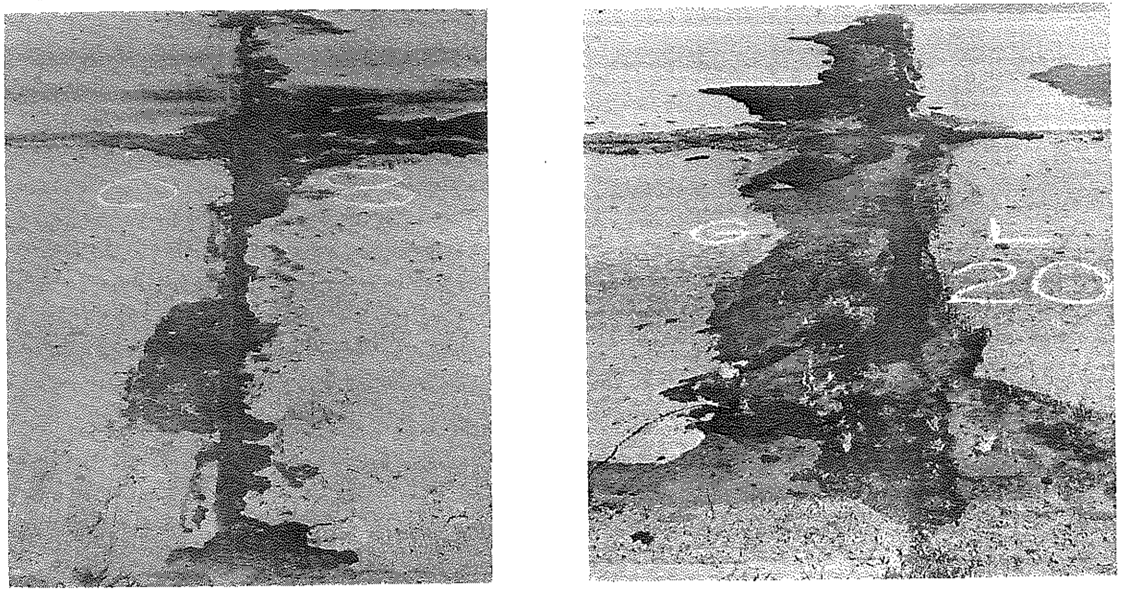
Flexural strengths of beams made during construction are given in Table 4. No flexural strengths have been obtained for beams other than those made in 1941, but it is interesting to examine these strengths for each section. The same trend apparent in the 1957 compressive strengths is also apparent in the strengths obtained at the beginning of the project. Average flexural strengths for the sections containing limestone coarse aggregate are lower than average flexural strengths for the sections with gravel. However, the difference between average flexural strengths is not as great as that between average compressive strengths. Also, as with the compressive strengths, the flexural strengths are not necessarily low for the sections which show the most deterioration. It follows that flexural strengths, like compressive strengths, are not a good indicator of durability.

In order to interpret clearly the crack survey data presented in Table 5, an understanding of the designations A, B, C, and D, used to describe the condition of cracks and joints, is necessary. Figure 4 illustrates the difference between an A, B, C, and D crack or joint. An A crack or joint is in like-new condition, a B crack or joint shows more deterioration, a C crack or joint shows further deterioration, and a D crack or joint shows maximum deterioration.



A - Fine crack or normal joint without spalling or other deterioration

B - Fine crack or normal joint with slight spalling and minor corner breaking



C - Enlarged crack or joint, showing considerable spalling and corner breaking

D - Greatly enlarged crack or joint, with excessive spalling and corner breaking

Fig. 4: Joints Illustrating Typical A, B, C, and D Conditions as Designated in Table 5.

To summarize, the 10 test sections to be compared have been supported by virtually the same sub-grade material, have the same reinforcing, have endured the same weather conditions and have been subjected to approximately the same traffic. Consideration has been given to variables such as different air contents of the sections, different maintenance practices, and differences in construction factors. These constants and variables appear to be of minor importance in the evaluation of the sections. Hence, differences in performance among the sections are attributable in the most part to the differences in the coarse aggregates and the cement blends.

CONCLUSIONS

Conclusions about the comparative performance of these 10 test sections have been restricted in most part to the effects of the two major variables: cement blends and coarse aggregates.

Data indicating the present condition of each of the 10 sections may be found in Table 5. With these data a rating has been determined for each section for each of the factors given. These ratings are presented in Table 6. Construction, test and design data for each of the sections, recorded early in the history of the project, may be found in Tables 3 and 4. With these data the ratings for each section, given in Table 7, would have been predictable at that time. They are presented for comparison with the actual performance data in Table 6.

Comparison of these two tables indicates that different factors when used in the evaluation of concrete pavements give different results, and that evaluation by one factor will not necessarily bear out trends found by another. This difference stands out where compressive strengths of cores show one trend and flexural strengths of beams show another, and neither of these is borne out by the actual pavement condition. From these and other factors presented in Tables 6 and 7, it is obvious that the many different factors involved in concrete pavement evaluation must be considered individually.

It is impossible to say that any one section is altogether better than any of the others. However, Tables 6 and 7 do show specific ways in which each section is superior to the others. Further, by considering the factors in Table 6, it is possible to rate the 10 test sections on several generally valid assumptions:

TABLE 5: SUMMARY OF PERFORMANCE DATA BY SECTIONS

SECTION NO.	I	II	III	IV	V	AVG. FOR SECT I-V	AVG. FOR SECT VI-X	VI	VII	VIII	IX	X
Approx. Jt. Spacing	60 ft	60 ft	60 ft	60 ft	60 ft	60 ft	30 ft	30 ft	30 ft	30 ft	30 ft	30 ft
A Cracks / Mi.*	55.65	48.60	23.70	8.05	18.39	30.87	133.39	120.00	92.04	138.74	146.15	170.03
A Joints / Mi.	82.77	88.90	85.33	72.47	81.21	82.14	80.34	69.23	62.91	71.20	103.22	95.15
A Cracks / Slab	0.64	0.57	0.27	0.097	0.20	—	—	0.94	0.61	0.81	0.88	0.97
B Cracks / Mi.*	2.85	—	—	—	1.53	0.88	—	—	—	—	—	—
B Joints / Mi.	5.71	1.03	4.12	10.35	7.66	5.67	68.45	55.38	78.04	88.54	50.08	70.19
B Cracks / Slab	0.03	—	—	—	0.02	—	—	—	—	—	—	—
C Joints / Mi.*	—	—	—	1.15	1.53	0.54	7.94	4.61	8.15	10.95	8.18	7.82
D Joints / Mi.*	—	—	—	—	—	—	2.68	—	2.34	1.83	6.12	3.13
Half Lane Cracks / Mi.	51.37	43.43	19.58	5.75	13.79	26.78	45.25	46.15	40.78	50.20	47.01	42.12
Full Lane Cracks / Mi.	4.28	5.17	4.12	2.30	6.13	4.40	88.14	73.84	51.26	88.54	99.14	127.91
Total Cracks / Mi.	55.65	50.67	23.70	8.05	19.92	31.60	133.39	119.99	92.04	138.74	146.15	170.03
Total Joints / Mi.	88.48	89.33	89.65	83.97	90.40	88.37	159.42	129.22	151.45	172.52	167.60	176.29
Total Cracks / Slab	0.64	0.57	0.27	0.097	0.22	0.76	0.84	0.94	0.61	0.81	0.88	0.97
Total Cracks and Joints / Mi.	144.13	140.00	113.35	92.02	110.32	119.96	292.83	249.21	243.49	311.26	313.85	346.32
Avg. Crack and Joint Spacing (ft.)	36.63	37.71	46.58	57.38	47.86	45.23	18.38	21.19	21.68	16.96	16.82	15.25
Avg. Comp. Strengths of Cores, '57 (psi)	4714	4250	4550	4888	6718	5024	6246	7365	6428	5330	6063	6045
Surface Spalling	None	None	0.15%	4.09%	4.51%			11.87%	0.25%	0.12%	None	None

* Crack and joint designations A, B, C, and D are as illustrated in fig. 3.

TABLE 6: SECTION PERFORMANCE RATINGS AS DETERMINED BY PRESENT CONDITION

SECTION NO.	I	II	III	IV	V	VI	VII	VIII	IX	X
A Cracks and Joints / Mi.	5	4	3	1	2	7	6	8	9	10
B Cracks and Joints / Mi.	3	1	2	5	4	7	9	10	6	8
C Joints / Mi.	—	—	—	4	5	6	8	10	9	7
D Joints / Mi.	—	—	—	—	—	—	8	7	10	9
Total Cracks and Joints / Mi.	5	4	3	1	2	7	6	8	9	10
Avg. Comp. Strengths of Cores '57	8	10	9	7	2	1	3	6	4	5
Surface Spalling	—	—	6	8	9	10	7	5	—	—
Total Performance Rating	21	19	24	26	24	38	47	54	47	49
Rank	2	1	3,4	5	3,4	6	7,8	10	7,8	9

TABLE 7: SECTION PERFORMANCE RATINGS AS PREDICTED BY CONSTRUCTION DATA

SECTION NO.	I	II	III	IV	V	VI	VII	VIII	IX	X
Avg. Cement Factor	5	6	8	1	3	2	7	10	9	4
Avg. W / C Ratio	6	7	9	8	10	2	5	4	3	1
Avg. Slump	4	3	2	9	1	6	8	10	7	5
Avg. Air Content	1	5	2,3	7	8,9	10	8,9	6	4	2,3
Avg. Density	1	2	3	6	8	10	9	7	4	5
Avg. Flex. Str. Before F&T										
1) Control*	2,3	7	8	5	4	1	2,3	6	9	10
2) Stock*	9	8	10	7	6	3	1	4	2	5
Compensated Avg. of Control and Stock	3	6	10	7	4	2	1	5	8	9
Avg. No. of F & T Cycles Endured Before Failure	2	1	3	10	9	8	5	4	6,7	6,7
Avg. % of Flex. Str. Lost During F & T*	1	3	2	5	6	9	8	4	—	7
Avg. Comp Strengths of Cores '47	4	7	10	8	1	2	3	5	9	6
Total Performance Rating	26	37	47	56	44	42	46	51	50	38
Rank	1	2	7	10	5	4	6	9	8	3

*Ratings for these factors not included in total.

1. The fewer cracks and joints in a unit length the more desirable the pavement.
2. The better the condition of existing cracks and joints in a unit length of pavement the better its condition.
3. The less surface spalling existing in a unit length of pavement the better its condition.
4. The higher the average compressive strength of concrete in a unit length of pavement the better its condition.

Table 6 assigns a numerical rating to each section for each of these factors. These ratings have been totaled to determine how each section ranks with respect to the others. By these total performance ratings an over-all order of performance has been established for the sections.

Data indicating the present condition of each of the 5 test sections in the limestone coarse aggregate group and the 5 test sections in the gravel group may be found in Table 5. With these data the ratings in Table 8 have been determined for each section for the factors given for each coarse aggregate group.

Construction, test and design data for each of the 5 test sections in the limestone coarse aggregate group and the 5 test sections in the gravel group may be found in Tables 3 and 4. With these data the ratings given in Table 9 could have been predicted for each section for the factors given for each coarse aggregate group.

Tables 8 and 9 give comparative ratings for the limestone coarse aggregate group and for the gravel group separately according to the many variables involved. However, it is nearly impossible to say even in these groups that any one section is better in every way than the others.

TABLE 8: SECTION PERFORMANCE RATINGS AS DETERMINED BY PRESENT CONDITION, FOR EACH COARSE AGGREGATE GROUP

	Limestone					Gravel				
SECTION NO.	I	II	III	IV	V	VI	VII	VIII	IX	X
A Cracks and Joints / Mi.	5	4	3	1	2	2	1	3	4	5
B Cracks and Joints / Mi.	3	1	2	5	4	2	4	5	1	3
C Joints / Mi.	—	—	—	4	5	1	3	5	4	2
D Joints / Mi.	—	—	—	—	—	1	3	2	5	4
Total Cracks and Joints / Mi.	5	4	3	1	2	2	1	3	4	5
Avg. Comp. Strengths of Cores '57	3	5	4	3	1	1	2	5	3	4
Surface Spalling	—	—	3	4	5	5	4	3	—	—
Total Performance Rating	16	14	15	17	19	14	18	26	21	23
Rank	3	1	2	4	5	1	2	5	3	4

TABLE 9: SECTION PERFORMANCE RATINGS AS PREDICTED BY CONSTRUCTION DATA, FOR EACH COARSE AGGREGATE GROUP

SECTION NO.	Limestone					Gravel				
	I	II	III	IV	V	VI	VII	VIII	IX	X
Avg. Cement Factor	3	4	5	1	2	1	3	5	4	2
Avg. W / C Ratio	1	2	4	3	5	2	5	4	3	1
Avg. Slump	4	3	2	5	1	2	4	5	3	1
Avg. Air Content	1	3	2	4	5	5	4	3	2	1
Avg. Density	1	2	3	4	5	5	4	3	1	2
Avg. Flex. Str. Before F&T: 1) Control*	1	4	5	3	2	1	2	4	3	5
2) Stock*	4	3	5	2	1	3	1	4	2	5
Compensated Avg. of Control and Stock	1	3	5	4	2	2	1	3	4	5
Avg. No. of F & T Cycles Endured Before Failure	2	1	3	5	4	5	2	1	3,4	3,4
Avg. % of Flex. Str. Lost During F & T*	1	3	2	4	5	4	3	1	—	2
Avg. Comp. Strengths of Cores ' 47	2	3	5	4	1	1	2	3	5	4
Total Performance Rating	15	21	29	30	25	23	25	27	25	19
Rank	1	2	4	5	3	2	3,4	5	3,4	1

*Ratings for these factors not included in total.

Nevertheless, the 5 test sections for each group can be rated by the same assumptions used in rating all 10 sections in Table 6. On this same basis Table 9 gives a numerical rating for each section, comparing it to the other sections for each of the significant factors previously given for each coarse aggregate group. Again, these ratings are totaled to determine how each section ranks with respect to the others within its group. By these total performance ratings an over-all order of performance is established for the sections for each group.

Finally, to determine the more suitable coarse aggregate according to performance under the conditions of this test project, average performance data for the Lexington Series limestone coarse aggregate group of sections can be compared to average performance data for the Cleves Pit gravel coarse aggregate group of sections.

On the assumptions that (1) the fewer cracks and joints in a given section of pavement the better its performance, and (2) the better the condition of the cracks and joints in the same section of pavement, the better its performance, the data in Table 10, taken from Table 5, may be analyzed.

TABLE 10: AVERAGE NUMBER OF CRACKS AND JOINTS WITHIN EACH COARSE AGGREGATE GROUP

	Limestone Group	Gravel Group
A cracks and joints / mi.	113.01	213.73
B cracks and joints / mi.	6.55	68.45
C joints / mi.	0.54	7.94
D joints / mi.	0	2.68
Total cracks and joints / mi.	119.96	292.83

Dealing only with the number of cracks and joints per mile of pavement, Table 10 shows that this average concrete pavement, made with similar materials, by similar methods and subjected to similar conditions, had fewer than half as many cracks and joints when Lexington Series limestone coarse aggregate was used than when Cleves Pit gravel coarse aggregate was used. Further and more important, this average concrete had many fewer deteriorated cracks and joints where the Lexington Series limestone coarse aggregate was used.

Before concluding on the basis of the above that the gravel is inferior to the limestone aggregate, consideration should be given to a well established fact: for many years good practice has required that concrete pavements utilizing gravel aggregate have closer joint spacing than concrete pavements with limestone aggregate, since experience has shown that gravel pavements naturally crack more frequently than limestone pavements. This difference in crack interval may result from factors such as the difference in thermal expansion coefficients of the two aggregates. Therefore, to prevent excessive uncontrolled cracking in gravel pavements the formed joints must be comparatively close. This practice was followed in this project and the gravel aggregate sections were constructed with 30 ft. joint spacing, while the limestone aggregate sections were given 60 ft. joint spacing.

This difference in itself is undesirable in the method of evaluation used, because there are twice as many formed joints in the gravel sections as in the limestone sections. Also, in spite of this difference in joint interval, designed to prevent cracking, more cracks occurred per mile in the gravel sections than in the limestone sections. And further, the cracks and joints in the gravel sections generally deteriorated more than those in the limestone sections.

However, if the number of good joints in a pavement is considered unimportant and a pavement with many joints is considered to be as good as one with few, then *condition* of joints becomes all important. Theoretically, if a joint or a crack is properly maintained and kept sealed it should stay in good condition. But the more joints and cracks there are in a section, the more maintenance is required. If maintenance is neglected for any reason, the section of pavement with more cracks and joints --- in this case, the gravel section --- will deteriorate faster.

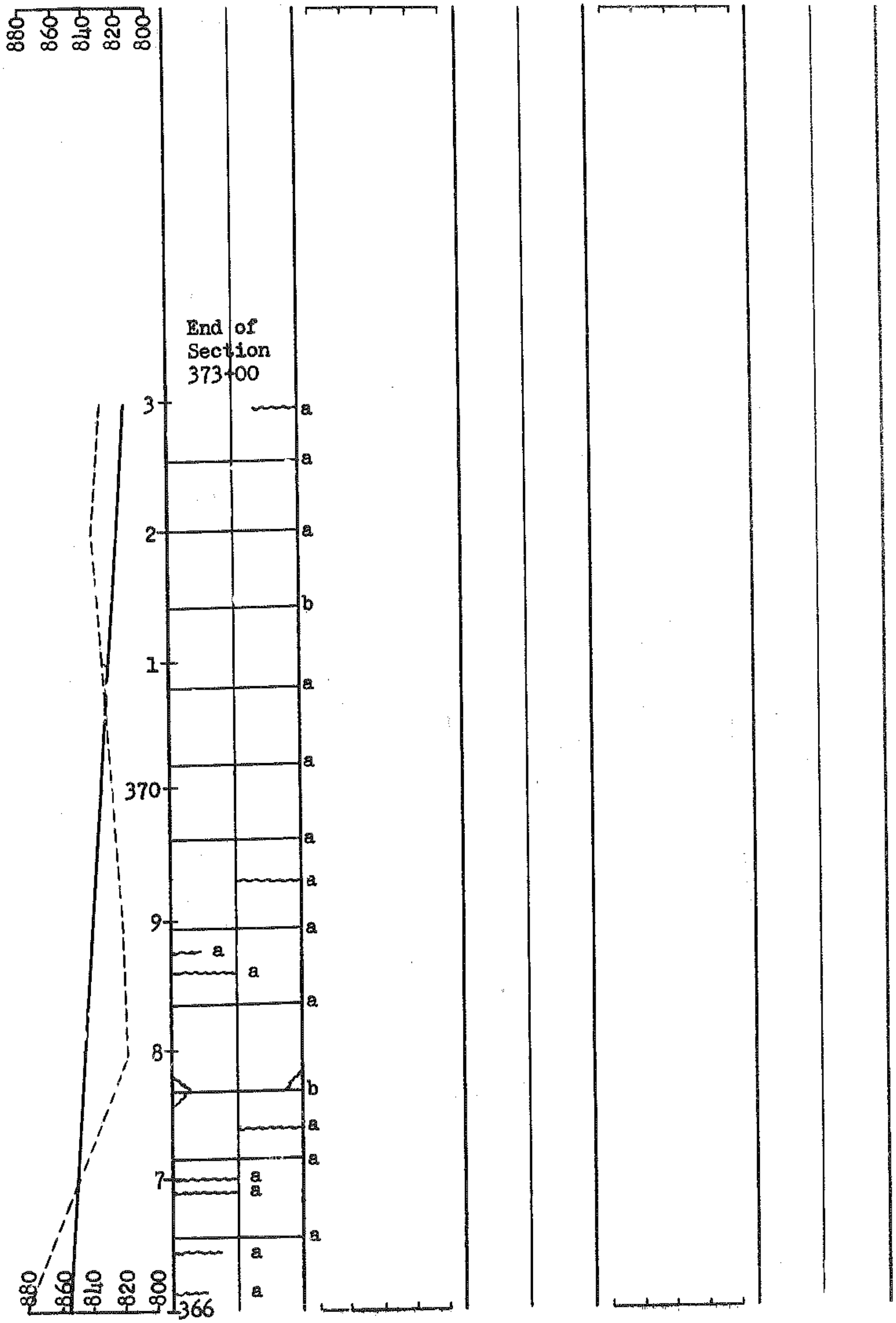
Finally, going back to Table 10, using the framework of evaluation set up herein, the test sections utilizing Lexington Series limestone coarse aggregate have, on the average, performed better than the test sections utilizing Cleves Pit gravel coarse aggregate.

APPENDIX

Crack Survey---Plan and Profile

for

Test Project F. A. 366, C1 and C2
Harrison - Pendleton Counties
July - August, 1957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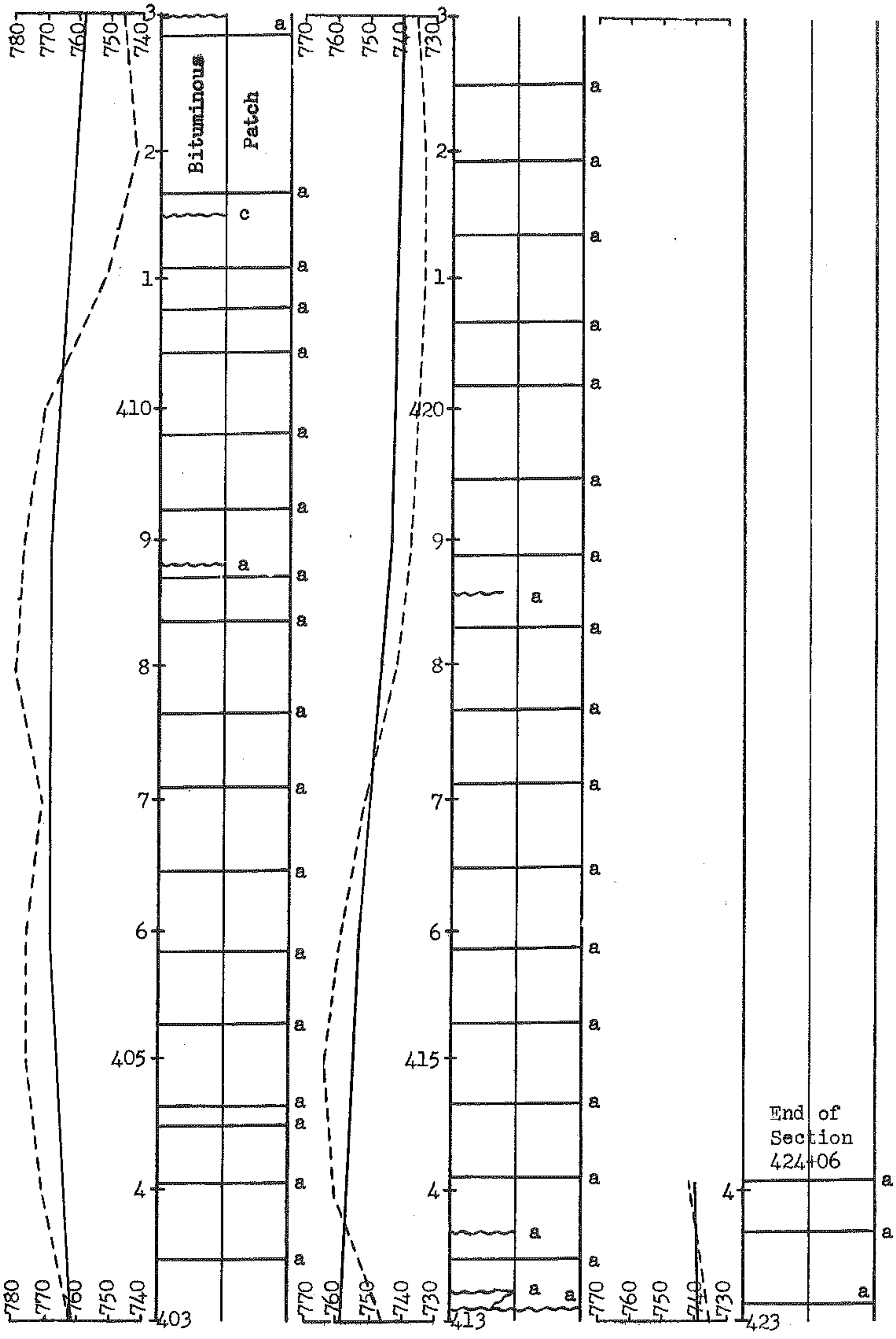
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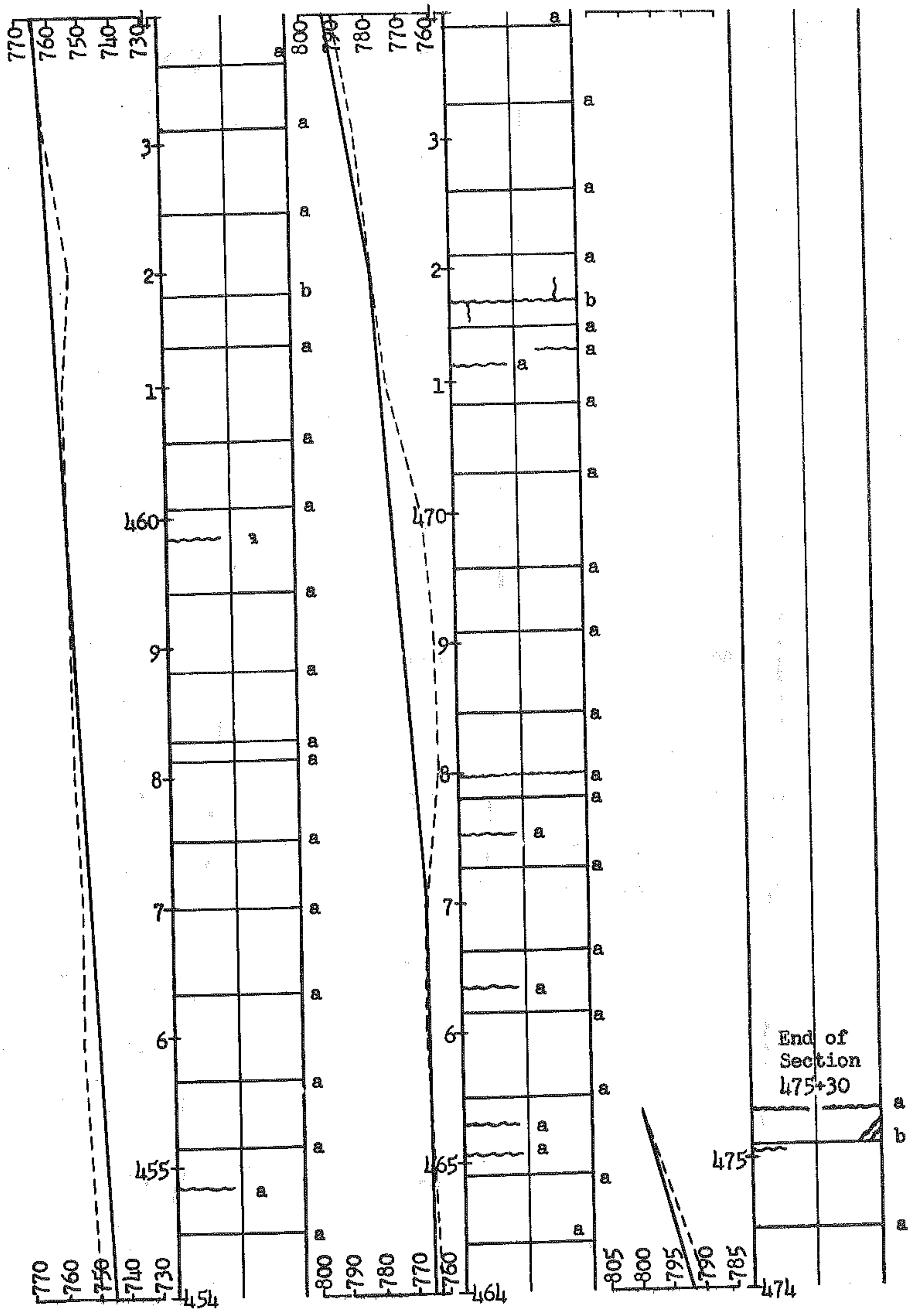
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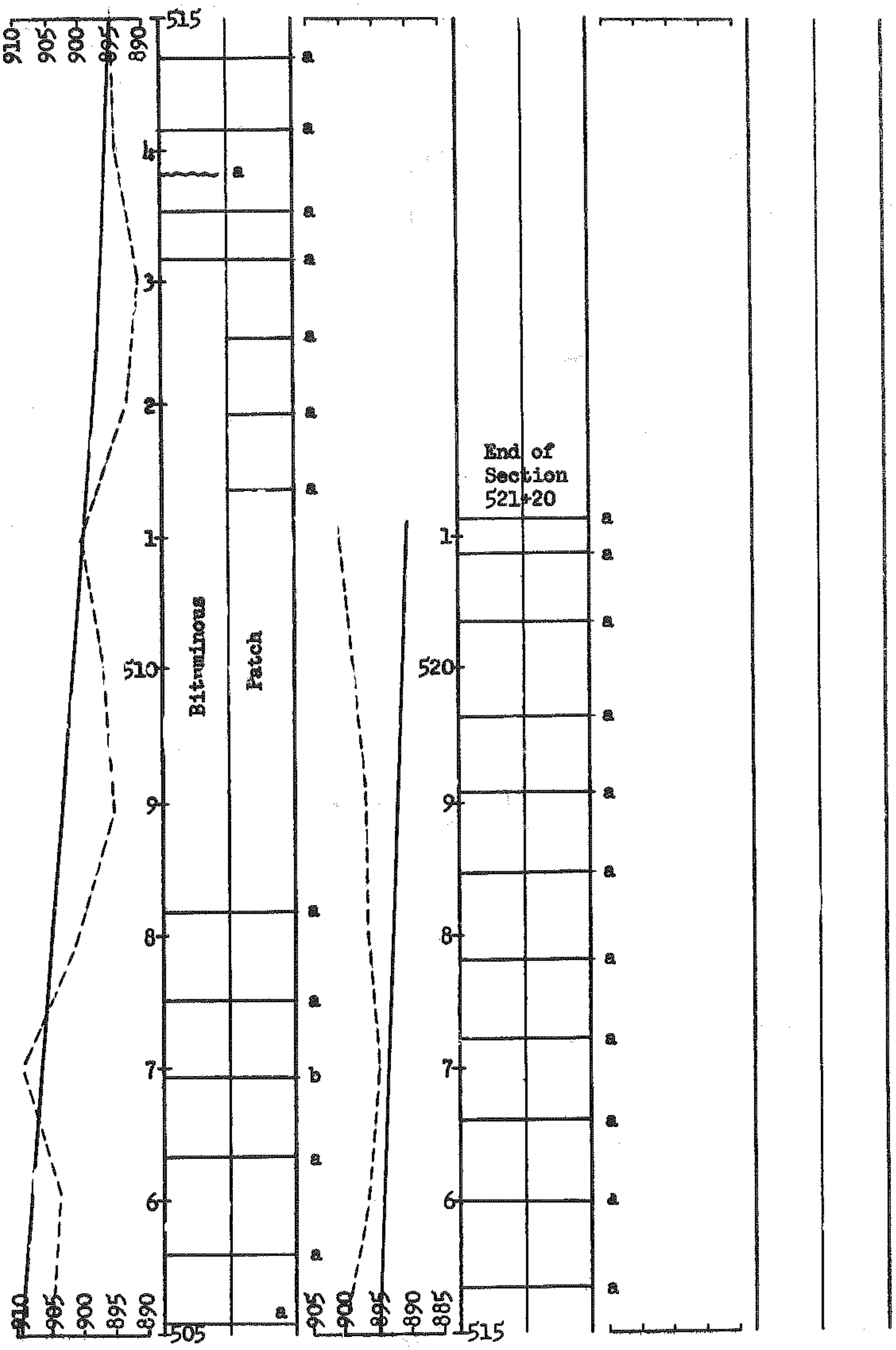
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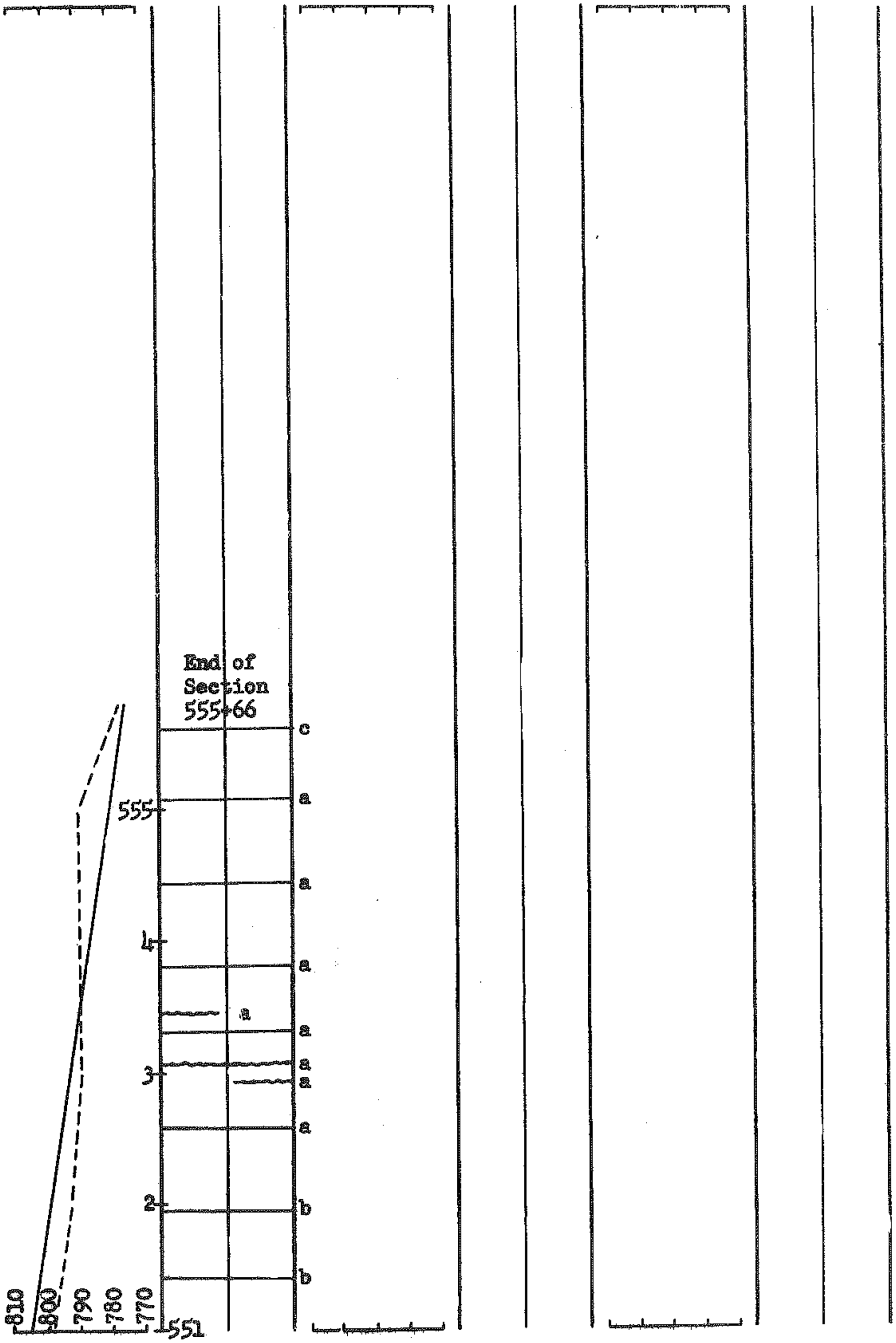
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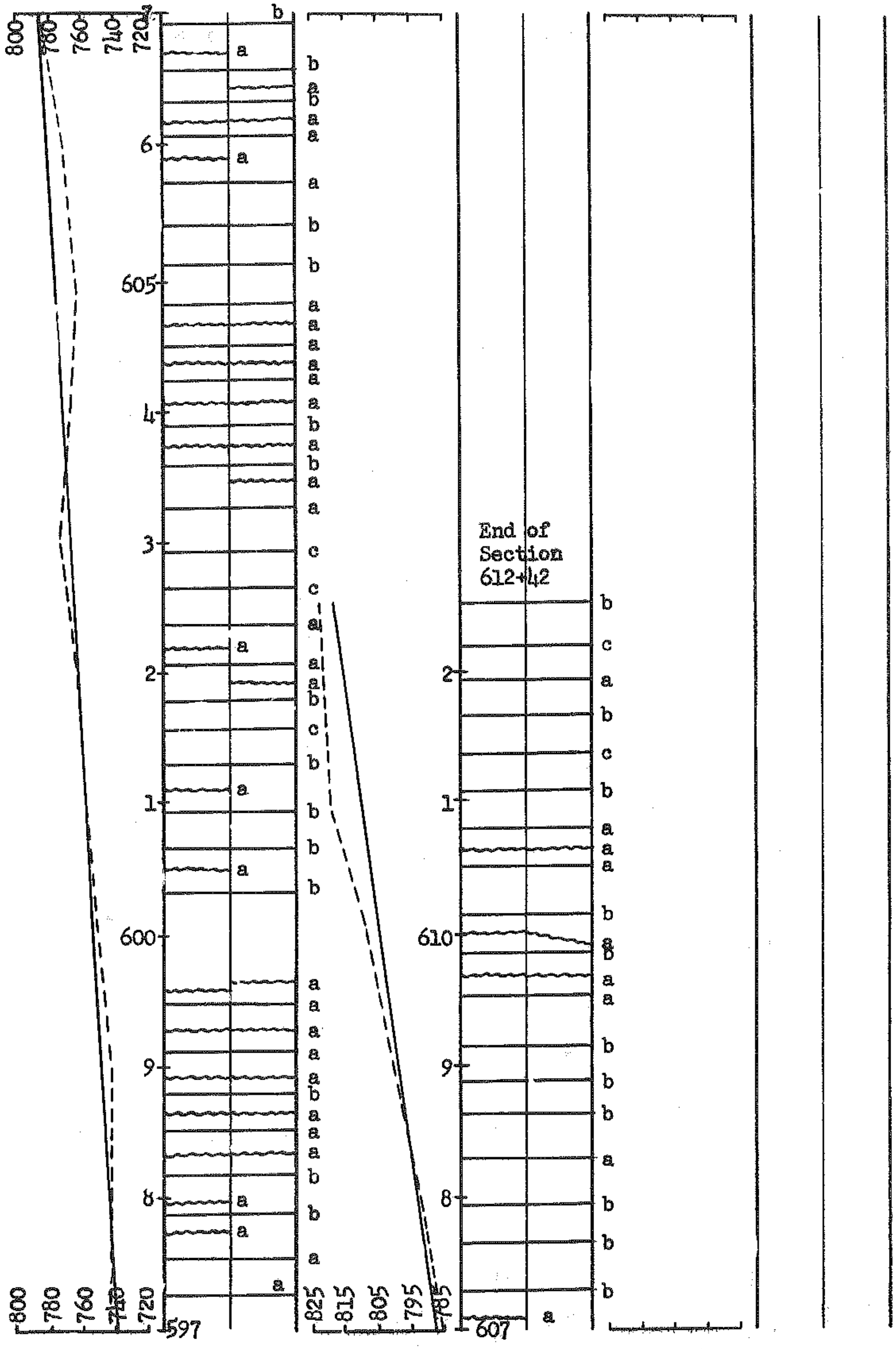
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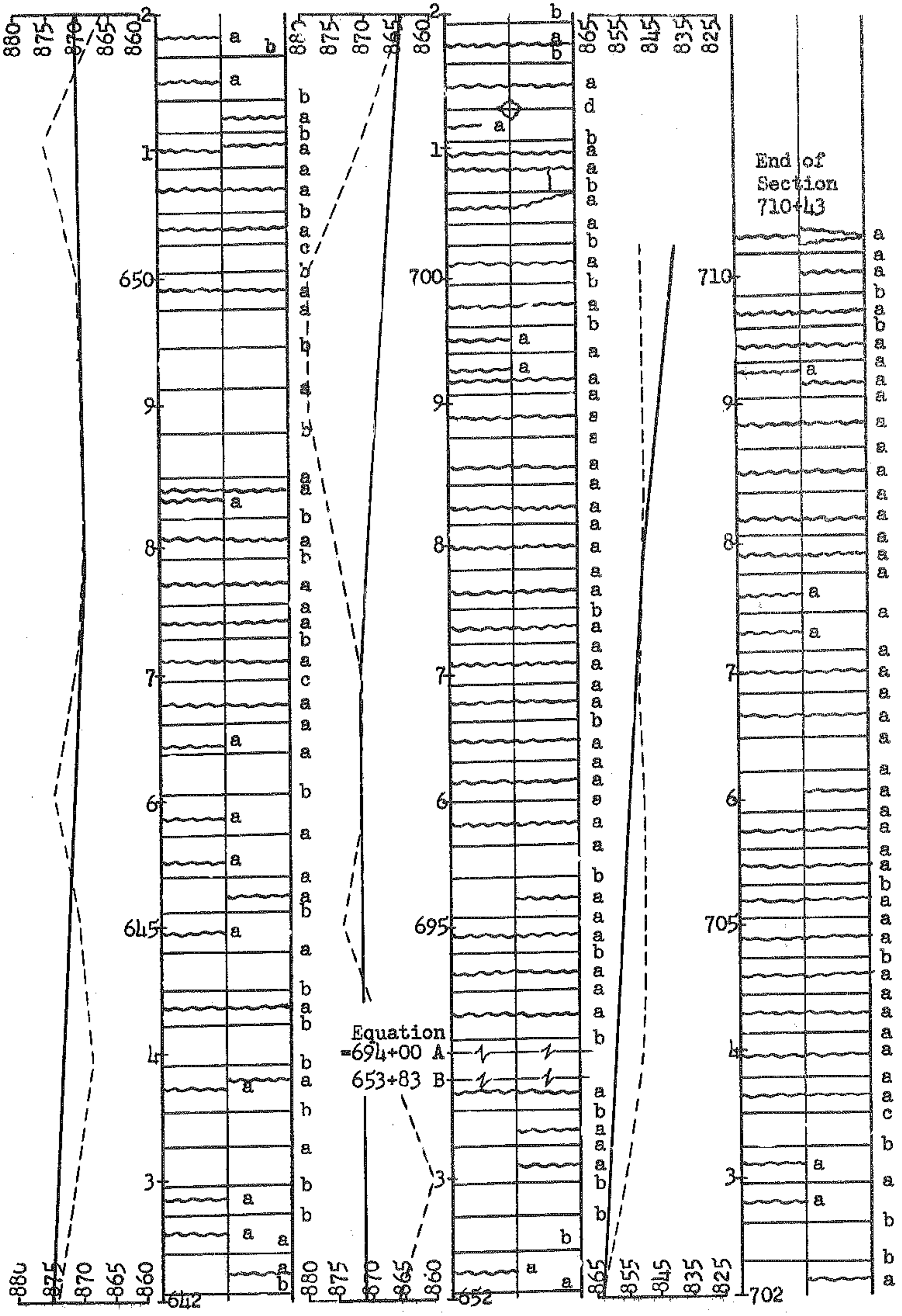

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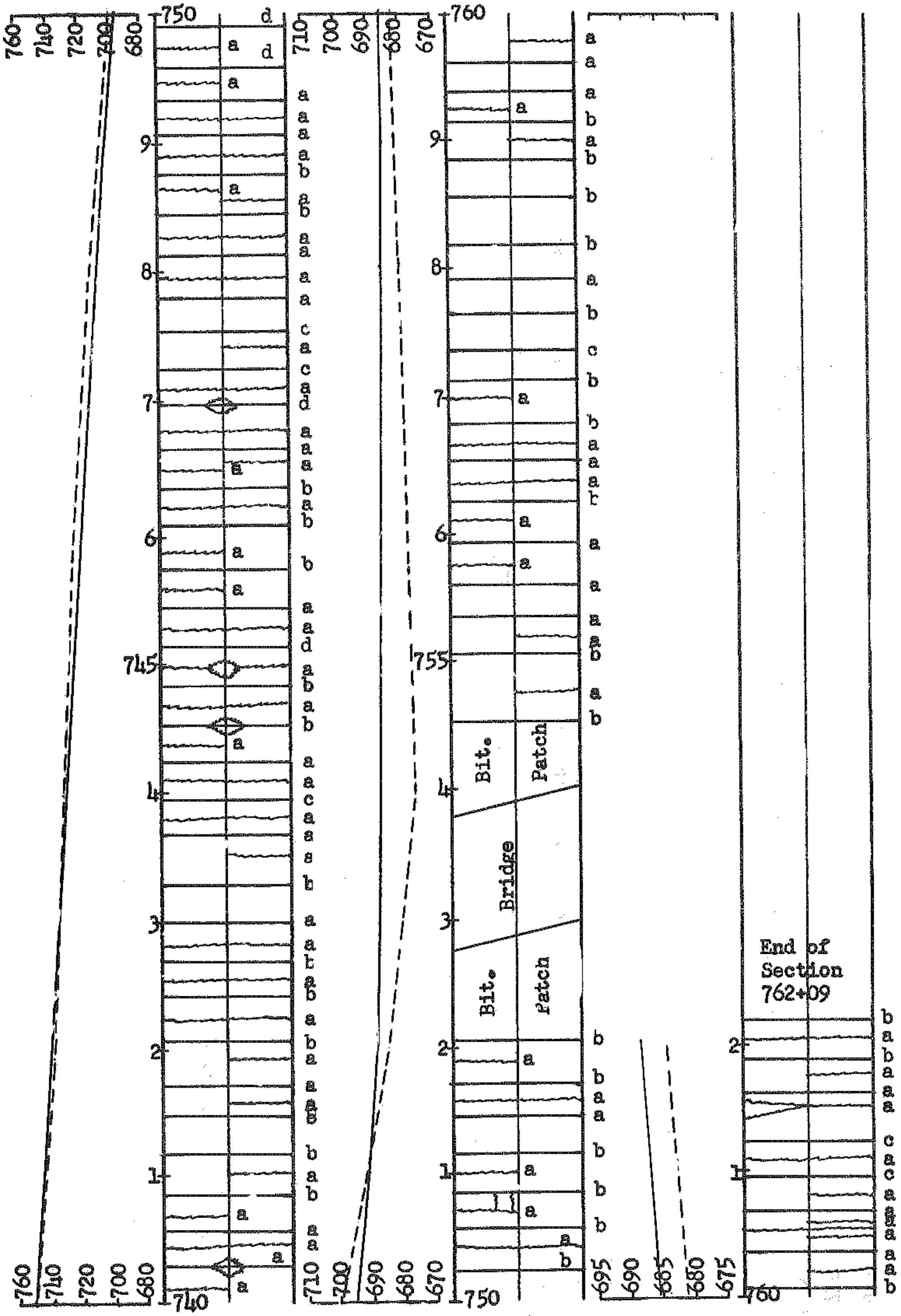

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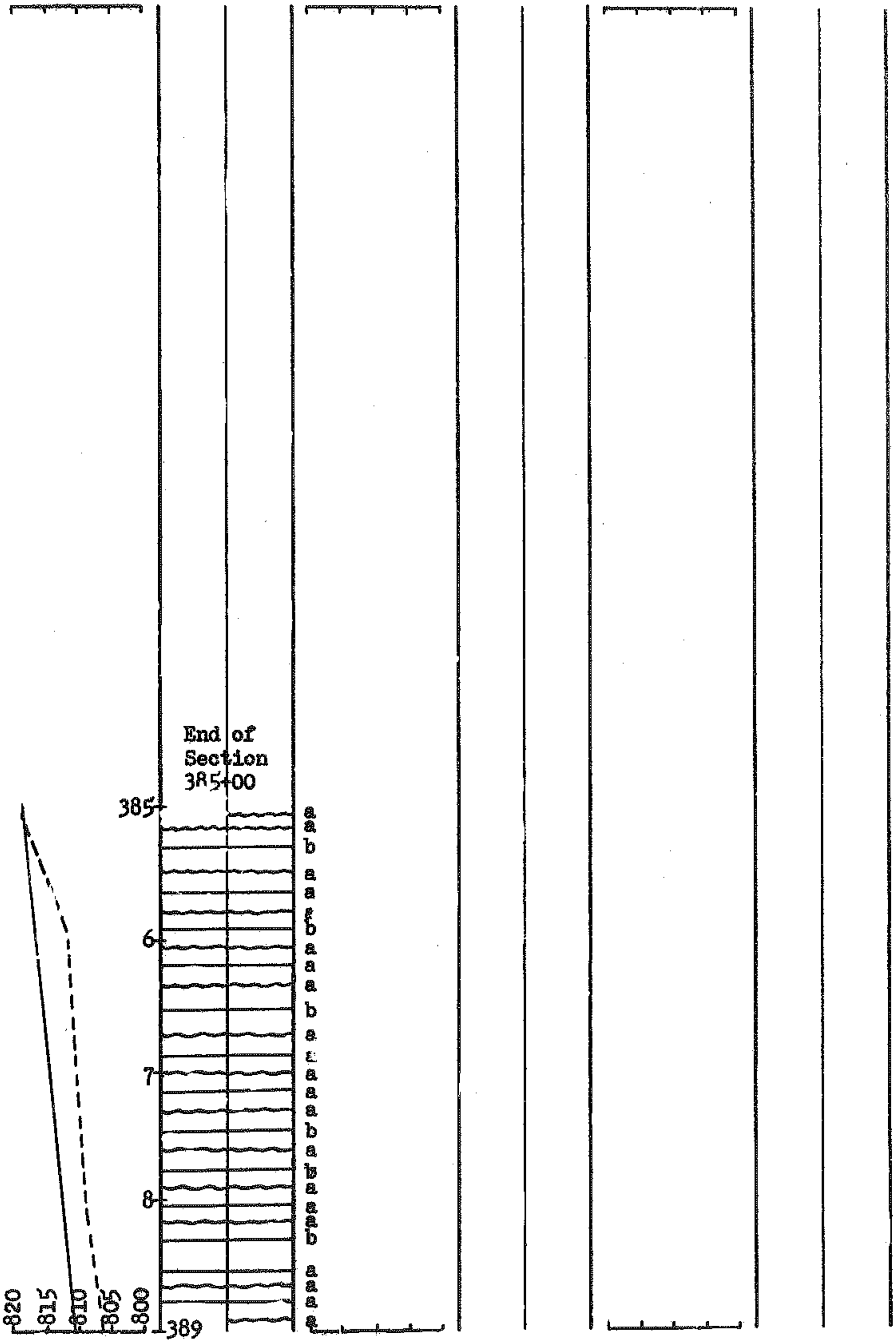
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Section X