Acoustic Characteristics of Roadway Surfaces

Final Report
WA-RD 129.1

September 1987

Washington State Department of Transportation
Planning, Research and Public Transportation Division

in cooperation with the
United States Department of Transportation
Federal Highway Administration

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16. Abstract

This project studies the ways in which tire noise changes as the pavement on which they run ages and wears. Initial measurements of the levels and spectral distribution of noise generated at the tire-road surface interface have been made on a number of road surfaces of a variety of asphaltic and concrete compositions. In all, noise characteristics from thirty-one roadway sections are under biannual study. All of these sections were freshly completed within six months of the initiation of the study. Data from the first four biannual sessions are presented in graphical form.

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ACOUSTIC CHARACTERISTICS OF ROADWAY SURFACES

by
James D. Chalupnik
Donald S. Anderson

Washington State Transportation Center

Department of Mechanical Engineering
University of Washington
Seattle, Washington

Final Report

Research Project Y-2811
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1.0 EXECUTIVE SUMMARY:

This project is a pilot study of the way in which tire/road noise changes as the pavement ages and wears. Initial measurements of the noise levels and spectral distribution of noise generated at the tire-road surface interface have been made on number of road surfaces of a variety of asphaltic and concrete compositions. In all, noise characteristics are measured and analyzed biannually for forty-one roadway sections. All of these sections were freshly completed within six months of the initiation of the study. Data from the first four biannual sessions are presented in graphical form. At this point in this pilot study, the trends in the way the tire/road noise will change are not clearly established. Since the roadway sections are still in the early stages of their expected useful lives, even for the asphaltic sections, it was not expected that significant changes would show up during the pilot study.

2.0 BACKGROUND:

Measurement of the noise generated by the interaction between tires and the road surface are plentiful; the list of references gives selected references obtained from our literature search. Several of these are particularly useful in that they relate the near field measurement techniques used in this study to the far field noise levels, which can be thought of as the community noise exposure.

Information concerning the way in which noise produced by various payment types change with wear is lacking in the literature. In order to fill this information gap, the initial phase of this study (which will be referred to as "Phase I") was undertaken by WSDOT and the University of Washington. Since the main purpose of this investigation is to study the effects of wear and aging on the noise characteristics and normal life time expectancies for some roadway surfaces can reach as high as twenty years, the initial study, which is reported here, lasted only two years, can be considered to be a pilot study for the larger project.

The work performed in Phase I represents a major portion of the overall research project, because it involves setting up the experiment. This entails design of the experiment, design and fabrication of special hardware needed in the experiment, purchase of specialized equipment and instruments, selection of the test sections of roadway, setting of test and data protocols, etc.

An initial selection of over fifty roadway sections was ultimately reduced to thirty-one sections including several sections each of,

- High density portland cement concrete.
- Latex modified portland cement concrete.
- Class "D" ACP Open Graded.
- Polyester Fiber ACP.
- Class "B" ACP.
- Rubber Mod ACP. (Plus ride asphalt)

The study is being performed jointly by Washington State Department of Transportation (WSDOT) and the Sound and Vibration Research Laboratory (SVRL) of the Department of Mechanical Engineering, University of Washington. Donald S. Anderson is the contact person for WSDOT, and Professor James D. Chalupnik is the contact person for SVRL.

WSDOT is responsible for the data acquisition and SVRL is responsible for the experiment design and data analysis aspects of the project. SVRL has lead responsibility for preparation of reports, subject to WSDOT review.

3.0 OBJECTIVE:

The long term objective of this study is to measure the A-weighted levels and the spectra of tire noise from selected pavement types on a yearly basis to compare the effects of the following variables on tire noise:

1. Surface composition.
2. Surface wear.
3. Surface roughness.

4.0 PROCEDURE:

In order to accomplish the objective stated above it will be necessary to make measurements of the characteristics of noise generated by the tire interaction with a number of pavement types and to track their behavior over the lifetime of the surfaces. Before this could be done, certain preliminary tasks which set up the longer term experiment were required. These tasks were performed in the this phase of our study. Finally, the data acquisition portion of the study was initiated.

The tasks worked on in this phase of the overall project were:

- Literature search.
- Test vehicle selection.
- Roadway test section identification.
- Experimental equipment design.
- Data acquisition.
- Initial data collection. (four sessions)

These tasks are discussed in more detail in the following sections.

4.1 Literature Search

A literature search was performed at the University of Washington using the Computer-Based Reference Services, CBRS. This service provides access to a comprehensive cross-section of scientific holdings in libraries throughout the US and Western Europe. The library search, which included the topics pavement, surface, noise, and acoustic in several combinations, yielded 192 references, from which thirty-one references were selected for inclusion in the List of References at the end of this report. These references are given in alphabetical order by author.

4.2 Test vehicle selection

Originally, it was planned that one of the Department of Transportation standard sedans would be used as the test vehicle for the road tests; however, further consideration dissuaded us from this plan. Since the tests ultimately will run for many years (10-20), it was not imagined that a sedan in the vehicle pool would be reliably available for that period of time. Furthermore, vehicle aging and tire wear would certainly lead to problems in controlling the variability of the test conditions. Researchers in Europe have used trailers for tire noise stidies for a number of years, so the advantages of this approach were investigated.

Advantages offered by using a trailer for this research are:

1) The trailer could be made available always.
2) The same tire(s) can be used for the entire study period.
3) The microphone can be moved further from the exhaust, motor, differential, and transmission and other noise sources in the propulsion system.
4) It is not necessary to mount and demount the microphone mounting bracket from the test vehicle after each test run, as would be required if a vehicle from the pool were to be used.

A utility trailer was purchased for $630 for exclusive use on this project. The trailer is fitted with standard duty passenger tires. (Sears "Superguard" P185/75R14 radials) A tread print of the tire is shown in Figure 1. The trailer is strictly controlled and is used only for this project, so mileage on the tires is limited to about 500 miles per year. The trailer and tires should last the duration of the total project. The trailer has been loaded to a wheel load of 780 pounds to simulate the wheel load of a mid-sized sedan.

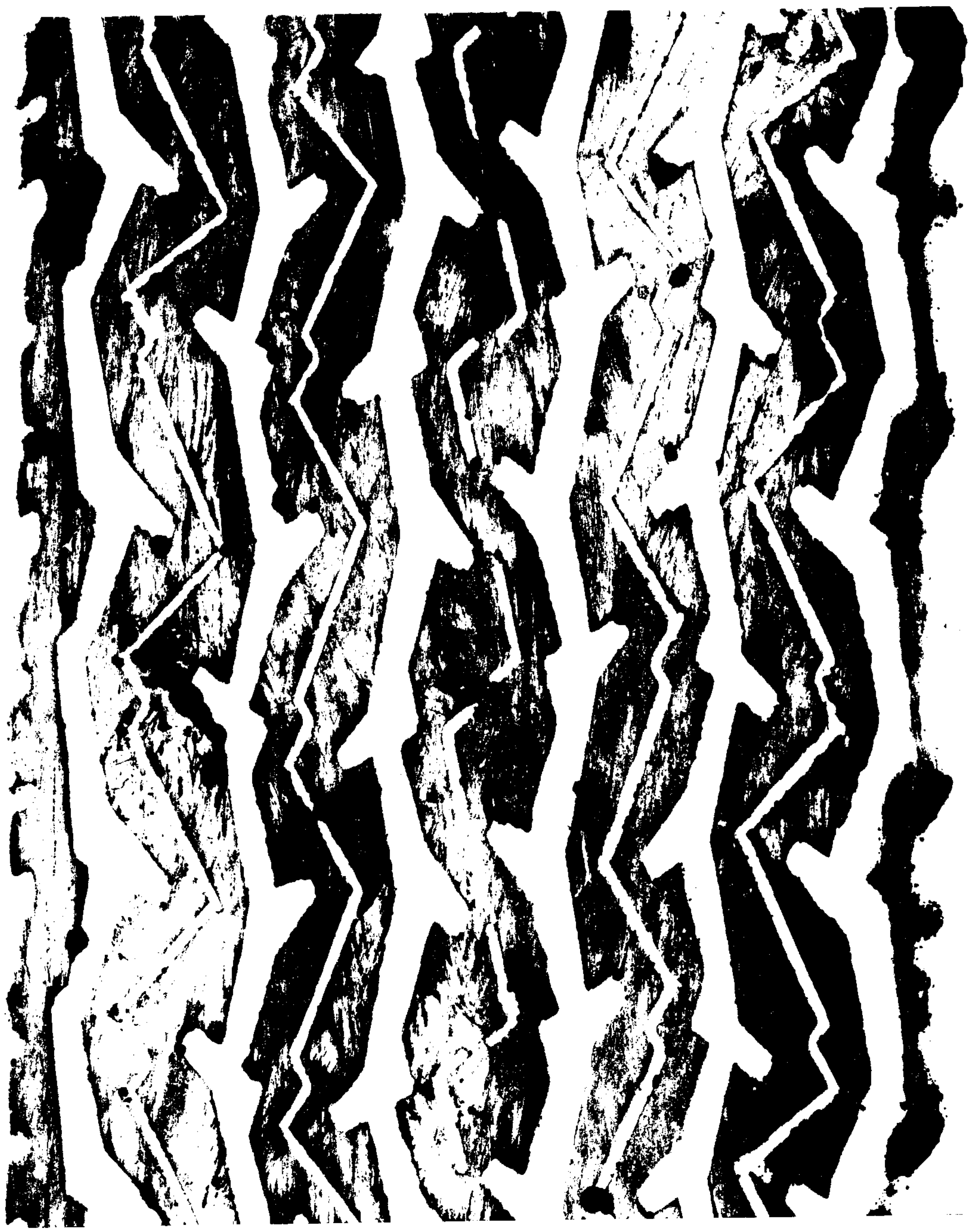

Figure 1 Tread print of the Sears Superguard radial tire used in this study.

In the first series of tests, a pickup truck from the Department of Mechanical Engineering at the University of Washington was used to pull the trailer, but this was not completely satisfactory, because the truck was old and under-powered. There was no guarantee that the truck would last the project out. As an alternative, a new V-8 powered van was located in the DOT vehicle pool. Thus far, we have been able to reserve this vehicle at the times that we are scheduled to make road tests.

4.3 Roadway test section identification

One of the first actions that needed to be performed before this study could be initiated was to identify the test sections that would be used for the remainder of the study period. Since our WSDOT representation is with District #1, it was logical to select test sections in that district. It is also the best solution logistically, since the University of Washington is located in District #1.

Don Anderson coordinated these efforts and created a list of over fifty potential test sections in District #1 ranging from the Skagit County line on the north to Olympia on the south and as far east as the Kittitas County line at Snoqualmie Summit. The principal criterion used for the selection process was that the candidate section be recently completed in the summer of 1985. Other criteria included the surface type (in order to provide a broad variety of road surface types) and ease of access to the test section from our center of operations at the University of Washington.

The large number of test sections was selected to provide a large enough sample to provide the necessary statistical confidence level. In particular, it has been noted that there is significant variability in the surface characteristics of a particular type of road serface from one installation to another, and in some cases, variability has been observed in a single paving job in which the stretch of roadway is layed down by the same contractor.

In the initial proposal, it was thought that only a few sections of highway would be used, and that these sections would be studied intensively. The availability of a number of newly completed sections of pavement in District #1 allowed us to extend the study to a larger number of test sections, which it is thought would give a better distribution of data for the study. The roadway types selected represent most of the surface preparations currently used by WSDOT. These include the following surfaces,

- High density portland cement concrete.
- Latex modified portland cement concrete.
- Class "D" ACP Open Graded.
- Polyester Fiber ACP.
- Class "B" ACP.
- Rubber Mod ACP. (Plus ride asphalt)

Most of the sections south of Tacoma are on bridges, which offered little difference from several other sections nearer the center of operation and, consequently, were abandoned. Another section, the Renton "S"-curves, was abandoned because the surface, which is an asphalt overlayment started lifting, making that section unsatisfactory for our measurements. Additionally, we were unable to consistently maintain our test speed of 55 MPH in that area due to congestion during normal test times.

After the narrowing process, we are left with 41 test sections, which, are listed in Table I below. The lanes are identified by a number and a direction. Lanes are numbered from the left most lane outward to the shoulder; whereas, the directions are abreviations of North Bound, East Bound, etc. Aerial photographs of the test sections are given in Appendix A.

Test sections 1 and 2 are of particular interest, because they are sections of a roadway that have been laid down for a relatively long period of time and are virtually unused; therefore, they represent surfaces that should remain relatively constant during the test period. By comparing the data from these sections from run to run, we can obtain a measure of how consistent our measurements are. These sections will be referred to as our "Reference sections" in future.

The reference sections are located on a service road on King County International Airport (Boeing Field). They were chosen because they are lightly used and long enough for us to get our vehicle up to the required speed of 55 mph. It would have been preferable for the reference sections to be portland cement concrete sections, but it is not common to lay down roadway sections of PCC that will not be used heavily.

The test sections all lie in the Puget Sound Basin and are within a couple hundred feet of sea level and within a 40 mile radius of the University of Washington , with the exception of sections 38-41, which are located at or near the summet of Snoqualmie Pass at an elevation of 3,022 feet. With this exception all of the test sections are exposed to the same climatic conditions.

4.4 Experimental equipment design

As in many experiments, a goodly portion of the time spent during the initial phase of this project was spent in selecting, designing and manufacturing the hardware to be used in the data gathering phase. Substantial time was saved by purchasing a test trailer, rather than trying to design hardware to fit on a DOT vehicle because of the simple geometry of the test trailer.

Table I
Compilation of Test Roadway Sections
Giving the Location, Lane and Pavement Type

No.	S.R.	Description	Lane	Pavement
1.		King County Airport Reference Sec.	1 SB	Class "B" ACP
2.		King County Airport Reference Sec.	1 NB	Class "B" ACP
3.	I-5	Puyallup River to King Co. Line	2 SB	Class "D" ACP Open Graded
4.	I-5	Puyallup River to King Co. Line	1 NB	Class "D" ACP Open Graded
5.	I-5	East T St. Overcrossing	3 SB	Latex ModifiedPCCP
6.	I-5	S.R. 167 Overcrossing	3 SB	Latex Modified PCCP
7.	I-5	Portland Ave. Overcrossing	3 SB	Latex Modified PCCP
8.		West Seattle Bridge	1 WB	High Density PCCP
9.		West Seattle Bridge	2 WB	High Density PCCP
10.		West Seattle Bridge	1 EB	High Density PCCP
11.		West Seattle Bridge	2 EB	High Density PCCP
12.	I-5	Galer/Lakeview Viaduct	2 NB	Latex Modified PCCP
13.	I-5	Galer/Lakeview Viaduct	2 SB	Latex Modified PCCP
14.	I-5	Galer/Lakeview Viaduct	3 SB	Latex Modified PCCP
15.	I-5	Ship Canal Bridge	1 NB	Latex Modified PCCP
16.	I-5	Ship Canal Bridge	2 NB	Latex Modified PCCP
17.	I-5	Ship Canal Bridge	2 SB	Latex Modified PCCP
18.	I-5	Ship Canal Bridge	3 SB	Latex Modified PCCP
19.	I-5	Swamp Creek Interchange North	1 NB	Class "B" ACP
20.	I-5	Swamp Creek Interchange North	2 NB	Class "B" ACP
21.	I-5	Swamp Creek Interchange North	1 SB	Class "B" ACP
22.	I-5	Swamp Creek Interchange North	2 SB	Class "B" ACP
23.	I-5	Union Slough Bridge	1 NB	Latex Modified PCCP
24.	I-5	Union Slough Bridge	2 NB	Latex Modified PCCP
25.	I-5	Union Slough Bridge	1 SB	Latex Modified PCCP
26.	I-5	Union Slough Bridge	3 SB	Latex Modified PCCP
27.	I-5	Steamboat Slough Bridge	1 SB	Latex Modified PCCP
28.	I-5	Steamboat Slough Bridge	3 SB	Latex Modified PCCP
29.	I-5	Ebey Slough Bridge	1 SB	Latex Modified PCCP
30.	I-5	Ebey Slough Bridge	3 SB	Latex Modified PCCP
31.	530	Dahlgren Rd. to Skagit Co. Line	1 NB	Class "B" ACP
32.	530	Dahlgren Rd. to Skagit Co. Line	1 SB	Class "B" ACP
33.	530	Dahlgren Rd. to Skagit Co. Line	1 NB	Polyester Fiber ACP
34.	530	Dahlgren Rd. to Skagit Co. Line	1 SB	Polyester Fiber ACP
35.	530	Dahlgren Rd. to Skagit Co. Line	1 NB	Rubber Mod ACP
36.	530	Dahlgren Rd. to Skagit Co. Line	1 SB	Rubber Mod ACP
37.	I-405	Factoria I/C to Sunset I/C	HOV	Class "B" ACP
38.	I-90	Asahel Curtis I/C to Snow Shed	1 EB	High Density PCCP
39.	I-90	Asahel Curtis I/C to Snow Shed	2 EB	High Density PCCP
40.	I-90	West Snoqualmie Summit Interchange	3 EB	High Density PCCP
41.	I-90	West Snoqualmie Summit Interchange	4 EB	High Density PCCP

The most crucial item that had to be designed and fabricated was a mounting bracket for the test microphone. This device has to accurately hold the microphone close to the tire-pavement interface.

It was decided to position the microphone 20 cm from the edge of the tire on a 45° angle from the road surface and in the vertical plane containing the axle. The microphone, a Brüel & Kjær Model 4134 is fitted with an nose cone and a wind screen to minimize aerodynamic noise. This particular location was chosen because it is close enough so that the predominant noises at that location are the noises from the tire and from the tire/road interface. Located this close to the tire/road interface reduces the effect of interfering noises from other adjacent noise sources. This location has been shown to be close enough to the source of interest to prevent interference from most vehicles in adjacent lanes.

The microphone is located in the wind stream around the tire near the road surface. As such, it is exposed to the noise generated at the tire/road interface and to aerodynamic wind noise. To minimize the latter, a Brüel & Kjær Model UA 0386 nose cone and a model UA 0237 wind screen were used. Brock[6] tested the nose cone in an anechoic chamber on a rotating boom at speeds above and below the speeds at which our tests were run. His results show that the wind induced noise with this configuration were 10 dB or more below the noises measured by us in these tests, indication that this is not a factor in the noise data reported here. The noise data channel was monitored during the tests by earphone to assure that the data was tire noise, and to avoid the presenting data from extremely loud vehicles passing near the microphone.

The original design for the microphone bracket consisted of a tubular aluminum bracket welded to a mounting plate that attached to the spring shackle on the left wheel of the 4' x 6' utility trailer. In order to provide maximum rigidity, the bracket was designed to pass behind the wheel the shortest way. This resulted in the bracket passing very close to the road surface. The bracket functioned well during the first series of road tests; however, during the second test series, the new test van and trailer encountered a tilted slab of concrete roadway, which tossed the van up and the trailer down against the discontinuous roadway destroying the microphone bracket and microphone.

A new bracket was designed to provide more clearance, and at the same time provide adequate stiffness. The new bracket has been in use since the accident with no further difficulty. A diagram showing the schematic location of the microphone relative to the trailer tire is shown in Figure 2.

4.5 Data acquisition

Before attacking such a long term project as this, it is important to asses the method in which the data will be acquired and cataloged. For the purposes of this project, the data is collected on magnetic tape, which is labeled and saved for future reference. After each biannual data gathering session, the data is reduced to 1/3 octave band data using a Hewlett-Packard Model 3561A Dynamic Signal Analyzer and an H-P 236 computer, on which the data is stored on magnetic disk media. Duplicate data is maintained to insure that the data available for future reference.

A significant portion of the effort reported in this report was devoted to the design of the computer program used to acquire the data from the data runs and record it on disk files. Each run on each surface is recorded in graphical form in the figures presented in Appendix A.

The data is presented in 1/3 octave format to show the frequency distribution of the near field noise from the tire/road interface. This information is summarized by an A-weighted noise level, shown both graphically and numerically at the right hand side of the graph.

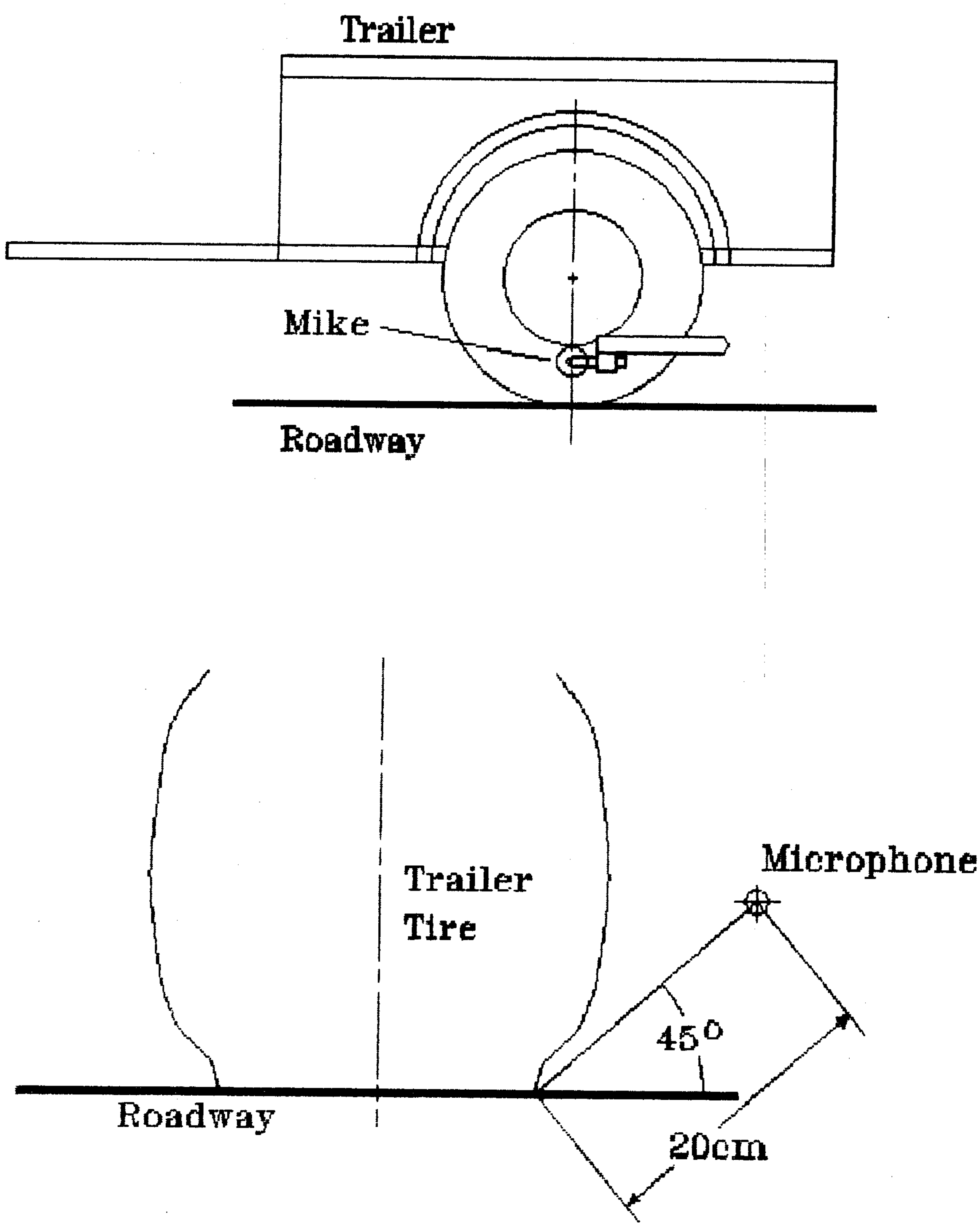

Figure 2 Schematic drawing of the microphone location relative to the tire on the test trailer.

4.6 Initial data collection

The ultimate goal of this project is to study the way in which the acoustical characteristics of tire/road noises change with the wear and aging of the road surface. The research on this project will take place over a period of several years in order to obtain the desired data on the effects of wear of road surfaces on noise generation. The paving projects we are studying were completed shortly before the beginning of Phase I. Over fifty new sections of pavement that had been laid down in the immediate past were identified as potential test sections in the first selection process. Further screening has reduced the total number to approximately forty-one sections of roadway that will be tracked during the life of these sections in WSDOT District #1, in western Washington state.

Work during the first year was very heavy, being devoted to designing, fabricating, and installing the test instrumentation on a test vehicle, collecting of initial data on the test surfaces, and performing the search of the literature, nevertheless, data was gathered in four sessions spaced approximately semi-annually over the two-year period. These data have been compiled in Appendix A at the end of this report. Detailed analysis of this data awaits the completion, or at least the continuation, of this research project.

5.0 RESULTS:

A summary of the data is presented in Figures 3 through 9 in which the A-weighted noise levels recorded for the numerous test sections is presented in comparitive form. The data is presented as follows: The reference surface data is presented in Figure 3, which is followed by the data from the following types of surfaces, respectively.

- High density portland cement concrete.
- Latex modified portland cement concrete.
- Class "D" ACP Open Graded.
- Polyester Fiber ACP.
- Class "B" ACP.
- Rubber Mod ACP. (Plus ride asphalt)

All the data for each type of surface is plotted on the same graph, regardless of the location of the test section, source of construction materials, paving contractor, or other factors which might affect the acoustical characteristics of the section. There are some outlying points, but on the whole, the data is quite consistent.

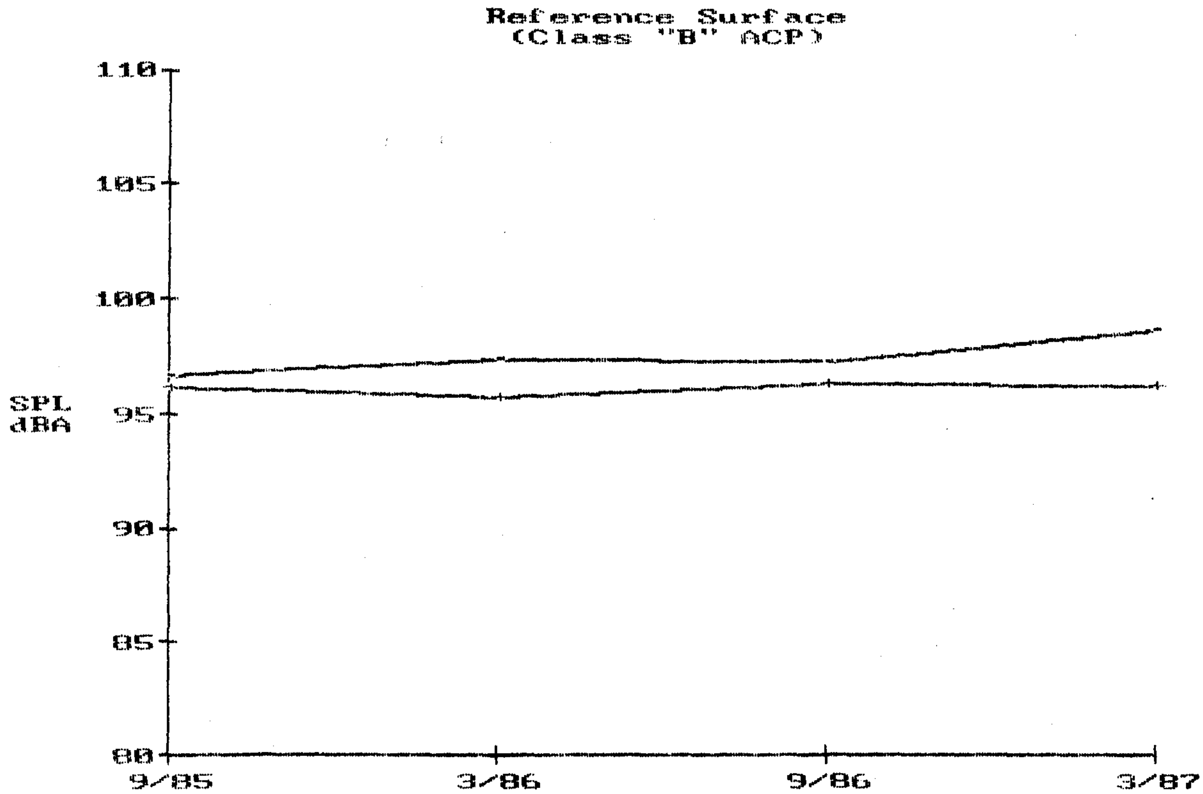

Figure 3 A-weighted SPL's for the Boeing Field Reference Sections measured over the two-year period of this study.

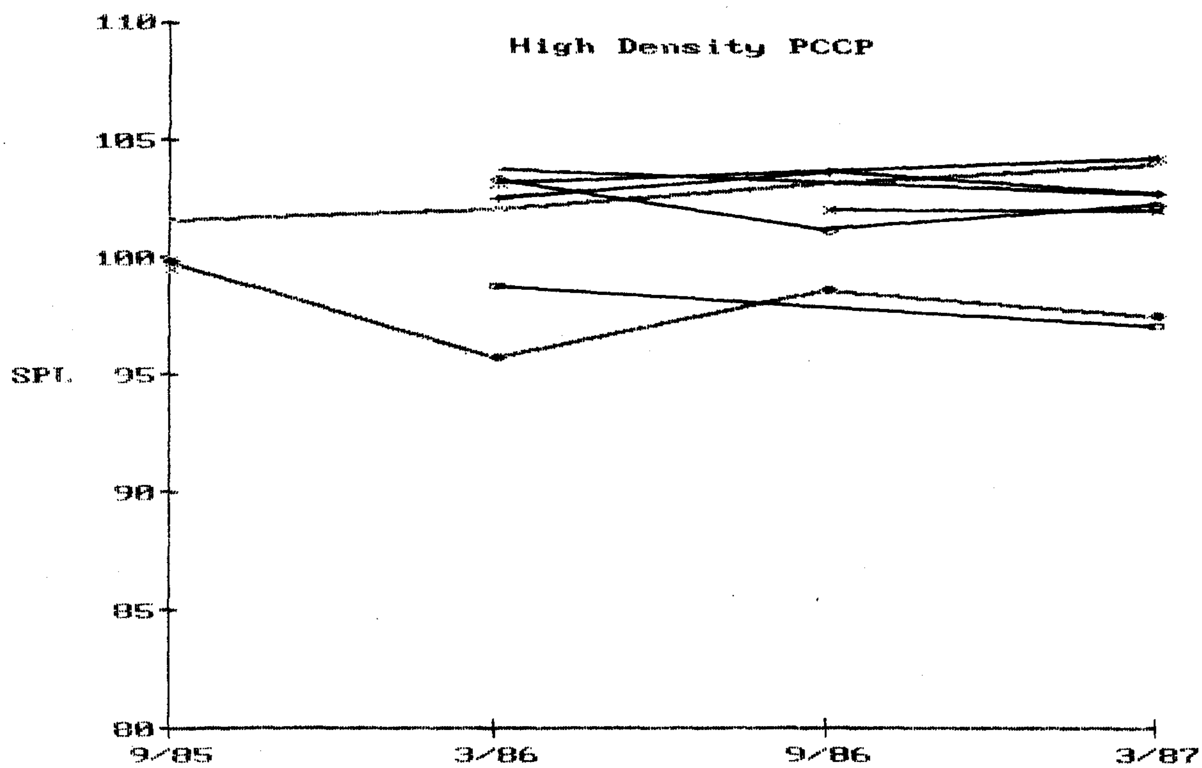

Figure 4 A-weighted SPL's for the high density PCCP sections measured over the two-year period of this study.

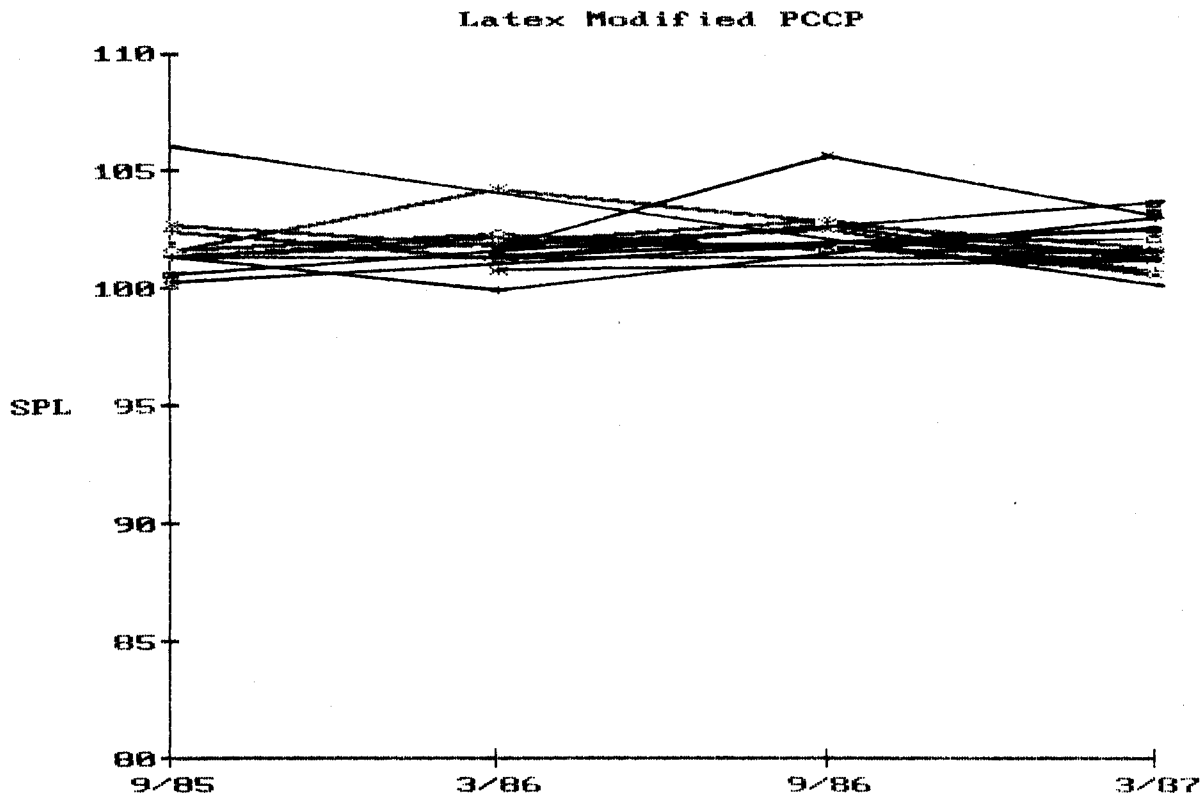

Figure 5 A-weighted SPL's for the latex modified PCCP sections measured over the two-year period of this study.

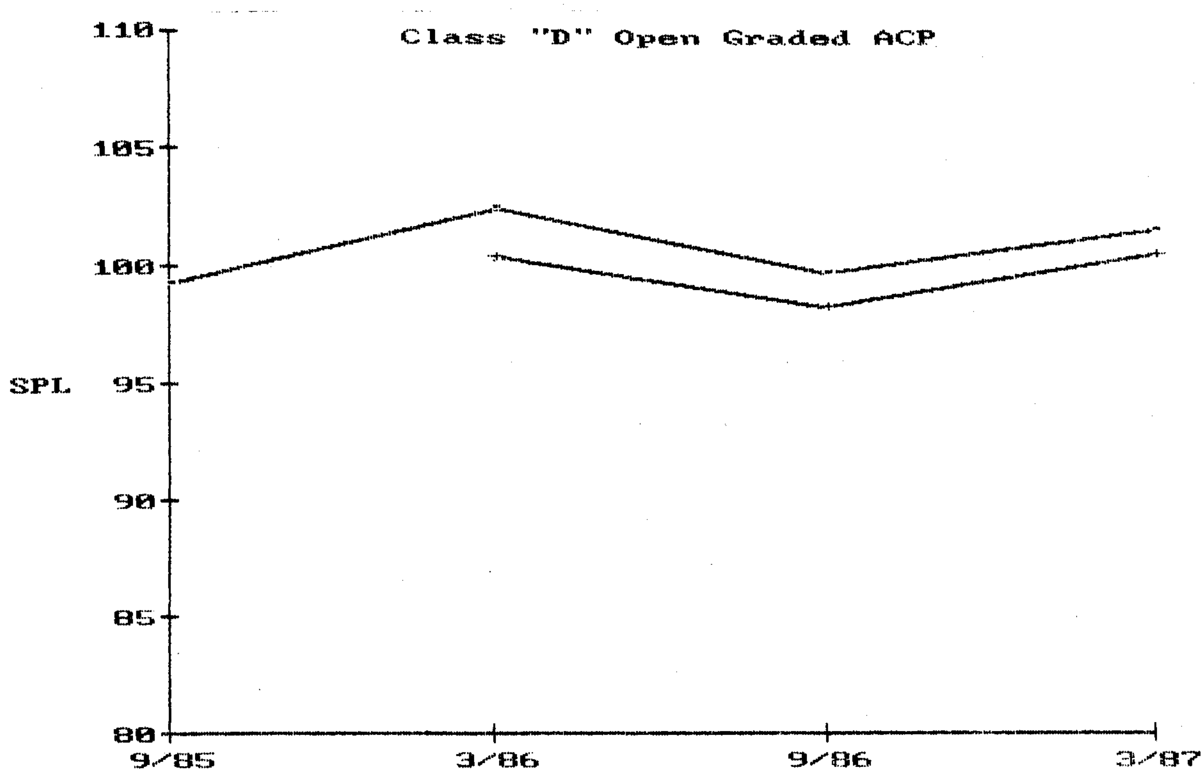

Figure 6 A-weighted SPL's for the Class "D" open graded ACP sections measured over the two-year period of this study.

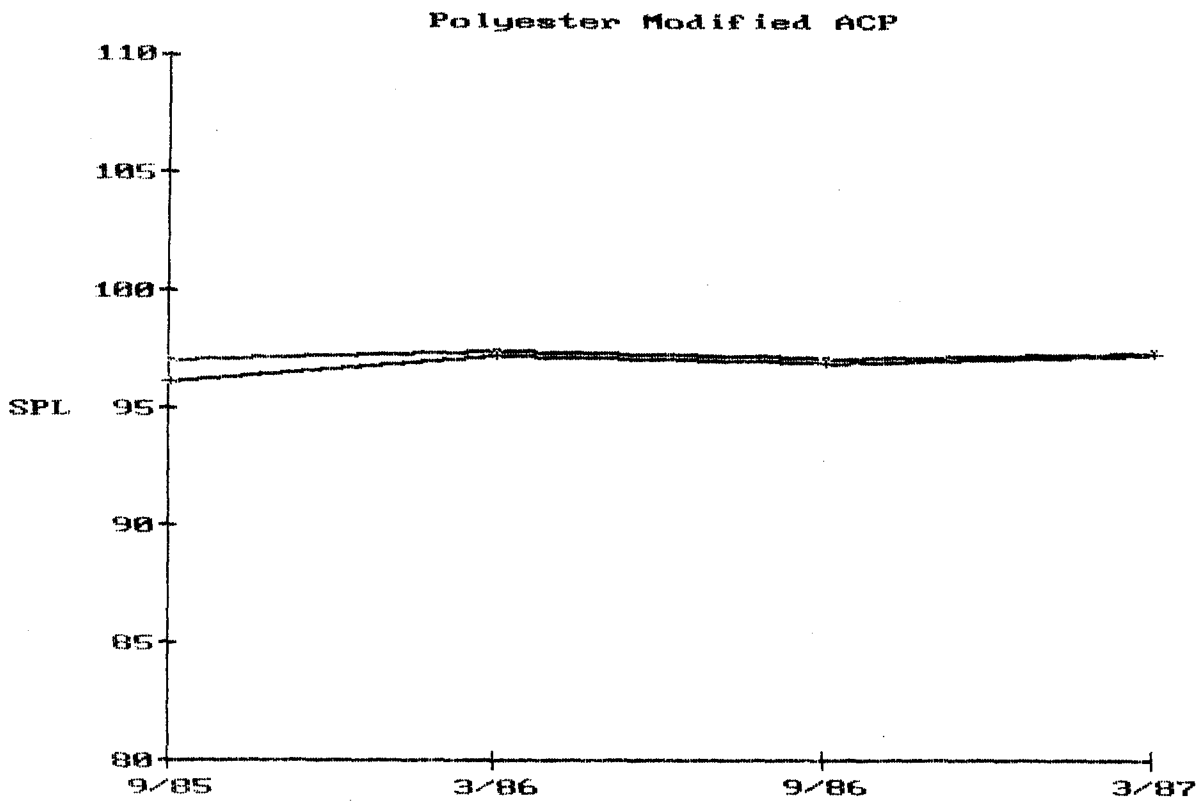

Figure 7 A-weighted SPL's for the polyester modified ACP sections measured over the two-year period of this study.

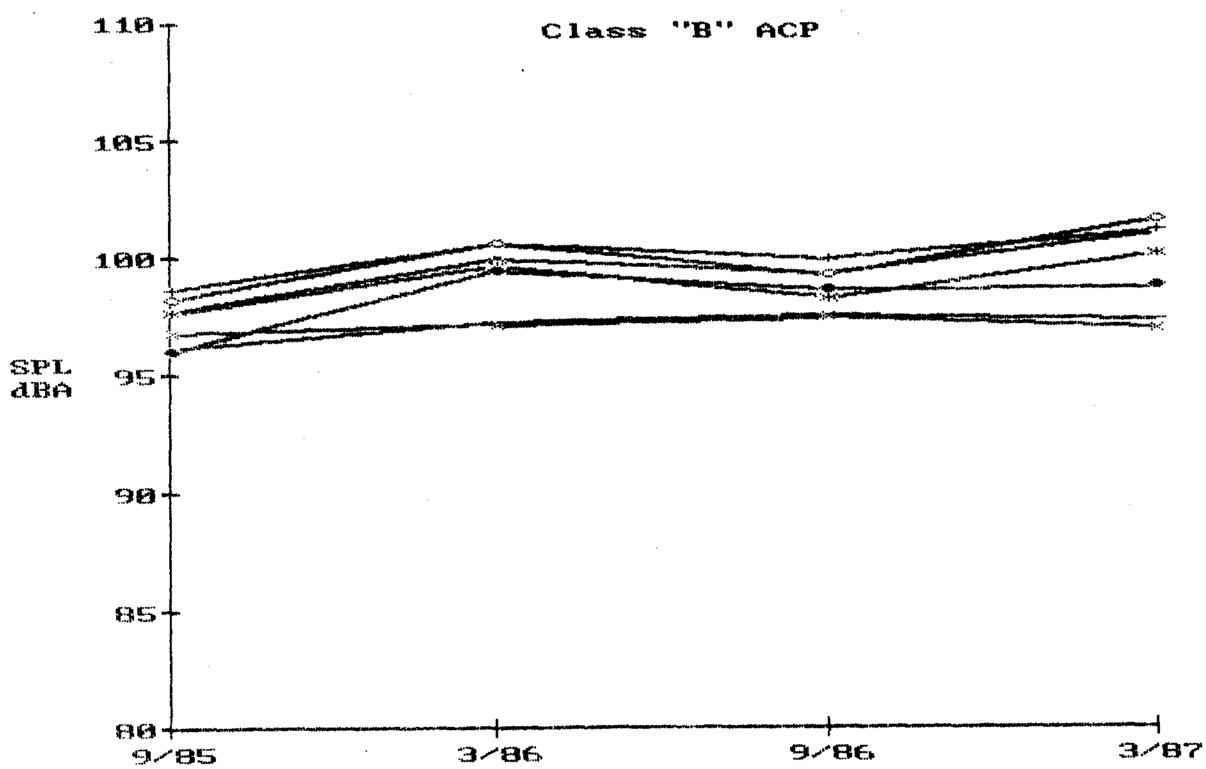

Figure 8 A-weighted SPL's for the Class "B" ACP sections measured over the two-year period of this study.

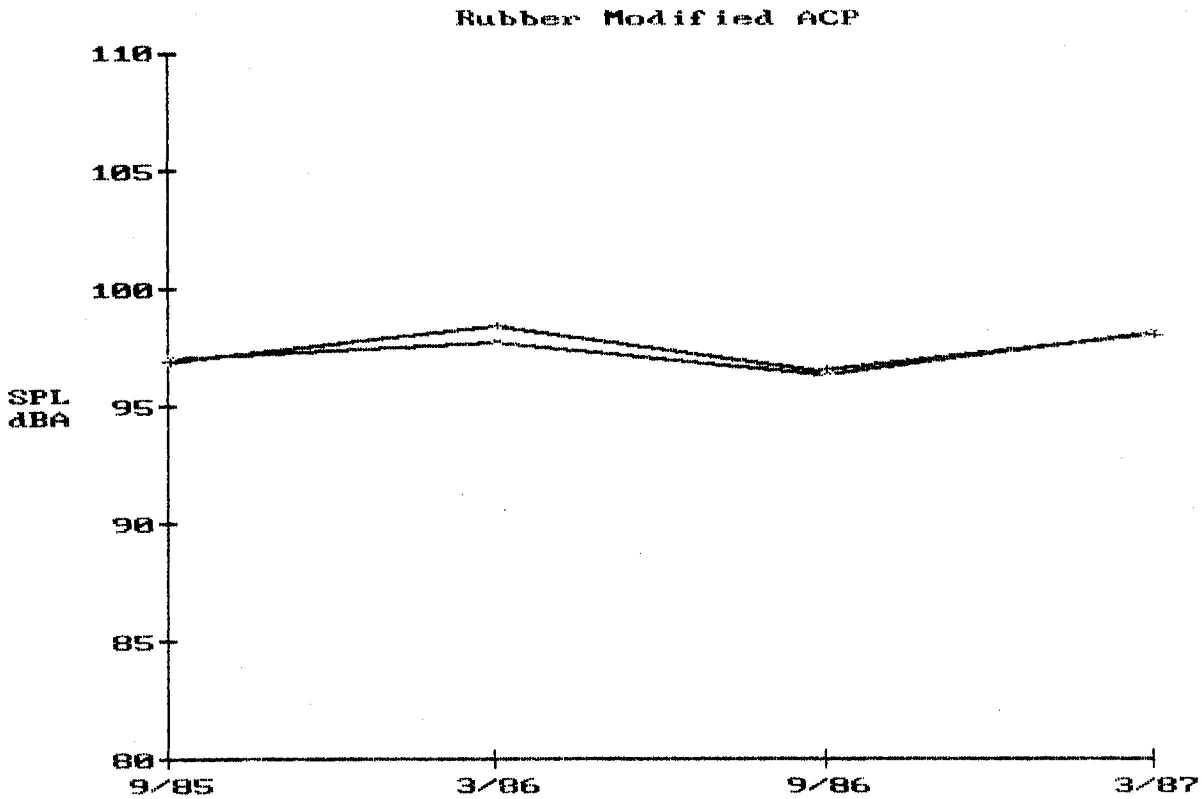

Figure 9 A-weighted SPL's for the rubber modified ACP sections measured over the two-year period of this study.

6.0 DISCUSSION:

Although this is only a pilot study several observations can be made on the basis of the data in hand. First, it is obvious that asphalt concrete pavement is quieter than portland cement concrete pavement in the initial phases of life span of these surfaces. Secondly, it is possible to observe trends in the early stages of the roadway noise development. The asphalt pavements show a definite tendency to increase in A-weighted Sound Pressure Level with age over the short period observed here; whereas, noise levels for the portland cement concrete (modified or not) seem to remain relatively constant over this same period.

These observations are consistent with our common understanding of how these surfaces age and wear. The portland cement surfaces are more durable and have a longer expected lifetime; whereas, the asphaltic surfaces wear more rapidly exposing the coarse agregate more rapidly. The portland cement surfaces wear more slowly, and so the coarse agregate is not not yet exposed. On the other hand, the traction enhansing brush marks that were scribed into the surface have not worn as quickly as had been expected, and so the contribution of these marks to the noise has kept the noise level of this type of pavement higher than expected.

7.0 CONCLUSIONS:

While this research project is only beginning, it is obvious that the project is proceeding at a steady pace and we have every right to expect that data not previously available in the literature will result from this study. The methodology for the study has been firmly defined and an excellent sample base for statistical analysis of the problem has been established.

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APPENDIX A

Aerial Views of Test Sections

Table A.1

Information About Sites in Photographs

Figure No.	Site No.	Descriptions	Lane No.	Construction Completion Date	Pavement Surface Type
1	1	Calibration Site - King County Airport (Reference Section)	SB	6 - 85	Class "B" ACP
	2	Calibration Site - King County Airport (Reference Section)	NB	6 - 85	Class "B" ACP
2	3	I-5: Puyallup R. Bridge to King Co. Line	2SB	6 - 85	Class "D" ACP Open Graded
	4	I-5: Puyallup R. Bridge to King Co. Line	1NB	6 - 85	Class "D" ACP Open Graded
3	5	I-5: Portland Ave., SR 167, E. "T" St. Overcrossings	3SB	1985	Latex Modified PCCP
	6	I-5: Portland Ave., SR 167, E. "T" St. Overcrossings	3SB	1985	Latex Modified PCCP
	7	I-5: Portland Ave., SR 167, E. "T" St. Overcrossings	3SB	1985	Latex Modified PCCP
4	8	West Seattle Bridge	1WB	11 - 83	High Density PCCP
	9	West Seattle Bridge	2WB	11 - 83	High Density PCCP
	10	West Seattle Bridge	1EB	7 - 84	High Density PCCP
	11	West Seattle Bridge	2EB	7 - 84	High Density PCCP
5	12	I-5: Galer - Lakeview Viaduct	2NB	1984	Latex Modified PCCP
	13	I-5: Galer - Lakeview Viaduct	2SB	1985	Latex Modified PCCP
	14	I-5: Galer - Lakeview Viaduct	3SB	1985	Latex Modified PCCP
6	15	I-5: Ship Canal Bridge	1NB	1984	Latex Modified PCCP
	16	I-5: Ship Canal Bridge	2NB	1984	Latex Modified PCCP
	17	I-5: Ship Canal Bridge	2SB	1985	Latex Modified PCCP
	18	I-5: Ship Canal Bridge	3SB	1985	Latex Modified PCCP

Table A.1, continued

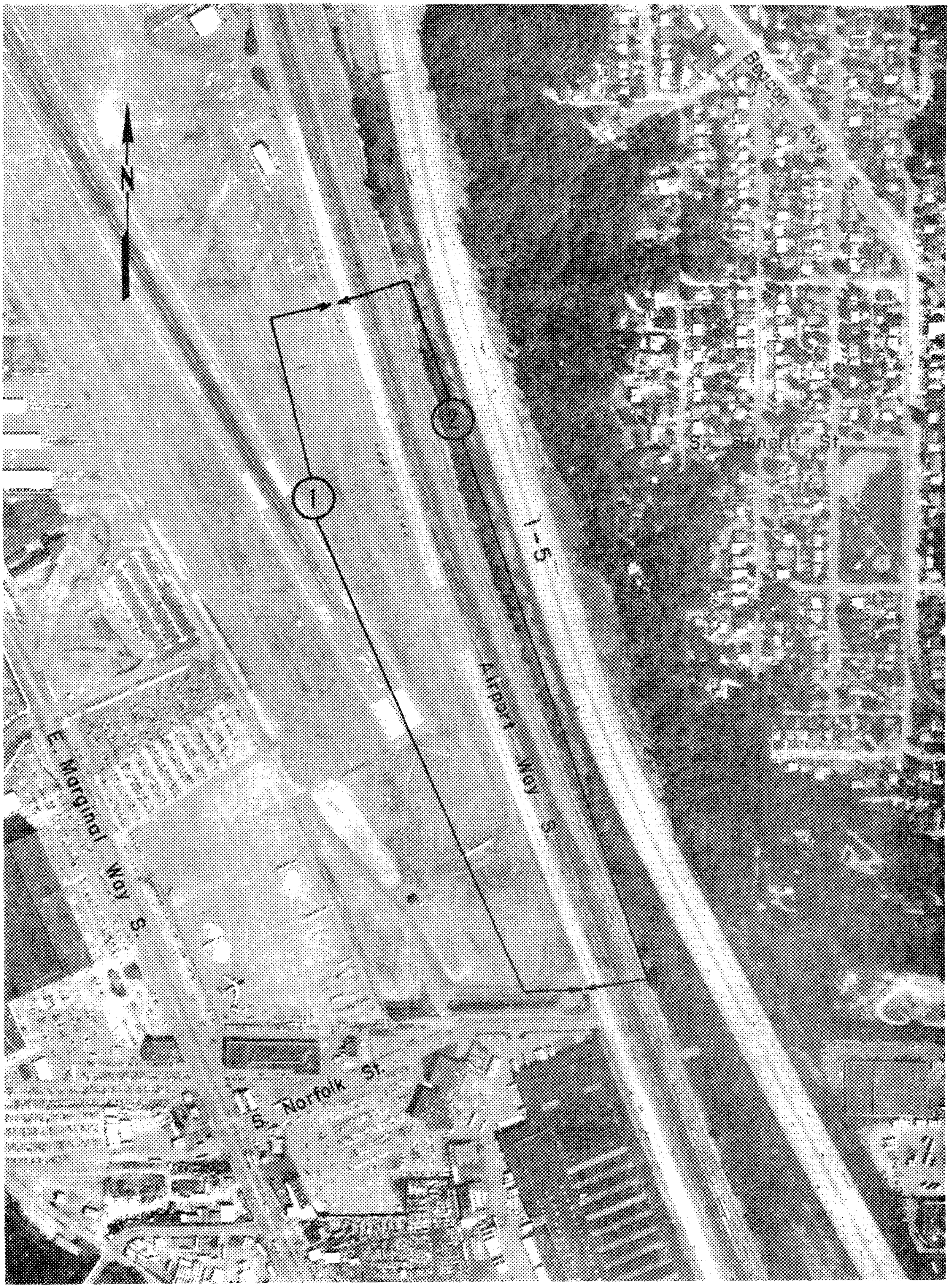
Information About Sites in Photographs

Figure No.	Site No.	Descriptions	Lane No.	Construction Completion Date	Pavement Surface Type
7	19	I-5: Swamp Creek Interchange North	1NB	6 - 86	Class "B" ACP
	20	I-5: Swamp Creek Interchange North	2NB	6 - 86	Class "B" ACP
	21	I-5: Swamp Creek Interchange North	1SB	6 - 86	Class "B" ACP
	22	I-5: Swamp Creek Interchange North	2SB	6 - 86	Class "B" ACP
8	23	I-5: Union, Steamboat, Ebey Sloughs	1NB	9 - 85	Latex Modified PCCP
	24	I-5: Union, Steamboat, Ebey Sloughs	2NB	9 - 85	Latex Modified PCCP
	25	I-5: Union, Steamboat, Ebey Sloughs	1SB	9 - 85	Latex Modified PCCP
	26	I-5: Union, Steamboat, Ebey Sloughs	3SB	9 - 85	Latex Modified PCCP
	27	I-5: Union, Steamboat, Ebey Sloughs	1SB	9 - 85	Latex Modified PCCP
	28	I-5: Union, Steamboat, Ebey Sloughs	3SB	9 - 85	Latex Modified PCCP
	29	I-5: Union, Steamboat, Ebey Sloughs	1SB	9 - 85	Latex Modified PCCP
	30	I-5: Union, Steamboat, Ebey Sloughs	3SB	9 - 85	Latex Modified PCCP
9	31	SR 530: Skagit Co. Line to Dahlgren Rd.	1NB	1985	Class "B" ACP
	32	SR 530: Skagit Co. Line to Dahlgren Rd.	1SB	1985	Class "B" ACP
	33	SR 530: Skagit Co. Line to Dahlgren Rd.	1NB	1985	Polyester Fiber ACP
	34	SR 530: Skagit Co. Line to Dahlgren Rd.	1SB	1985	Polyester Fiber ACP
	35	SR 530: Skagit Co. Line to Dahlgren Rd.	1NB	1985	Rubber Mod. ACP (PlusRide)
	36	SR 530: Skagit Co. Line to Dahlgren Rd.	1SB	1985	Rubber Mod. ACP (PlusRide)

Table A.1, continued

Information About Sites in Photographs

Figure No.	Site No.	Descriptions	Lane No.	Construction Completion Date	Pavement Surface Type
10	37	I-405: Factoria I/C to Sunset I/C HOV	HOV	9 - 85	Class "B" ACP
11, 12	38	I-90: Asahel Curtis I/C to Snowshed	1EB	1986	PCCP
	39	I-90: Asahel Curtis I/C to Snowshed	2EB	1986	PCCP
13, 14	40	I-90: West Summit Interchange	3EB	1986	PCCP
	41	I-90: East Summit Interchange	4EB	1986	PCCP



Location: Calibration Site — King County Airport

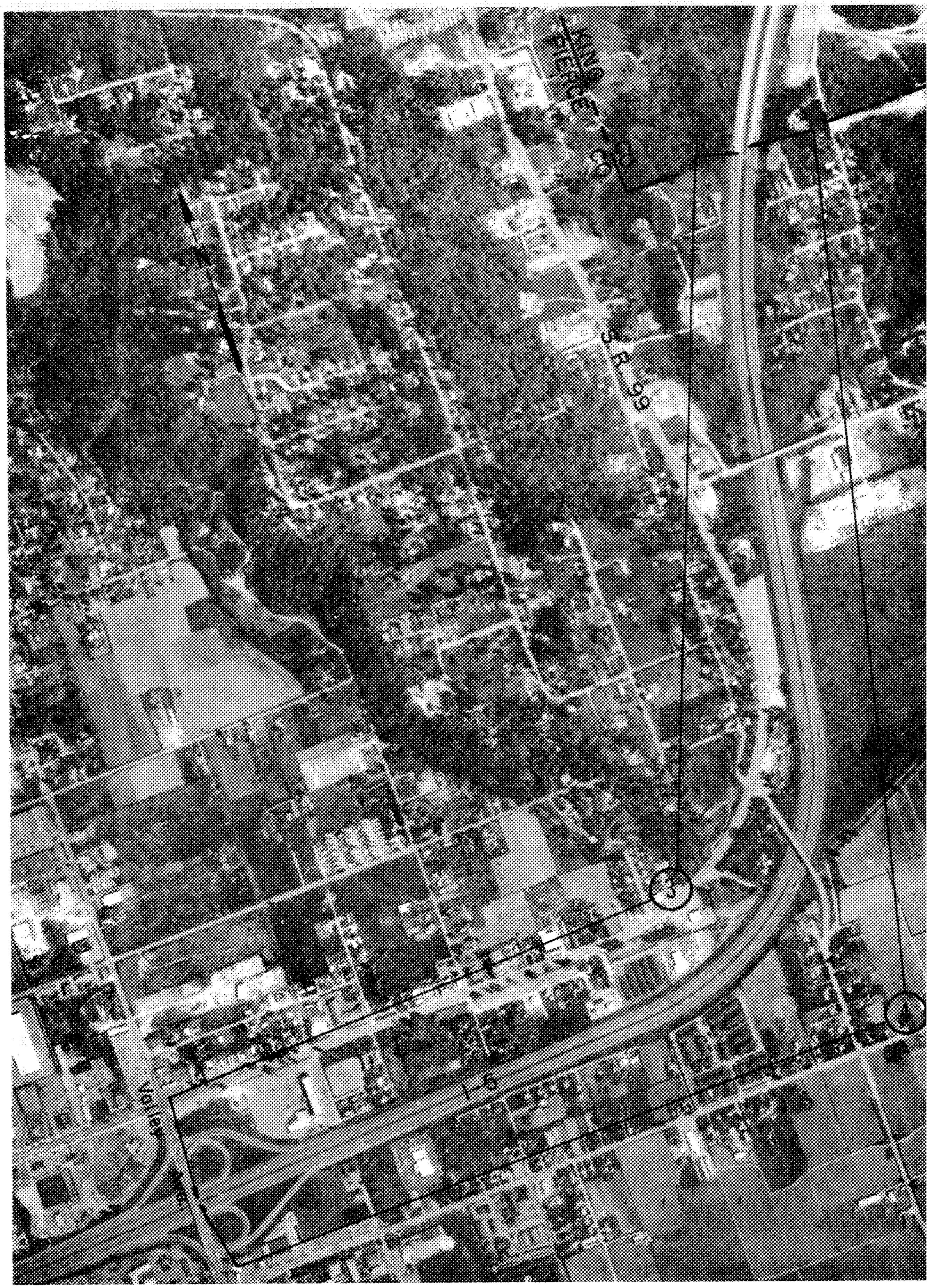
Figure 1

County: King

M.P. None

Scale: 1″ = 500′

Date of Photography: 8-14-85



Location: I-5: Puyallup R. Bridge to King Co. Line

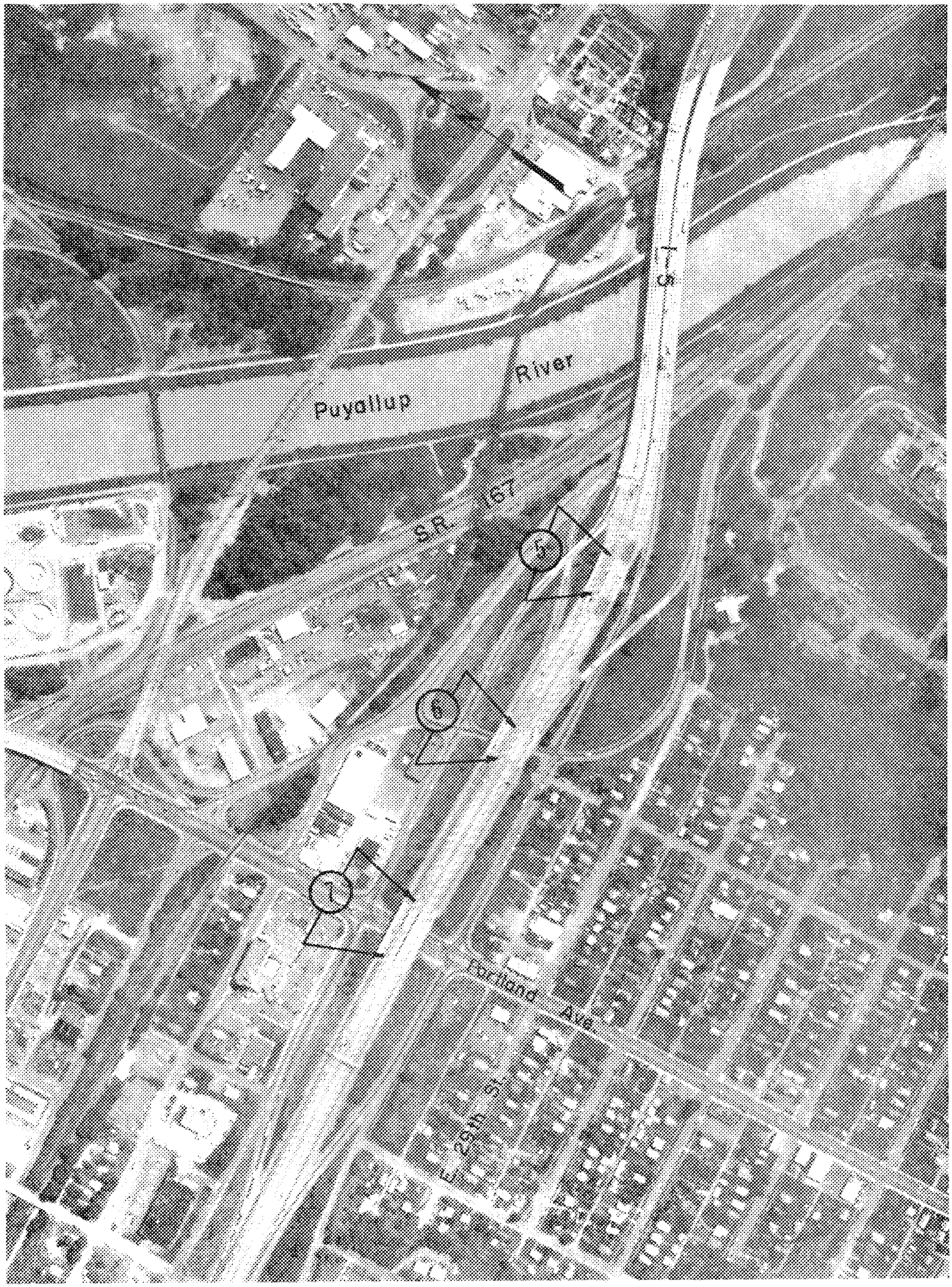
Figure

County: Pierce

M.P. 135.53 to 139.50

Scale: 1″ = 1000′

Date of Photography: 4-27-87



Location: I-5: Portland Ave., SR 167, E.T St. Overcrossings

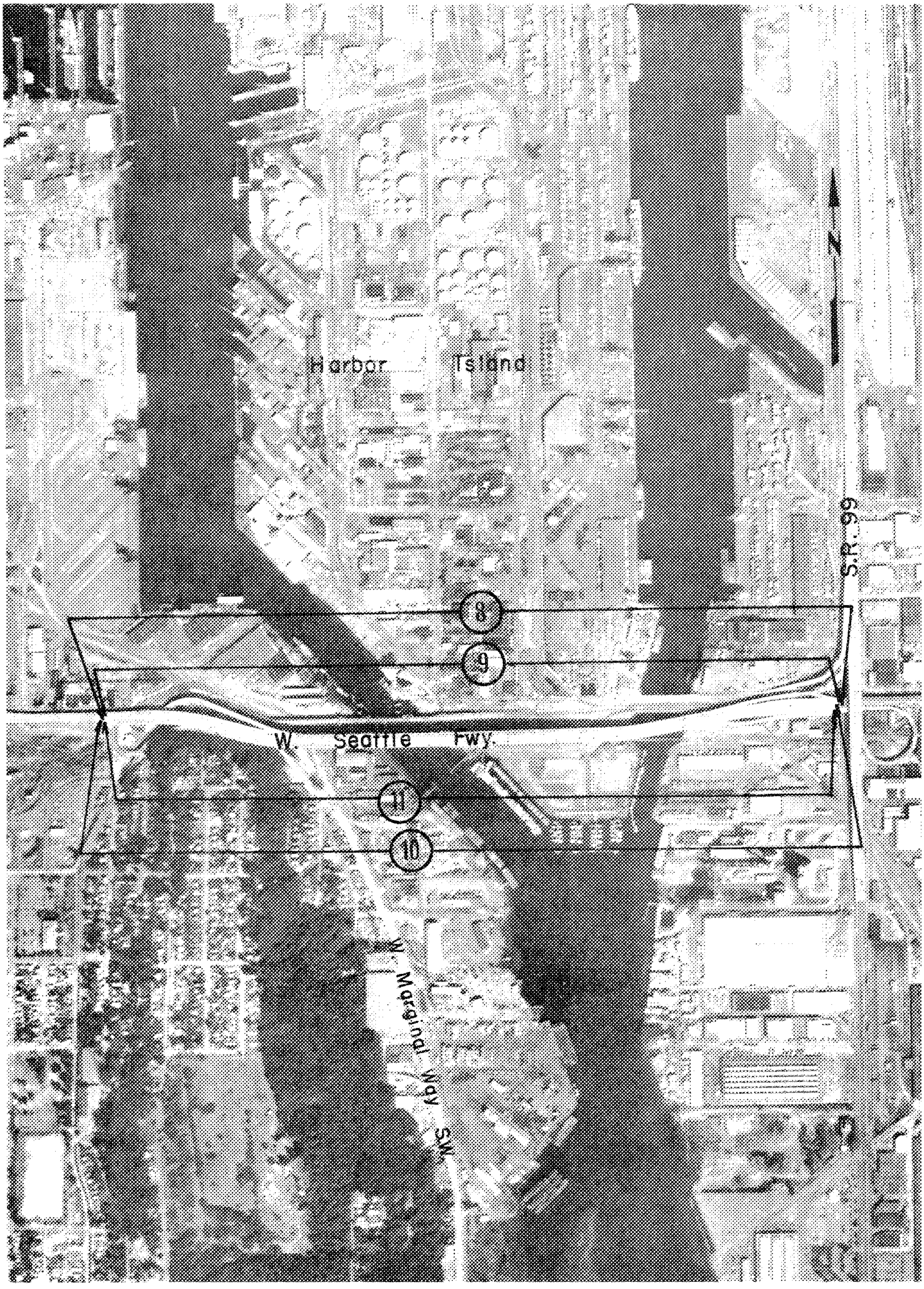
Figure 3

County: Pierce

M.P. 134.85 to 135.22

Scale: 1″ = 500′

Date of Photography: 6-17-87



Location: West Seattle Bridge

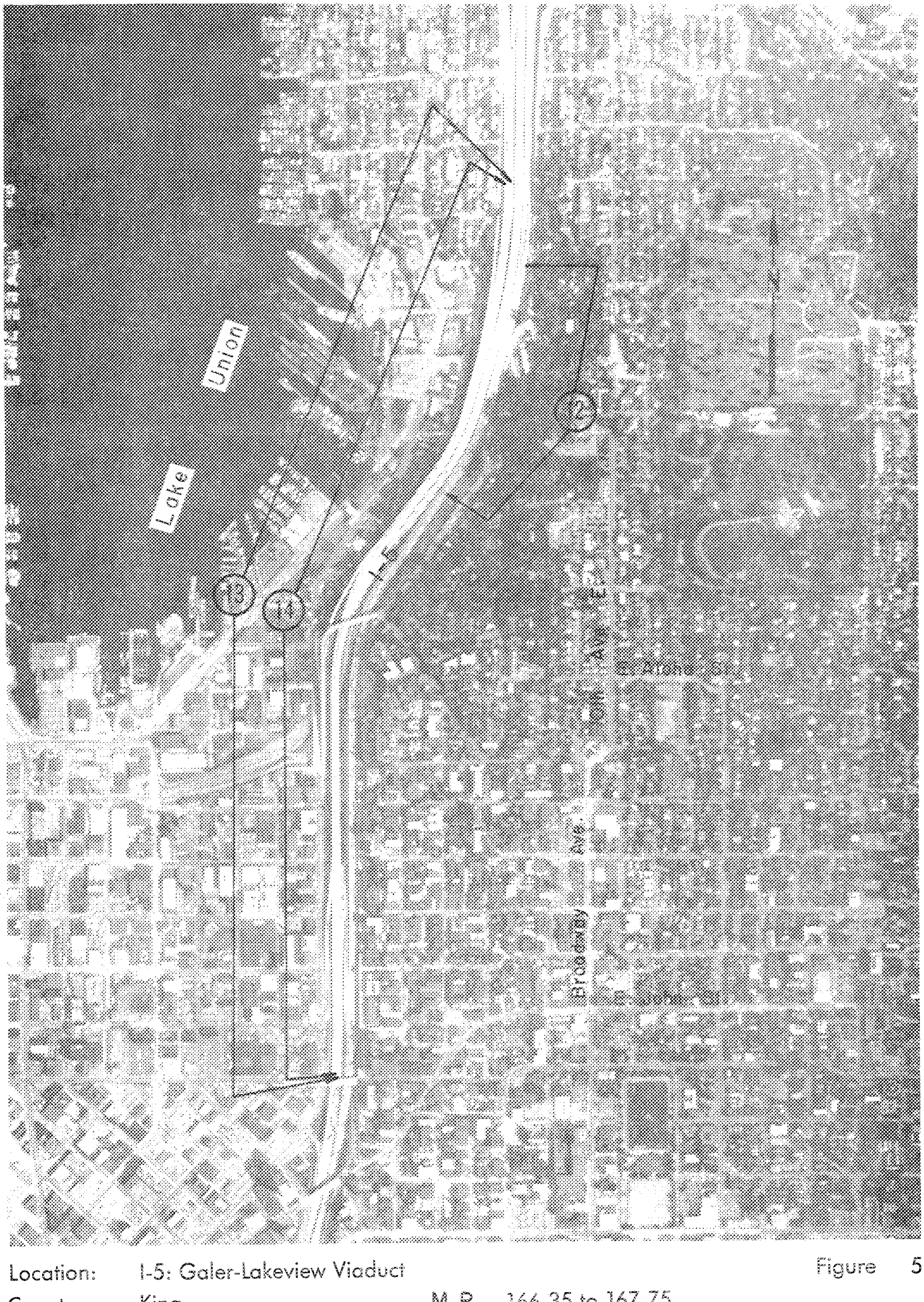
Figure

County: King

M.P. None

Scale: 1″ = 1000′

Date of Photography: 8-14-85



Location: I-5: Galer-Lakeview Viaduct

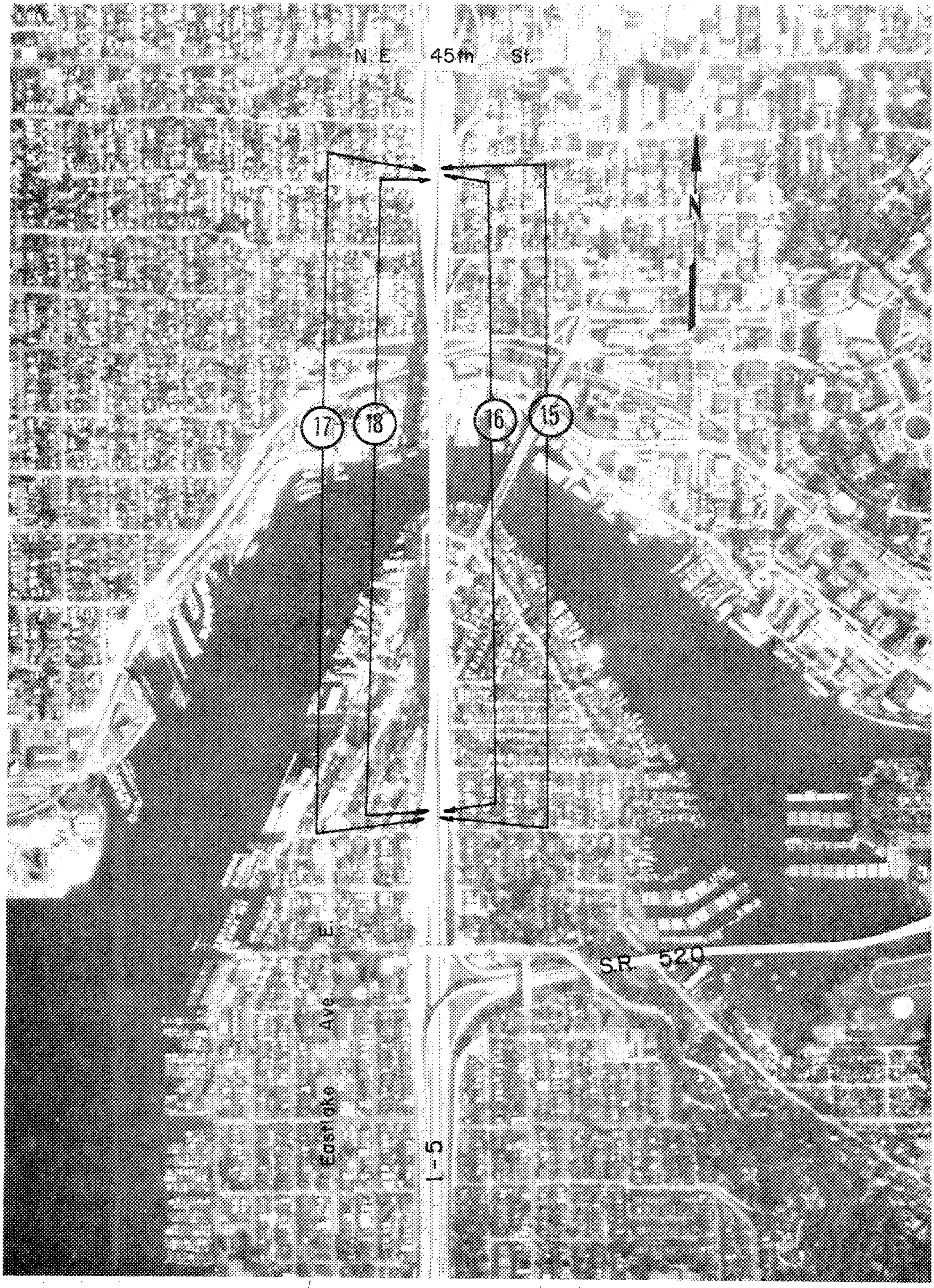
County: King

Scale: 1″ = 1000′

Figure 5

M.P. 166.35 to 167.75

Date of Photography: 8-14-85



Location: I-5: Ship Canal Bridge

County: King

Scale: 1″ = 1000′

Figure

M.P. 168.06 to 169.20

Date of Photography: 8-14-85

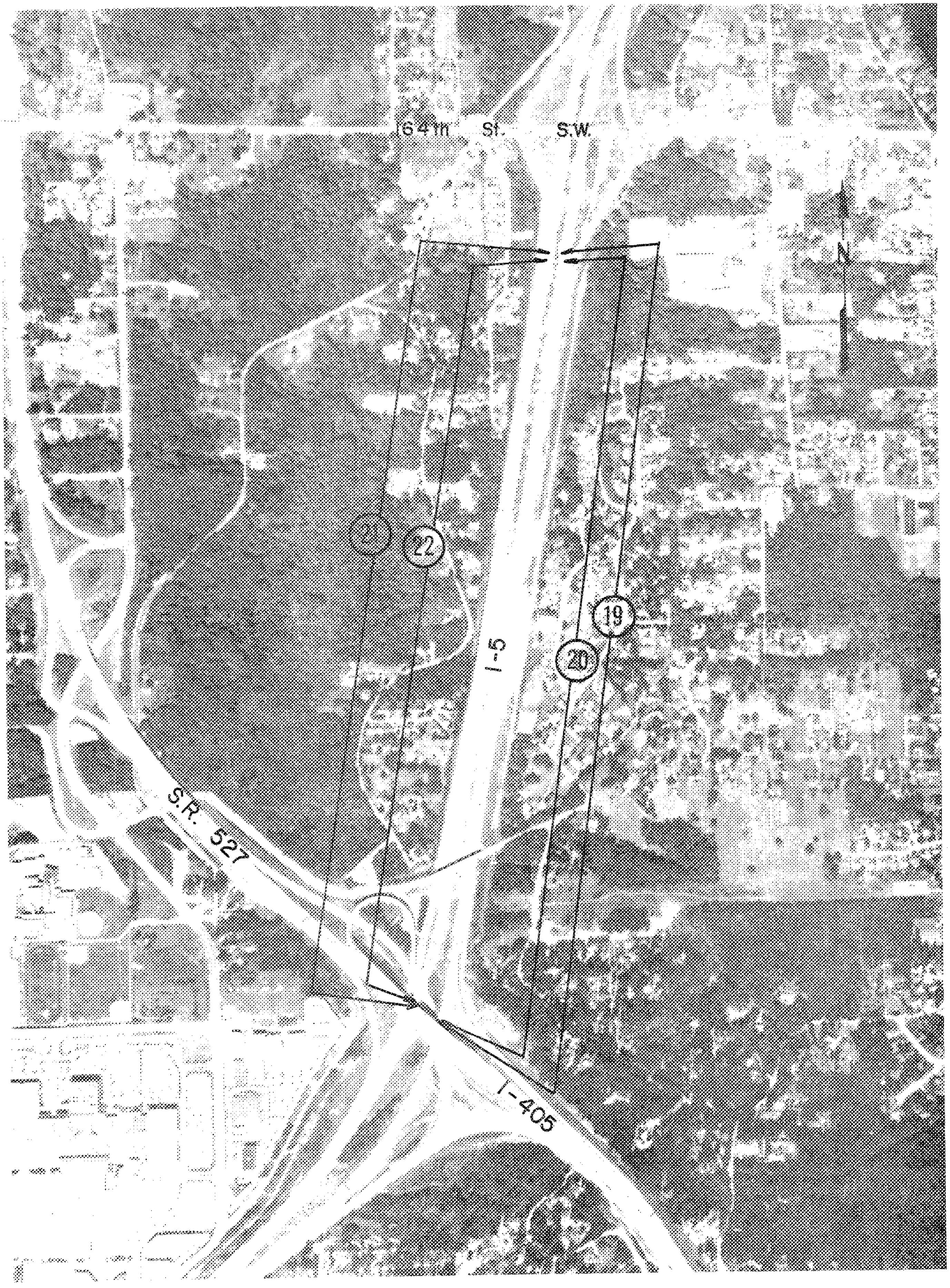


Figure 7

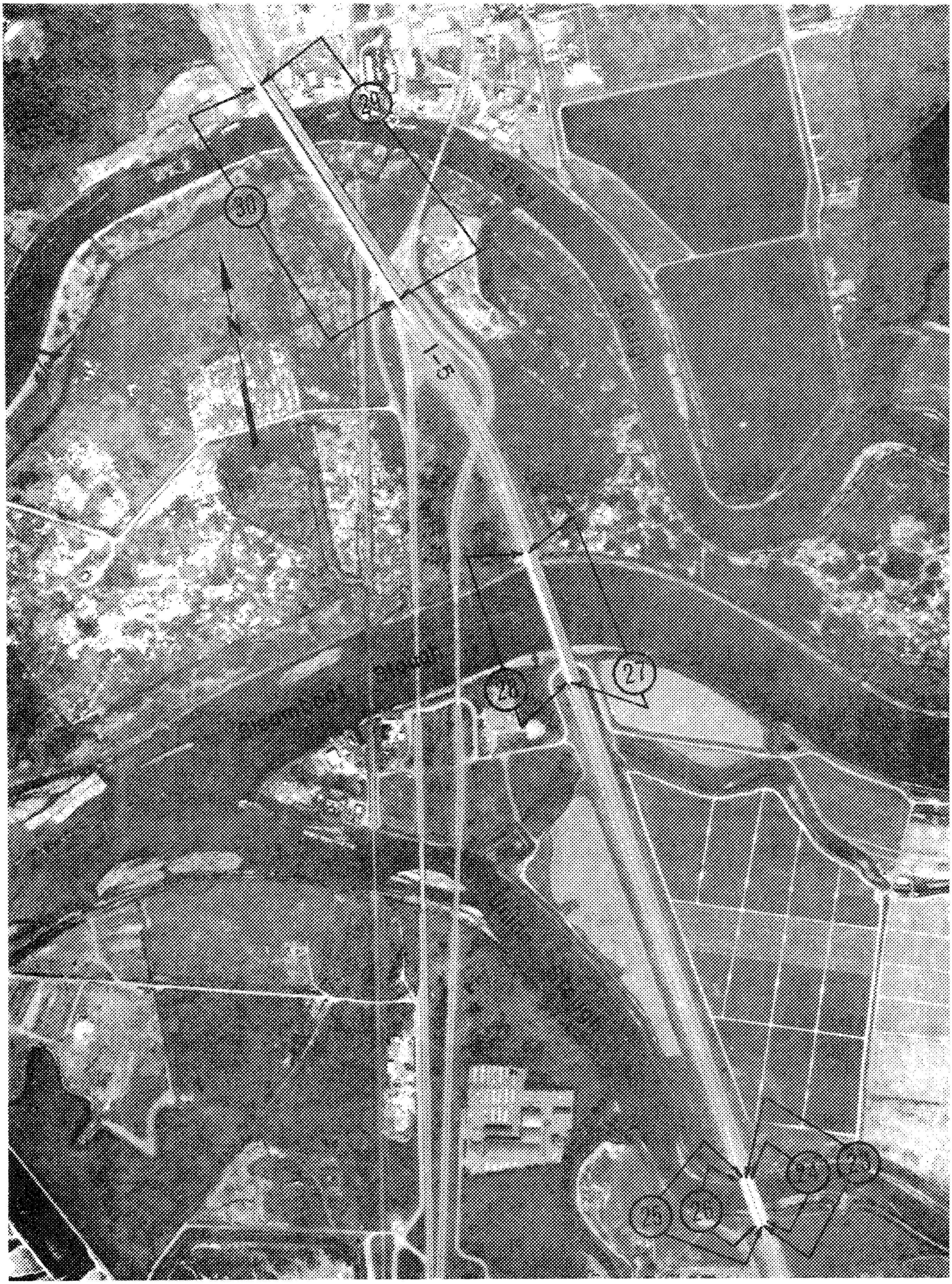
Location: I-5: Swamp Creek Interchange North

County: Snohomish

M.P. 181.51 to 183.96

Scale: 1″ = 1000′

Date of Photography: 8-14-85



Location: I-5: Union, Steamboat, Ebey Sloughs

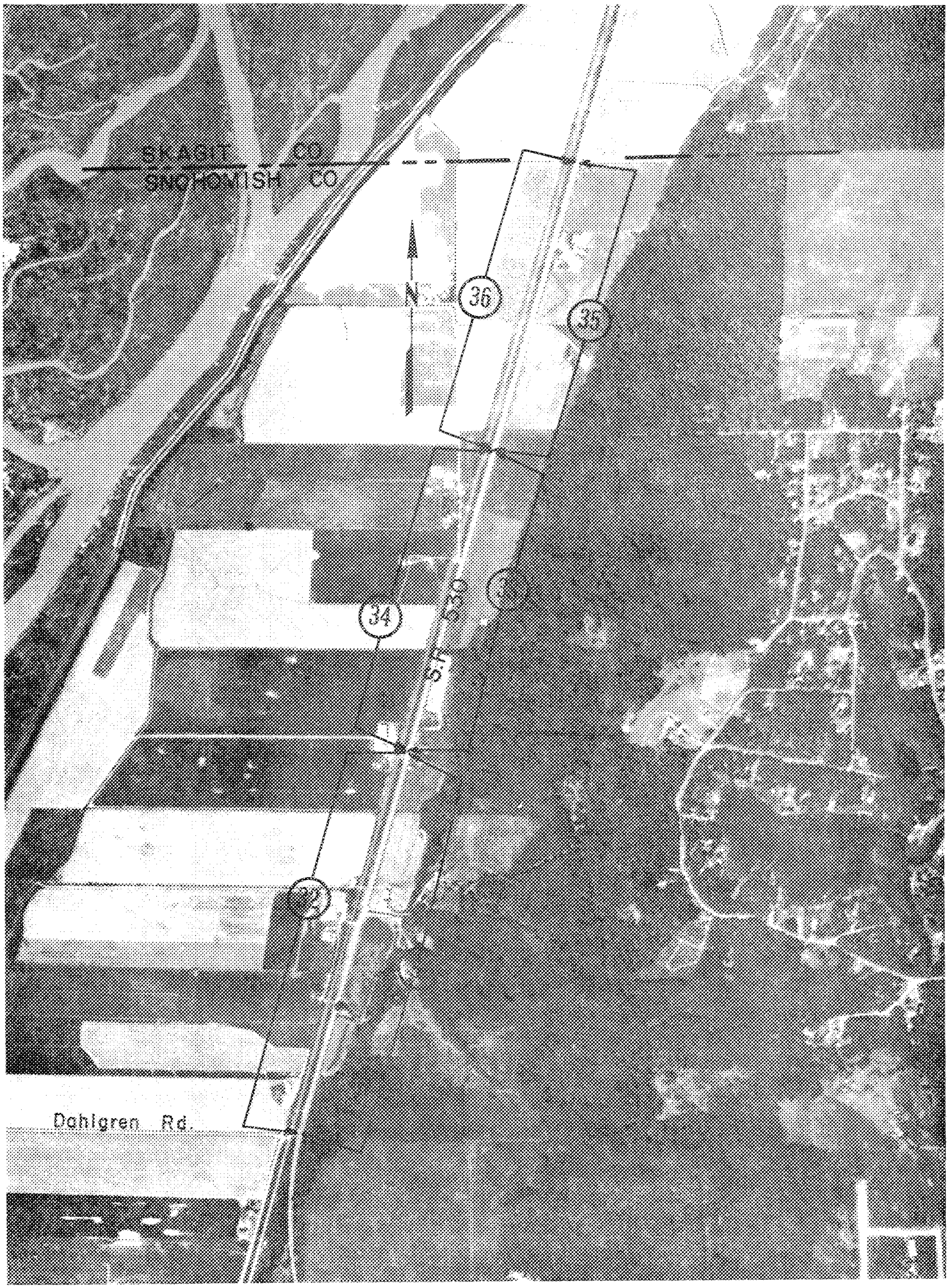
Figure 8

County: Snohomish

M.P. 197.08 to 198.90

Scale: 1″ = 1000′

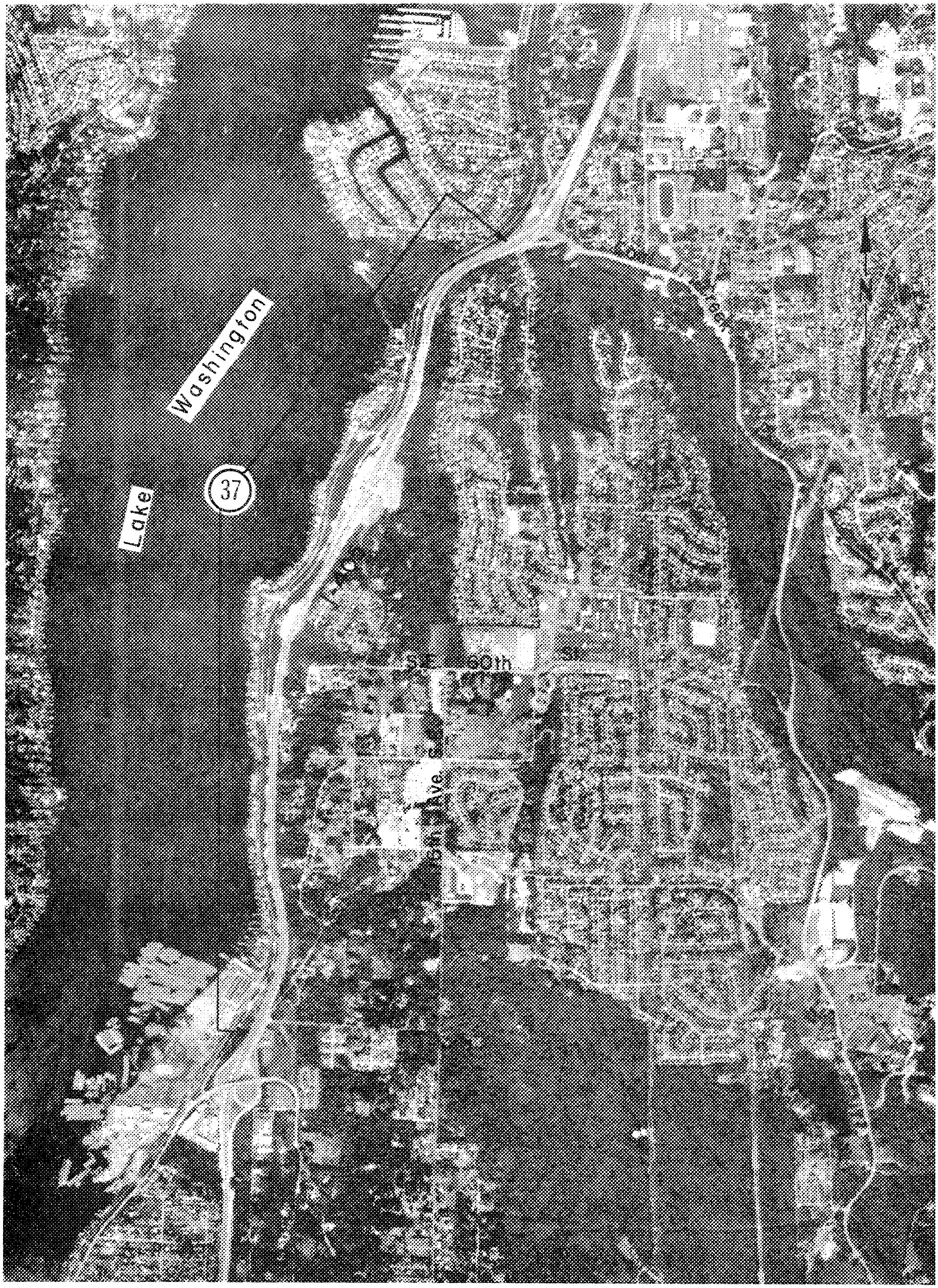
Date of Photography: 8-14-85



Location: SR 530: Skagit Co. Line to Dahlgren Rd. Figure 9

County: Snohomish M.P. 3.37 to 5.10

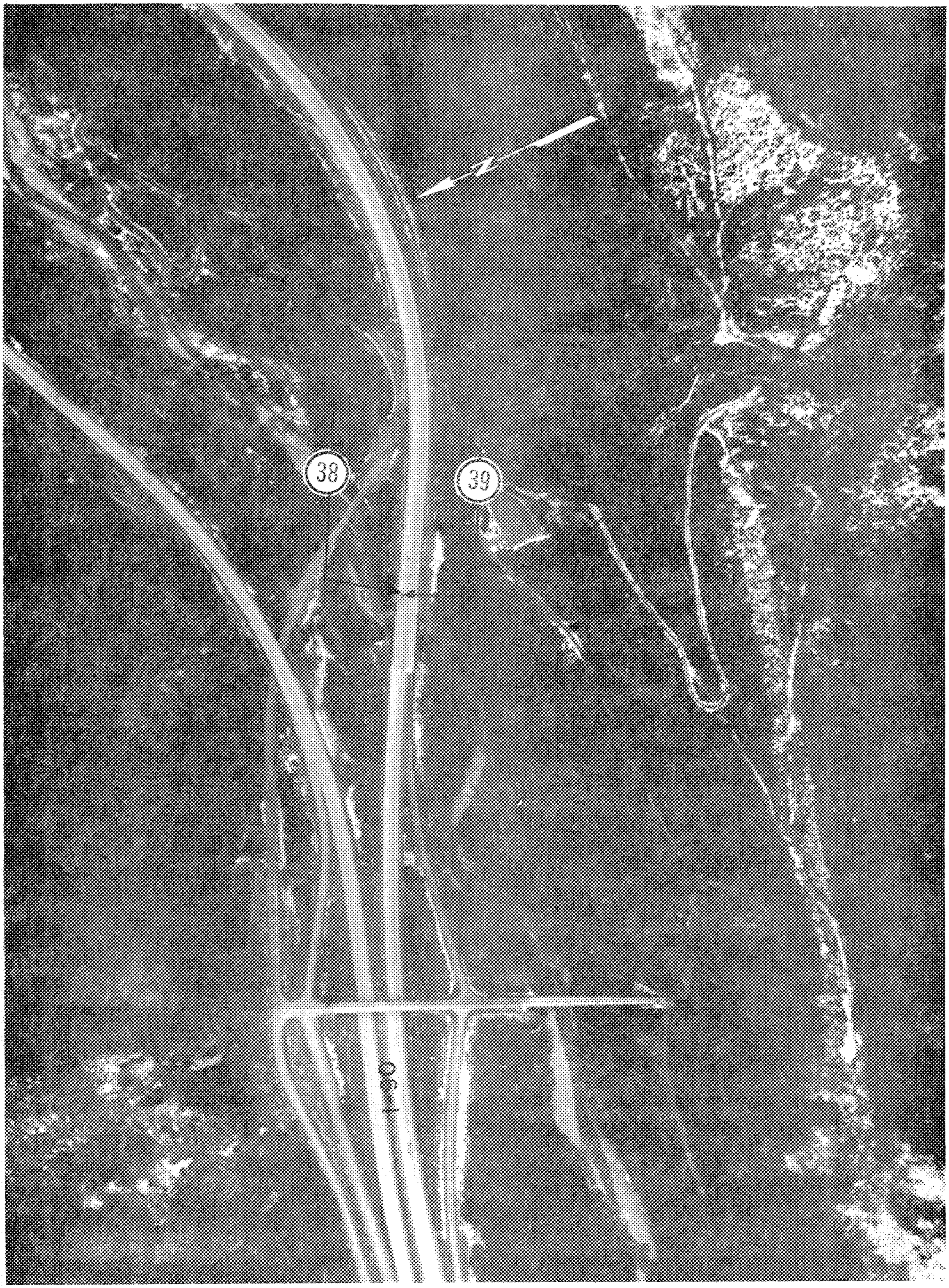
Scale: 1″ = 1000′ Date of Photography: 6-18-82



Location: I-405: Factoria I/C to Sunset I/C HOV — Figure 1

County: King — M.P. 4.54 to 10.53

Scale: 1″ = 2000′ — Date of Photography: 8-14-85



Location: I-90: Asahel Curtis I/C to Snowshed

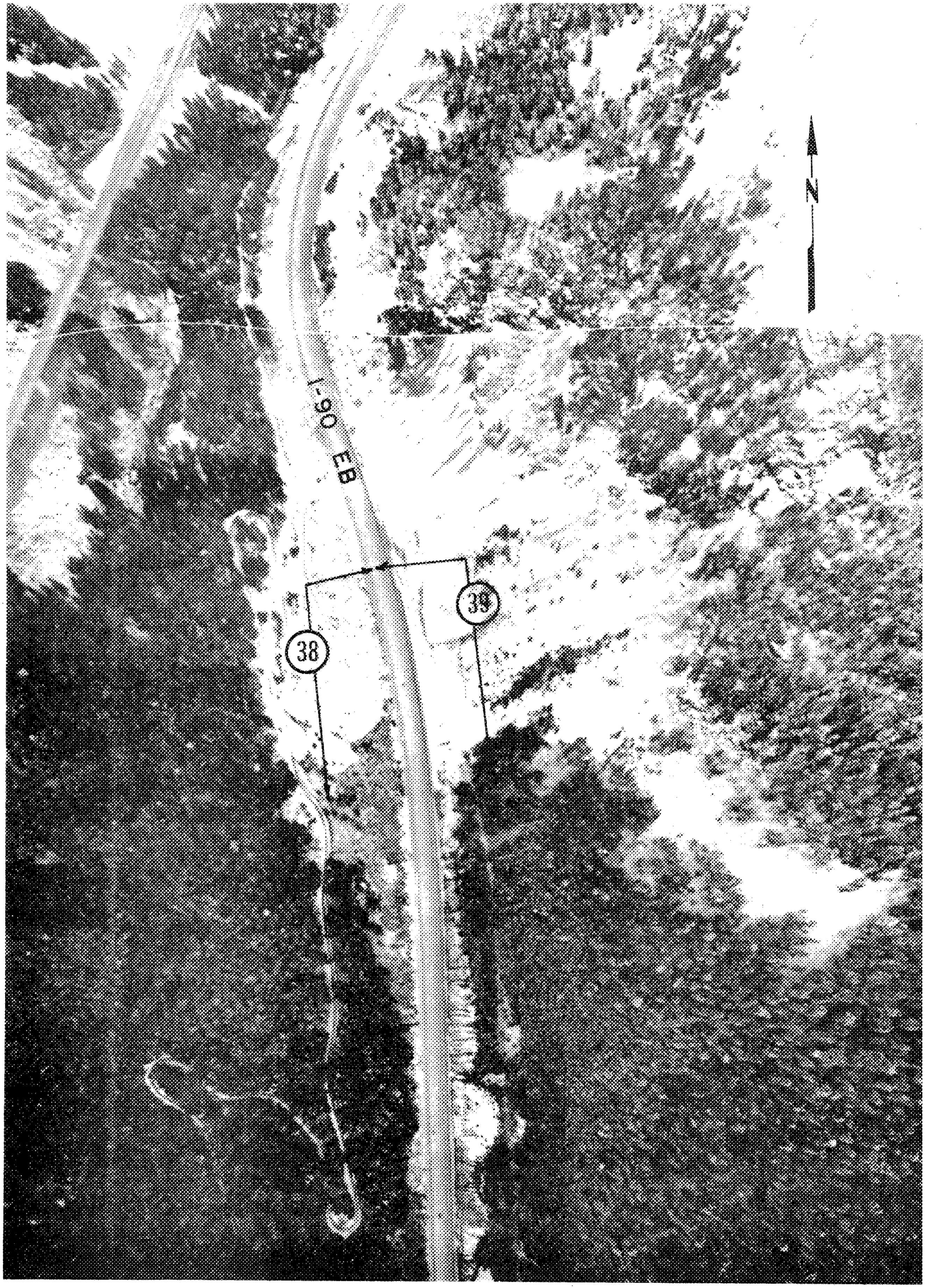
County: King

Scale: 1" = 500'

M.P. 46.95 to 54.94

Date of Photography: 11-14-85

Figure 11



Location: I-90: Asahel Curtis I/C to Snowshed

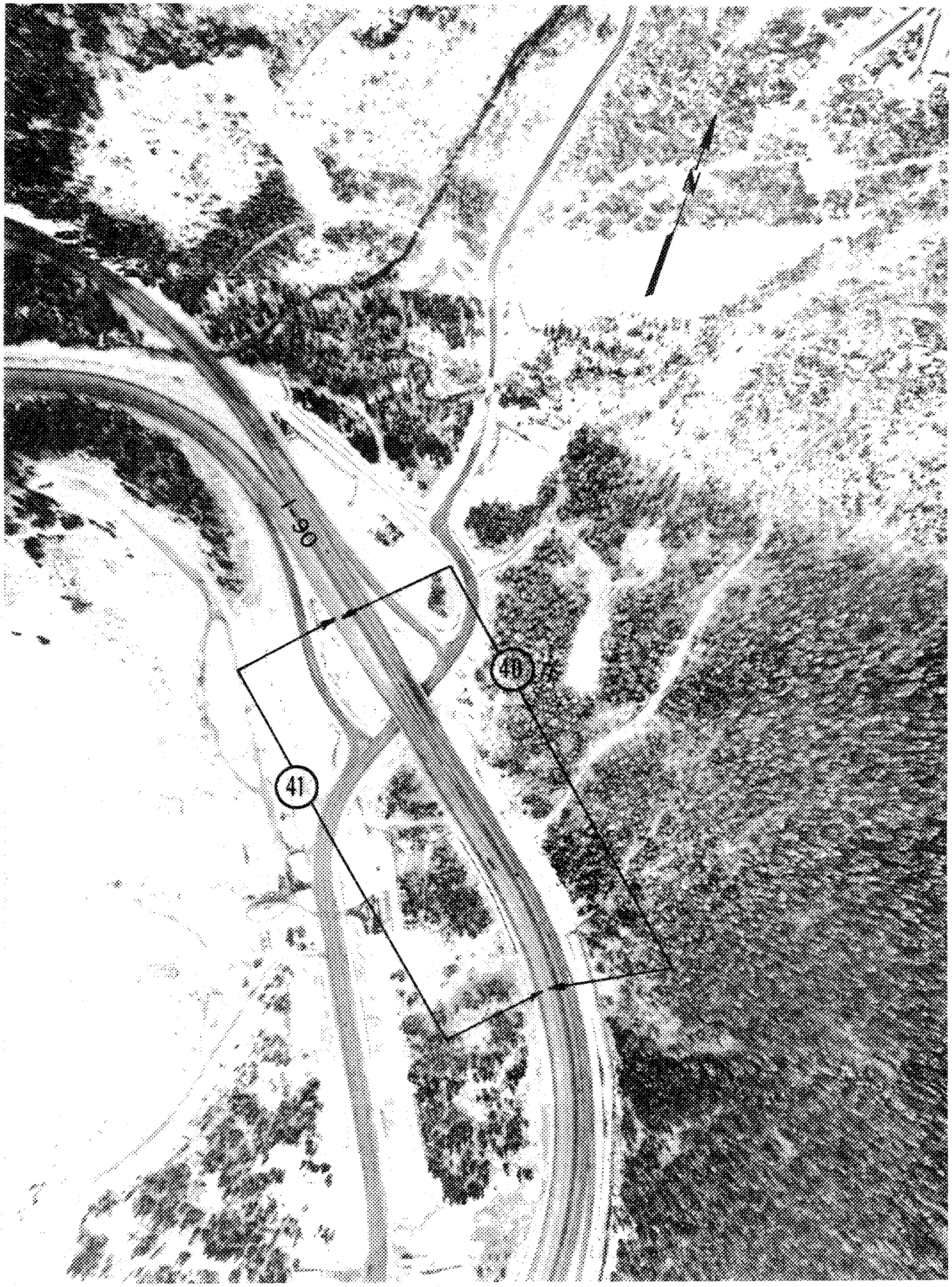
Figure

County: King

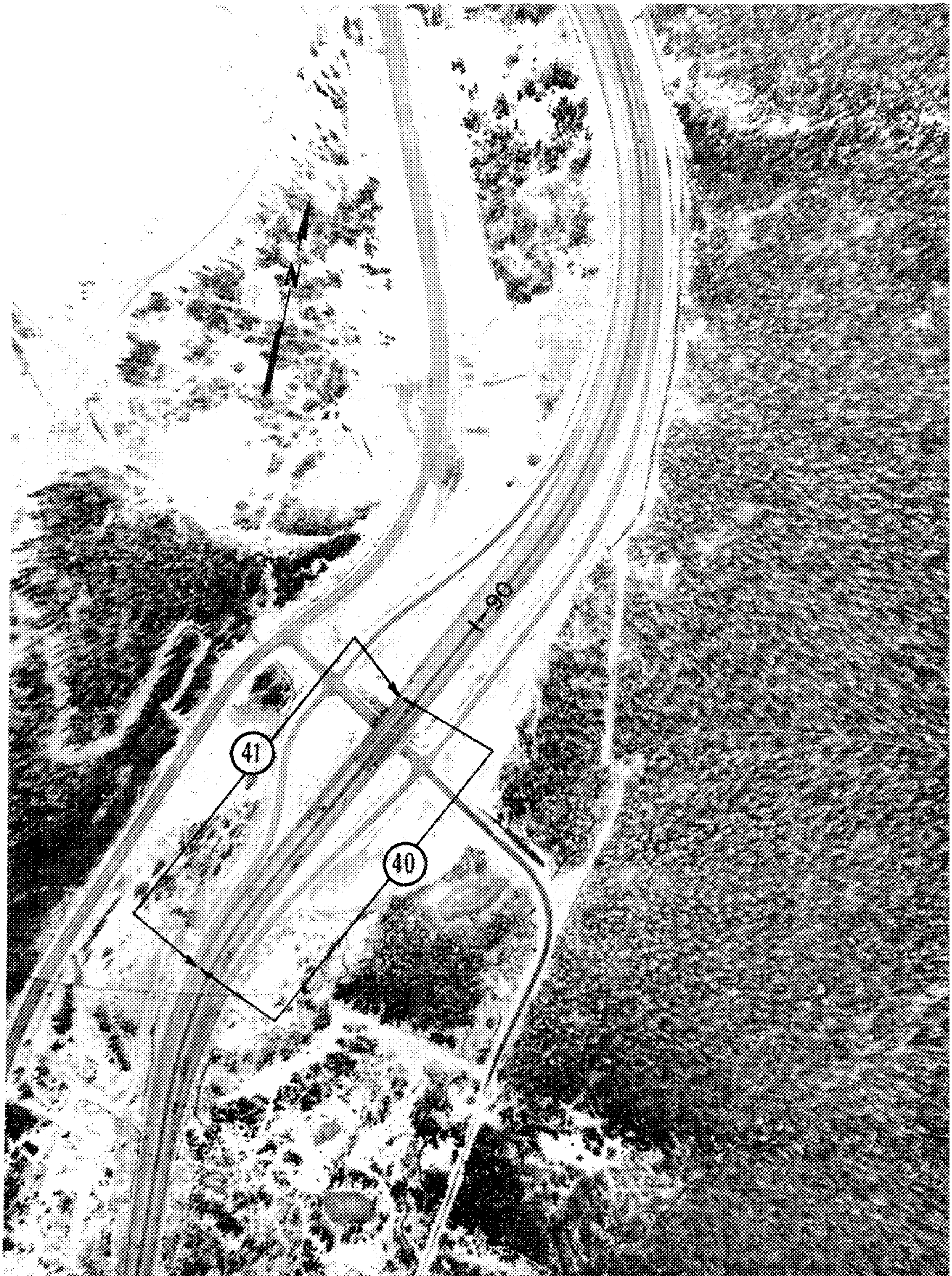
M.P. 46.95 to 54.94

Scale: 1″ = 500′

Date of Photography: 11-14-85



Location:	I-90: West Summit Interchange		Figure 13
County:	King	M.P.	46.95 to 54.94
Scale:	1″ = 500′	Date of Photography:	11-14-85



Location: I-90: East Summit Interchange

Figure 14

County: Kittitas

M.P. 46.95 to 54.94

Scale: 1″ = 500′

Date of Photography: 11-14-85