IOWA HIGHWAY RESEARCH

REPORT NO. 2

1950-1951.

Chapter I.

General Statement

1. Progress in Research

During the fiscal year, July 1, 1950 to June 30, 1951, the Iowa State Highway Commission expanded its research program by adding to the work under way during the previous fiscal year, fifteen substantial projects recommended to the Commission by the Iowa Highway Research Board. The major portion of the projects under way in the previous fiscal year have been active in this fiscal year. All of the additional projects have gotten under way during this fiscal year.

This year, as in the past, the work has been performed partly by Commission forces and partly by outside agencies such as the Institute of Hydraulic Research at Iowa City, the State University of Iowa, Iowa State College, the Iowa Geological Survey and the United States Geological Survey. The major portion of the fifteen new projects has been assigned to these outside agencies.

2. Other Research Cooperation

The Commission is affiliated with the Highway Research Board of the National Research Council of the National Academy of Sciences.

Engineers of the Commission regularly attend the annual meetings of that Board and take part in committee work throughout the year. Mr. W. H. Root, Maintenance Engineer of the Commission, is now a member of the Board of Directors of the Highway Research Board and is also a member of the Iowa Highway Research Board.

The State Highway Commission has been a contributor to the Correlation Service of the Highway Research Board since the inauguration of that service in 1944. The contribution of the Commission to that service is now $2,956.00 per year. This contribution is paid, one half from State primary road funds and one half from Federal aid road funds allotted to the State, The purpose of this correlation service is to keep the Bureau of Public Roads and all of the state highway departments informed as to the nature and the progress of all highway research work being carried on by the highway research agencies in all of the states. Through this service, the research data developed in any state are made available to all other states. The effect of the service is to eliminate unnecessary duplication of work and to provide for an efficient distribution of research data as soon as it becomes available.

3. <u>Highway Research Projects under way on July 1, 1949</u>.

Previous to July 1, 1949, the Iowa State Highway Commission had initiated and carried on a substantial research program pertaining principally to primary road problems. The major portion of the research projects in this program have been active only when technical personnel has been available between assignments in routine duties in testing and inspection work associated with construction and maintenance operations. As a consequence, only a little is accomplished on each of a number of research projects in each year. Sometimes, a given project may remain inactive for a year or more at a time. In these circumstances, the list of projects active in a given year varies from year to year even without the addition or completion of projects. For the present, it seems advisable to continue this program on the same basis as in the past with respect to the projects under way in some form on July 1, 1949. Some work was done on each of the following of this group of projects during the fiscal year July 1, 1950 to June 30, 1951.

In the list which follows, these projects have been classified in two groups, one containing the projects carried on by the Commission with its own forces, principally by the Department of Materials and Tests, and the other containing the projects carried on by outside agencies for the Commission under contract with the Commission.

A. Projects initiated prior to July 1, 1949 and carried on by the Commission through the Department of Materials and Tests.

R-11	Strength of Concrete
R-62	Soundness Tests on Stone
R-69	Tests of Subgrade Soils
R-79	Durability of Concrete
R-84	Freezing & Thawing Tests on Large Stone Blocks
R-89	Durability of Oil-Soil Mixtures
R-90	Study of Rolled Stone Bases
R-102	Durability of Concrete Pavements
R-103	Service Tests of Centerline Paints
R-111	Service Tests on Metal Blast Plates
R-121	Absorption Test Methods for Concrete and Clay Pipe
R-123	Pre-Mixes for Highway Maintenance Work
R-128	Miscellaneous Minor Investigations

R-130 Crystallographic Study of Iowa Limestones

R-131 Load Carrying Capacity of Roads as Affected by Frost

R-133 Cracking of Asphaltic Wearing Surfaces

R-134 Methods of Testing Asphaltic Concrete Mixtures

R-135 Condition and Crack Surveys of Concrete Pavement

R-137 Strength and Durability of Clay Drain Tile

R-139 Light Weight Aggregates for Concrete

R-140 Variable Base and Mat Thickness

R-143 Variable Thickness Concrete Pavement for Light Traffic Roads

B. Projects initiated prior to July 1, 1949 and carried on by the Commission through outside agencies.

1216-A Scour Around Bridge Piers and Abutments

1216-B Loads on Negative Projecting Conduits

1216-C Roadside Seeding

4. Secondary Road Research

While there has been a considerable amount of primary road research carried on in the past, there has been little research work pertaining specifically to secondary roads. This has been due largely to the fact that funds were unavailable especially for secondary road research. A remedy for this situation was provided through an

Act of the 53rd General Assembly that now appears as Section 310.34 to 310.36, Code 1950, in which authorization is given for the expenditure of not more than one and one half per cent of the farm-to-market road fund in any year for secondary road research. Under the provisions of this Act, a total of $50,000 was set aside from farm-to-market funds during the fiscal year July 1, 1950 to June 30, 1951 for secondary road research.

5. Iowa Highway Research Board Created

All highway research has some relation to all classes or systems of roads. A given highway research project may be instituted, carried on, completed and paid for as a primary road project, but the data and findings derived therefrom may be equally valuable in the design, construction and maintenance of secondary roads. Likewise, the results of a secondary road research project may be equally useful on primary roads. There is no clear dividing line between the two. It is obvious, therefor, that there should be one central clearing house for all highway research in the State. Such a clearing house should bring together all agencies in the State that are especially interested in highway research and should seek a correlation of their efforts in a well balanced long range research program specifically focused on the major needs of each class or system of highways in the State.

To affect this correlation, the Iowa State Highway Commission created the Iowa Highway Research Board which undertook its duties late in the fiscal year which ended June 30, 1950. This Board deals with all highway research, both for primary and secondary roads, that may be carried on under the jurisdiction of the Commission from either primary or farm-to-market road funds. The Board was actively engaged throughout the whole of this fiscal year in the discharge of the duties imposed upon it by the Commission.

6. Members and Alternate Members of the Iowa Highway Research Board.

The membership of the Iowa Highway Research Board as of June 30, 1951 was as follows:

Name	Appointed by	Position	Term Expires
F. M. Dawson	State University of Iowa	Dean, College of Engineering	1-1-53
J. F. Downie Smith,	Iowa State College	Dean, Engineering Division	1-1-53
R. E. Robertson 1/	Iowa Association of County Engineers	Cerro Gordo County Engineer	1-1-54

Name	Appointed by	Position	Term Expires
P. A. Michel 1/	Iowa Association of County Engineers	Montgomery County Engineer	1-1-54
C. A. Elliott	Iowa Association of County Engineers	Greene County Engineer	1-1-52
J. R. Dougherty	Iowa Association of County Engineers	Muscatine County Engineer	1-1-52
Edward Winkel	Iowa Association of County Engineers	Osceola County Engineer	1-1-53
R. J. Wallace 2/	Iowa Association of County Engineers	Buchanan County Engineer	1-1-53
W. H. Root 1/	Iowa State Highway Commission	Maintenance Engineer	1-1-54
Bert Myers	Iowa State Highway Commission	Materials & Tests Engineer	1-1-52
W. E. Jones	Iowa State Highway Commission	Assistant to Chief Engineer	1-1-53

1/ Reappointed January 1, 1951 to full three year terms

2/ Appointed April 17, 1951 to serve unexpired portion of term of L. J. Schiltz who resigned March 30, 1951.

At the regular meeting, February 23, 1951, the Iowa Highway Research Board elected W. E. Jones, Chairman and Bert Myers, Vice Chairman, to succeed themselves in those positions for the year 1951.

Alternate members of the Board as of June 30, 1951 were as follows:

L. W. Croft, Dallas County Engineer as the alternate for C. A. Elliott.

Jas. L. Stover, Chickasaw County Engineer as the alternate for R. E. Robertson.

W. L. Anderson, O'Brien County Engineer as the alternate for Edward Winkel.

J. Sherman Held, Guthrie County Engineer as the alternate for P. A. Michel.

A. W. Hinderman, Louisa County Engineer as the alternate for J. R. Dougherty.

R. H. Justen, Johnson County Engineer as the alternate for R. J. Wallace.

George R. Town, Associate Director, Engineering Experiment Station, Iowa State College, as an alternate for J. F. Downie Smith.

Ladis H. Csanyi, Professor of Civil Engineering, Iowa State College as an alternate for J. F. Downie Smith.

V. R. Bennion, District Engineer, U. S. Geological Survey, as an alternate for F. M. Dawson.

J. W. Howe, Department of Mechanics and Hydraulics, State University of Iowa as an alternate for F. M. Dawson.

7. <u>Director of Highway Research</u>

Mark Morris served as secretary of the Iowa Highway Research Board and as Director of Highway Research for the Commission throughout the whole of this fiscal year.

8. <u>Meetings of the Board</u>

The Iowa Highway Research Board held eleven regular and no special meetings during this fiscal year. All of the meetings were well attended usually with the full membership, but occasionally with the absence of one or two members. The meetings were each fully occupied in thorough discussions of proposed research projects and of the needs for research data. A part of one meeting was given over to a visit to the Engineering Experiment Station, Iowa State College, at Ames for an inspection of the several research projects under way in the Station under the sponsorship of the Commission upon recommendation of the Board.

Chapter II.

Research Projects

9. <u>Research Projects Suggested</u>

During the period, July 1, 1950 to June 30, 1951, ten suggestions for research projects were received by the Iowa Highway Research Board. Two were submitted by county engineers, three by the Iowa State Highway Commission, one by the Iowa Geological Survey and four by Iowa State College.

<u>List of Suggestions Received</u>.

1. Thickness of Concrete Pavements for Light Traffic Secondary Roads.
2. Durability of Portland Cement Concrete.
3. Sources of Highway Materials in Southwestern Iowa.

4. Elastic Behavior of Steel Truss Members.

5. Live Load Distribution on Four Beam I-Beam Bridges.

6. Extent and Nature of Rural Road Usage.

7. Determination of New Formula for Bearing Value of Piles.

8. Preparation of Engineering Soils and Drainage Maps.

9. Lateral Pressures on Retaining Walls.

10. Limestones for Concrete Aggregates.

10. <u>Projects Recommended to Iowa State Highway Commission</u>.

During the period July 1, 1950 to June 30, 1951, nine suggestions were recommended by the Board to the Commission as subjects for research projects. Two of these recommendations were upon suggestions received by the Board in the previous fiscal year and seven of them were upon suggestions received by the Board during the fiscal year July 1, 1950 to June 30, 1951. These nine recommendations, with the total estimated cost, the time for completion, the name of the agency to conduct the research and a brief description of the project are as follows:

Project No. HR - 7 Accelerated Testing of Highway Pavements. Total Cost $7,000. Time required, one year. Agency to conduct the research, Iowa State College.

The suggestion for this project as received by the Board dealt with the construction of a track for the accelerated testing of pavements and subgrades, but as recommended by the Board to the Commission, involved only the investigation of the feasibility of constructing and operating such a testing track. Consideration is to be given later to a recommendation upon the original suggestion depending upon the results of the investigation of the feasibility of constructing and operating such a track.

Project No. HR - 8. Origin and Destination Traffic Surveys.

Estimated Total Cost, $5,700. Time required, one year. Agency to conduct the research, Iowa State College.

This project involves a study of means of conducting origin and destination traffic surveys with less work and at a lower cost than is now involved without sacrifice of the accuracy of the more extended operations now employed in this work.

Project No. HR - 9. Thickness of Concrete Pavements, for Light Traffic Roads.

Estimated Cost $25,000. Time required, one year. Agencies to conduct the research, Iowa State Highway Commission and Greene County Board of Supervisors.

This project provides for the construction of concrete pavements of lesser thicknesses than used for primary road construction in an attempt to find the minimum thickness suitable for the heavy traffic secondary roads which have a traffic either less than or comparable with that on light traffic primary roads, where pavements of less thickness than the usual standard for primary roads has been used successfully for a number of years. The thought behind the project is that perhaps a lesser thickness than that may serve the even lighter traffic of the heavier traffic portions of the secondary road system on which traffic bound gravel or stone fails to provide a satisfactory solution of the surfacing problem. Between ten and fifteen per cent of the secondary roads are in this category.

Project No. HR - 10. Durability of Portland Cement Concrete. Estimated Cost $3,000. Time required, one year. Agency to conduct the research, Iowa State Highway Commission.

For several years the Commission has been engaged in studies of the durability of concrete. This work has consisted of observations of concrete placed under the supervision of the Commission and of experimentation with a number of durability tests which may provide data that may give some indication of the performance of concrete in service. The current project provides financial support of this work from research funds for a one year period.

Project No. HR-11. Sources of Highway Materials in Southwestern Iowa. Estimated Total Cost, $24,000. Time required, three years. Agency to conduct the Research, Iowa Geological Survey.

The project consists of a basic geologic investigation of southwestern Iowa for the location of potential sources of highway material and for the collection of data needed for the exploitation of these resources for highway purposes. The current project is limited to southwestern Iowa, but the work may be extended later into any area of the State where the deposits of readily available highway material have been depleted.

Project No. HR - 12. Live Load Distribution in Four Beam I-Beam Bridges. Estimated cost, $10,000. Time required, one year. Agency to conduct the research, Iowa State Highway Commission.

As modified by the Board, this project provides for a pilot study of the distribution of live load stresses in four beam I-beam bridges with concrete floors to determine the need, if any, for a more extensive investigation of the subject.

Project No. HR - 13. Extent and Nature of Rural Road Usage. Estimated cost, $10,000. Time required, one year. Agency to conduct the research, Iowa State Highway Commission.

This project provides for the study of the extent and nature of the usage rural roads particularly those carrying small volumes of traffic and serving exclusively small land areas. In the secondary road system, there is an extensive mileage of such roads. On this portion of the system, there are many situations in which the cost of constructing a road is much greater than the value of the land served and the cost of maintaining a road is greatly in excess of the average revenue per unit of travel for the system as a whole. This project has been designed to obtain data and to develop criteria for the evaluation of such situations and for the determination of a sound course of action for the public benefit in dealing with them.

Project HR - 14. Lateral Pressures on Retaining Walls. Estimated Cost, $30,000. Time required, two years. Agency to conduct the research, Iowa State College.

This project provides for an investigation of lateral pressures in embankments against retaining walls, bridge abutments and similar structures under various conditions and amounts of loading from vehicles or other superimposed loads on the embankments.

Project No. HR - 15. Limestones for Concrete Aggregates. Estimated Cost, $7,000. Time required, two years. Agency to conduct the research, Iowa State College.

This project consists of the investigation of the characteristics of limestone affecting their behavior as coarse aggregate in concrete, particularly in pavements. In the project, a study is to be made of the geologic factors of limestone pertaining to the quality of the material for concrete aggregate.

11. Research projects approved.

During this fiscal year, that is, from July 1, 1950 to June 30, 1951, the Commission approved fifteen research projects. Six of these were recommended in the course of the fiscal year ending June 30, 1951. The Commission has approved all projects recommended to it by the Board to that date. These projects are listed by number and title in Table No. 1.

Table No. 1

List of Research Projects
Approved by the State Highway Commission
during fiscal year ending June 30, 1951

Research Project Number	Title of Project	Estimated Cost
HR - 1	Investigation of the Loess and Glacial Till Materials of Iowa	$ 45,000.00
HR - 2	Flood Frequency and Flood Magnitude Analysis	10,000.00
HR - 3	Determination of Flood Discharge Characteristics of Small Drainage Areas	50,000.00
HR - 4	Thickness of Stabilized Aggregate Bases for use with Bituminous Surfaces	25,000.00
HR - 5	Elimination of Long Bridges on Streams with Small Drainage Areas	8,000.00
HR - 6	Construction of Earth Fills to Resist Erosion when Flooded	10,000.00
HR - 7	Accelerated Testing of Highway Pavements	7,000.00
HR - 8	Origin and Destination Traffic Surveys	5,700.00
HR - 9	Thickness of Concrete Pavements for Light Traffic Roads	25,000.00
HR - 10	Durability of Portland Cement Concrete	5,000.00
HR - 11	Sources of Highway Materials in Southwestern Iowa	24,000.00
HR - 12	Live Load Distribution in Four Beam I-Beam Bridges	10,000.00
HR - 13	Extent and Nature of Rural Road Usage	10,000.00
HR - 14	Lateral Pressures on Retaining Walls	30,000.00
HR - 15	Limestone for Concrete Aggregates	7,000.00
	Total	$271,700.00

12. <u>Status of Research Project Suggestions</u>.

A total of 27 suggestions for research projects had been made to the Iowa Highway Research Board as of June 30, 1951. Fifteen of these had been recommended to the Commission as of that date, nine of them in the fiscal year ending June 30, 1951 and six of them in the fiscal year ending June 30, 1950. The status of all suggestions made to the Board to date of June 30, 1951 is shown in Table No. 2.

TABLE NO. 2

Iowa Highway Research Board
Status of Research Project Suggestions
June 30, 1951

Research Project Suggestion Number	Title of Project	Source of Suggestion and date Received	Estimated Cost	Project Period Years	Action upon Suggestion: By Board and Date	Action upon Suggestion: By Commission and Date	Highway Commission Research Project Number	Notes
RPS-1	Accelerated Testing of Highway Pavements	L. Csanyi May 25, 1950	$ 7,000.00	1	Adopted 7/28/50	Approved 8/16/50	HR-7	Conducted by Engnrg. Exp. Sta. Iowa State College
RPS-2	Investigation of the Loess and Glacial Till Materials of Iowa	D. T. Davidson May 25, 1950	45,000.00	3	Adopted 6/13/50	Approved 7/7/50	HR-1	Conducted by Engnrg. Exp. Sta. Iowa State College
RPS-3	The Supporting Strength of Concrete Pipes	M. G. Spangler May 25, 1950	12,720.00	1	Postponed 1/26/51	-	-	
RPS-4	Motor Vehicle Operating Costs	Robley Winfrey May 25, 1950	19,400.00	2	Postponed 9/29/50	-	-	
RPS-5	Origin and Destination Traffic Surveys	Robley Winfrey May 25, 1950	5,700.00	1	Adopted 7/28/50	Approved 8/16/50	HR-8	Conducted by Engnrg. Exp. Sta. Iowa State College
RPS-6	Elimination of Long Bridges on Streams with Small Drainage A	Paul Mahoney May 26, 1950	8,000.00	1	Adopted 6/13/50	Approved 7/7/50	HR-6	Conducted by Ia Inst of Hdy. Res. State Univ. of Iowa
RPS-7	Flood Frequency and Flood Magnitude Analysis	V. R. Bennion May 27, 1950	10,000.00	2	Adopted 6/9/50	Approved 7/7/50	HR-2	Conducted by U.S. Geol. Survey, Iowa City
RPS-8	Determination of Flood Discharge Characteristics of Small Drainage Areas	V. R. Bennion May 27, 1950	50,000.00	10	Adopted 6/9/50	Approved 7/7/50	HR-3	Conducted by U.S. Geol. Survey Ia. City
RPS-9	Strengthening of Existing Light Pony Trusses	L. J. Schiltz May 28, 1950	-	-	Postponed 8/25/50	-	-	-
RPS-10	Treatment of Wood Floors for Wearing Surfaces	L. J. Schiltz May 28, 1950	-	-	Postponed 8/25/50	-	-	-
RPS-11	Precast Concrete Bridge Floor Construction	L. J. Schiltz May 26, 1950	-	-	Postponed 8/25/50	-	-	-
RPS-12	Thickness of Stabilized Aggregate Bases for use with Bituminous Surfaces	L. J. Schiltz May 28, 1950	25,000.00	1	Adopted 6/9/50	Approved 7/7/50	HR-4	Conducted by Dubuque Co. and Ia. State Hwy. Comm.
RPS-13	Accounting Practices in County Engineer Offices	L. J. Schiltz May 28, 1950	-	-	Postponed 9/29/50	-	-	-
RPS-14	Hydraulic Design of Highway Culverts	Hunter Rouse June 1. 1950	39,000.00	3	Postponed 9/29/50	-	-	-

Iowa Highway Research Board
Status of Research Project Suggestions
June 30, 1951

Research Project Suggestion Number	Title of Project	Source of Suggestion and date Received	Estimated Cost	Project Period Years	Action upon Suggestion: By Board and Date	Action upon Suggestion: By Commission and date	Highway Commission Research Project Number	Notes
RPS-15	Hydraulic Design of Highway Valley Crossings	Hunter Rouse June 1, 1950	$ 34,000.00	2	Postponed 10/28/50	-	-	-
RPS-16	A Study of Limestones of Iowa for Low Cost Road Construction	W.H. Berhrens June 1, 1950	-	-	6/9/50	-	-	Data Available in Commission Files
RPS-17	Construction of Earth Fills to Resist Erosion When Flooded	F. M. Dawson June 2, 1950	10,000.00	1	Adopted 6/13/50	Approved 7/7/50	HR-6	Conducted by Iowa Inst. of Hyd. Res. State Univ. of Ia.
RPS-18	Thickness of Concrete Pavements for Light Traffic Roads	C. A. Elliott July 24, 1950	25,000.00	1	Adopted 12/5/50	Approved 12/20/50	HR-9	Conducted by Greene Co. and Ia. St. Hwy. Commission
RPS-19	Durability of Portland Cement Concrete	Bert Myers July 27, 1950	5,000.00	P	Adopted 12/5/50	Approved 12/20/50	HR-10	Conducted by Iowa State Hwy. Comm
RPS-20	Sources of Highway Materials in Southwestern Iowa	H. Garland Hershey Sept. 29, 1950	24,000.00	3	Adopted 12/5/50	Approved 12/20/50	HR-11	Conducted by Iowa Geol. Survey, Iowa City.
RPS-21	Elastic Behavior of Steel Truss Members	J. F. D. Smith Sept. 29, 1950	19,700.00	1	Postponed 1/26/51	-	-	-
RPS-22	Live Load Distribution in Four Beam I-Beam Bridges	F. W. Blumenschein Dec. 2, 1950	10,000.00	1	Adopted 2/23/51	Approved 3/20/51	HR-12	Conducted by the Iowa State Hwy. Comm.
RPS-23	Extent and Nature of Rural Road Usage	Mark Morris Feb. 23, 1951	10,000.00	1	Adopted 3/30/51	Approved 4/17/51	HR-13	Conducted by the Iowa State Hwy. Comm.
RPS-24	Determination of New Formula For Bearing Value of Piles	C. A. Elliott Feb. 23, 1951	-	-	-	-	-	-
RPS-25	Preparation of Engineering Soils and Drainage Maps	D.T. Davidson March 17, 1951	5,000.00 per year	-	Postponed 4/27/51	-	-	-
RPS-26	Lateral Pressures on Retaining Walls	M.G. Spangler March 20, 1951	30,000.00	2	Adopted 4/27/51	Approved 5/15/51	HR-14	Conducted by the Engr. Exp. Sta. Ia. State College
RPS-27	Limestones for Concrete Aggregates	Chamberlin J. Roy May 21, 1951	7,000.00	2	Adopted 5/25/51	Approved 5/29/51	HR-15	Conducted by the Ind. Sc. Research Inst., Iowa State College

Chapter III.

Research Reports.

13. Research Reports Issued

The first of the recommendations for research projects to the Iowa State Highway Research Board were received by the Commission late in the preceding fiscal year and approved by the Commission early in the fiscal year ending June 30, 1951.

As the least time required for any of these projects was one year and as some time was required to get the projects under way after their approval, none of them advanced to the stage at which a report could be prepared during this fiscal year.

A progress report was submitted for one of the list of projects under way at the time of the creation of the Iowa Highway Research Board. This progress report is included in this report as, "Appendix A". It presents the results of the work accomplished on project 1216-A, Scour around Bridge Piers and Abutments, to date of August 31, 1950, the end of a project year.

Chapter IV.

Expenditures for Research.

1. Expenditures July 1, 1950 to June 30, 1951.

During the fiscal year July 1, 1950 to June 30, 1951 an allotment of $50,000 from farm-to-market road funds was set aside under the provisions of Sections 310.34 to 310.35, Code, 1950, for secondary road research and a total of $19,320.50 was expended for that purpose on projects recommended to the Commission by the Iowa Highway Research Board and approved by the Commission.

During the same period an allotment of $50,000 was made from primary road funds for research projects and a total of $9,443.31 was expended for that purpose. An additional sum of $3,160.31 was expended from planning survey funds for projects recommended by the Board and approved by the Commission. The difference between the amounts allotted and the amounts expended for research for both the primary road funds and the farm-to-market road funds is due to the lag in getting projects under way after approval and in getting bills submitted for the work accomplished.

In addition to these expenditures for research projects recommended by the Iowa Highway Research Board, the Commission made other expenditures from primary road funds for research on projects which were under way at the time the Board was created and which are as yet uncompleted. Expenditures for such research projects from planning survey funds, which are approximately one half primary road funds and one half Federal aid allotment funds and may therefor be classified as primary road funds were in the total amount of $16,886.86. From these same funds, $2,956.00 was contributed to the Correlation Service of the Highway Research Board. Thus, the total for research purposes from planning survey funds, for projects other than recommended by the Board, was $19,842.86. Other expenditures from primary road funds directly were in the total amount of $12,155.70. Lists of all research expenditures itemized by projects and classified by funds from which expenditures were made are given in Tables No. 3, No. 4 and No. 5 on the following pages.

Table No. 3

Expenditures for Research on Projects under way prior to July 1, 1949 and active during the Fiscal Year, July, 1950 to June 30, 1951

Number of Project	Title of Project (Condensed)	Expenditure July 1, 1950 to June 30, 1951		
		From Primary Road Funds	From Farm-to-Market Road Funds	From All Funds Total
A.	Projects conducted by the Commission			
R-11	Strength of Concrete	$ 303.83	--	$ 303.83
R-62	Soundness Tests on Stone	235.86	--	235.86
R-69	Tests of Subgrade Soils	10.24	--	10.24
R-79	Durability of Concrete (HR-10)	3116.59	--	3116.59
R-84	Freezing & Thawing Tests on Large Stone Blocks	84.62	--	84.62
R-89	Durability of Oil-Soil Mixtures	922.89	--	922.89
R-90	Study of Rolled Stone Bases	96.08	--	96.08
R-102	Durability of Concrete Pavements	539.02	--	539.02
R-103	Service Tests of Centerline Paints	169.22	--	169.22
R-111	Service Tests on Metal Blast Plates	193.76	--	193.76
R-121	Absorption Test Methods for Concrete and Clay Pipe	45.34	--	45.34
R-123	Pre-Mixes for Highway Maintenance work	286.56	--	286.56
R-128	Miscellaneous Minor Investigations	145.69	--	145.69
R-130	Crystallographic Study of Iowa Limestones	21.31	--	21.31
R-131	Load Carrying Capacity of Roads as Affected by Frost	2765.80	--	2765.80
R-133	Cracking of Asphaltic Wearing Surfaces	321.56	--	321.56

Table No. 3
(Continued)
Expenditures for Research on Projects under way prior to July 1, 1949 and active during the Fiscal Year July, 1950 to June 30, 1951

Number of Project	Title of Project (Condensed)	Expenditure July 1, 1950 to June 30, 1951 From Primary Road Funds	From Farm-to-Market Road Funds	From All Funds Total
R-134	Methods of Testing Asphaltic Concrete Mixtures	$ 768.80	--	$ 768.80
R-135	Condition and Crack Surveys of Concrete Pavement	916.14	--	916.14
R-137	Strength and Durability of Clay Drain Tile	25.23	--	25.23
R-139	Light Weight Aggregates for Concrete	209.86	--	209.86
R-140	Variable Base and Mat Thickness (HR-4)	667.65	--	667.65
R-143	Variable Thickness Concrete Pavement for Light Traffic Roads (HR-9)	309.46	--	309.46
Sub-total		$12,155.77	--	$12,155.77

B. Projects conducted for the Commission by outside agencies

1216-A	Scour around Piers and Abutments	$14,333.36	--	$14,333.36
1216-B	Loads on Culverts	553.50	--	553.50
1216-C	Roadside Seeding	2,000.00	--	2,000.00
Sub-total		$16,886.86	--	$16,886.86

Table No. 3
(Continued)
Expenditures for Research on Projects under way prior to July 1, 1949 and active during the Fiscal Year July, 1950 to June 30, 1951

Number of Project	Title of Project (Condensed)	Expenditure July 1, 1950 to June 30, 1951		
		From Primary Road Funds	From Farm-to-Market Road Funds	From All Funds Total
C. Correlation Service of Highway Research Board				
1210	Payment for 1950	$ 2,956.00	---	$ 2,956.00
Sub-total		$ 2,956.00	---	$ 2,956.00
Total		$31,998.63	---	$31,998.63

Table No. 4
Expenditures for Research on Projects Recommended by the Iowa Highway Research Board, July 1, 1950 to June 30, 1951

Project Number	Title of Project (Condensed)	Expenditure From Primary Road Funds	Expenditure From Farm-to-Market Road Funds	From All Funds Total
HR-1	Investigation of Loess and Glacial Till	---	$16,903.44	$16,903.44
HR-2	Flood Frequency and Flood Magnitudes	$ 2,997.19	--	2,997.19
HR-3	Flood Discharge Characteristics	---	1,819.00	1,819.00
HR-7	Accelerated Testing Track	5,640.05	--	5,640.05
HR-8	Origin and Destination Survey	3,160.31	--	3,160.31
HR-12	Four Beam I-Beam Bridges	200.00	--	200.00
General	Expense of Highway Research Board	606.07	598.06	1,204.13
Total		$12,603.62	$19,320.50	$31,924.12

Table No. 5

Summary Expenditures for Highway Research

July 1, 1950 to June 30, 1951

Class of Project	Expenditures From Primary Road Funds	From Farm-to-Market Road Funds	From All Funds Total
A. For Projects under way prior to Creation of Iowa Highway Research Board			
1. Conducted by Commission Forces	$12,155.77	--	$12,155.77
2. Conducted for the Commission by outside agencies	16,886.86	--	16,886.86
B. Correlation Service of Highway Research Board	2,956.00	--	2,956.00
C. For Projects Recommended by Iowa Highway Research Board	11,997.55	$18,722.44	30,719.99
D. For Expense Iowa Highway Research Board	606.07	598.06	1,204.13
E. Total All Highway Research	$44,602.25	$19,320.50	$63,922.75

2. Obligations and Financial Program for Research.

On June 30, 1951, the total of the obligations for research in projects recommended by the Board and approved by the Commission was $271,700.00. The length of time for the research projects varies. The shortest time for a project is one year and the longest is ten years. The list of projects with the estimated rate of expenditure for each is shown in Table No. 6. This tabulation shows the obligations for the individual and the whole group of projects approved by the Commission during the fiscal year ending June 30, 1951.

TABLE NO. 6
Estimated Annual and Total Costs
to the Commission of Research Projects
Recommended by the Iowa Highway Research Board
to the Iowa State Highway Commission and Approved
by the Commission to date of June 30, 1951

Research Project Number	Title of Project	Estimated Expenditures for the Fiscal Year.										Total
		1950-51	1951-52	1952-53	1953-54	1954-55	1955-56	1956-57	1957-58	1958-59	1959-60	
HR-1	Investigation of the Loess and Glacial Till Materials of Iowa	$ 17,000	$ 14,000	$14,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$45,000
HR-2	Flood Frequency and Flood Magnitude Analysis	5,000	5,000	-	-	-	-	-	-	-	-	10,000
HR-3	Determination of Flood Discharge Characteristics of Small Drainage Areas	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	50,000
HR-4	Thickness of Stabilized Aggregate Bases for Use with Bituminous Surfaces	25,000	-	-	-	-	-	-	-	-	-	25,000
HR-5	Eliminination of Long Bridges on Streams with Small Drainage Areas	8,000	-	-	-	-	-	-	-	-	-	8,000
HR-6	Construction of Earth Fills to Resist Erosion When Flooded	10,000	-	-	-	-	-	-	-	-	-	10,000
HR-7	Accelerated Testing of Highway Pavements	7,000	-	-	-	-	-	-	-	-	-	7,000
HR-8	Origin and Destination Traffic Surveys	5,700	-	-	-	-	-	-	-	-	-	5,700
HR-9	Thickness of Concrete Pavements for Light Traffic Roads	25,000	-	-	-	-	-	-	-	-	-	25,000
HR-10	Durability of Portland Cement Concrete	5,000	-	-	-	-	-	-	-	-	-	5,000
HR-11	Sources of Highway Materials in Southwestern Iowa	8,000	8,000	8,000	-	-	-	-	-	-	-	24,000
HR-12	Live Load Disbribution in Four Beam I-Beam Bridges	-	10,000	-	-	-	-	-	-	-	-	10,000
HR-13	Extent and Nature of Rural Road Usage	-	10,000	-	-	-	-	-	-	-	-	10,000
HR-14	Lateral Pressures on Retaining Walls	-	20,000	10,000	-	-	-	-	-	-	-	30,000
HR-15	Limestones for Concrete Aggregates	-	4,000	3,000	-	-	-	-	-	-	-	7,000
Total		$120,700	$76,000	$27,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$271,700

Appendix A

Scour Around Bridge Piers and Abutments

Report No. 1

by

E. M. Laursen, Research Engineer
Iowa Institute of Hydraulic Research
State University of Iowa
Iowa City, Iowa.

SCOUR AROUND BRIDGE PIERS AND ABUTMENTS

Effect of Geometry of Representative Iowa Designs

Report No. 1

by

E. M. Laursen, Research Engineer

Iowa Institute of Hydraulic Research
State University of Iowa
Iowa City

Prepared for the
Iowa State Highway Commission

August, 1950

Report No. 1

SCOUR AROUND BRIDGE PIERS AND ABUTMENTS

Effect of Geometry of Representative Iowa Designs

Iowa Institute of Hydraulic Research
State University of Iowa
Iowa City

Introduction

Almost a hundred years ago, in a report on the St. Louis bridge now bearing his name, Captain James B. Eads described the foundation difficulties in an alluvial stream so aptly that even today his words are significant. His vivid portrayal of conditions at the bed is as follows:

"I had occasion to examine the bottom of the Mississippi below Cairo, during the flood of 1861, and at sixty-five feet below the surface I found the bed of the river, for at least three feet in depth, a moving mass, and so unstable that, in endeavoring to find a footing on it beneath my bell, my feet penetrated through it until I could feel, although standing erect, the sand rushing past my hands, driven by a current apparently as rapid as that at the surface. I could discover the sand in motion at least two feet below the surface of the bottom, and moving with a velocity diminishing in proportion to its depth."

Although the sand rushing past Captain Eads' hands was probably suspended or saltating load and the motion beneath his feet a local scouring action caused by his presence, his conclusions as to the extreme mobility of the bed material require no qualification. After further describing the characteristics of the river, he then concluded:

"For these reasons I have maintained and urged that there is no safety short of resting the piers for your Bridge firmly upon the rock itself. On no other question involved in its construction does my judgment more fully assure me that I am correct.... The recent destruction of many of the bridges in British India, by having their foundations undermined by the action of floods upon the sandy bottoms of the streams in that country, furnishes a warning that we should not neglect."

The Eads bridge in St. Louis was of an importance and cost which justified extending the piers and abutments to bedrock. However, there are great numbers of bridges, especially smaller structures, which would be prohibitively expensive if built in this manner. Instead they must be founded in some manner on the river deposits overlying the bed rock. But the problem of protecting such foundations has not been solved in the intervening years, and the judgment and experience of the engineer still provide the sole design criterion.

Once it is realized that the bed of the river is movable, it is readily apparent that the scour around a pier or abutment must be considered as a local augmentation of the more general movement of the bed as a whole. On some rivers, such as the Missouri, during flood stage this general movement results in an overall erosion of the bed of the same magnitude as the rise in the water surface. Thus the bed elevation from which the local scour is normally measured is itself variable with stream-flow conditions. Measurements included in the stream-gaging and sediment programs of various governmental agencies will provide the data whereby an estimate may be made of this characteristic of the stream.

Needless to say, a complete understanding of the cyclic degradation and aggradation of a stream will depend on the detailed evaluation of the dynamics of sediment transportation. Likewise, since scour around an obstruction may be regarded as the result of a localized increase in transport capacity, its rigorous solution is dependent on the solution of the more general problem.

Considering the overall complexity of field conditions, it is not surprising that no generally accepted principles (even rules of thumb) for the hydraulic design of piers and abutments have been developed from field experience alone. The flow of individual streams exhibits a manifold variation, with the magnitude of probable floods only roughly predictable, and there is a great disparity between different rivers. The alignment, cross section, and slope of a stream must all be related to its sediment-carrying capacity, and this in turn must be correlated with the characteristics of bed material ranging from clays and fine silts to gravel and boulders. Finally, the effect of the obstruction itself - the pier or abutment - upon the transport capacity must be assayed. Since most of these factors are likely to vary with time to some degree, and since the scour phenomenon as well is inherently unsteady, field measurements alone become virtually impossible of analysis. The interdependence of these many elements is so involved as to preclude analysis by any other means than a well considered laboratory program. Even so, the present state of knowledge of sediment movement will not yet allow extrapolation of laboratory results to full scale, and therefore a judicious combination of laboratory and field observations is needed for definite design procedures.

Isolation of each of the many variables for individual study is not possible; nevertheless, some simplification can be made by breaking the complex whole into several workable parts. A logical division of the more nearly independent elements amenable to laboratory procedure results in four relatively separate phases: geometry of pier or abutment, hydraulics of the stream, sediment characteristics, and channel shape and alignment. The present report concerns the first phase only and consists of a series of tests on typical pier and abutment shapes leading to a comparative measure of scour without regard to the other complicating factors. By holding all flow and sediment conditions constant, the pattern of scour is limited to a function of geometry alone.

Although certain recommendations are apparent from the results of these tests, they are strictly qualitative. Design requirements, however, necessitate knowledge of actual scour depth. Equipment has been constructed for the investigation of the second phase of the program, the hydraulics of the stream. It is hoped in addition that a current Institute study for the Office of Naval Research on the effect of sediment characteristics on the scour phenomenon will simplify the investigation of the third phase. When these latter studies are complete, it should be possible to begin field observations which may be correlated with the laboratory results.

Laboratory Equipment and Techniques

For the purpose of this study two flumes, 35 feet long and 5 feet wide, were specially designed and constructed in the Institute laboratory (Figs. 1 and 2). A pertinent feature is a removable center wall permitting the two flumes to be converted into a single one of double width. Flow is supplied by the general pumping system of the building, and is measured by an orifice in the 10-inch supply line with an air-water manometer. Simple tailgates control the depth of flow. To facilitate operation, the flumes are provided with level rails and a gage carriage.

Since the form of bridge piers has evolved largely according to structural and architectural criteria, countless different shapes exist. These were reduced arbitrarily to those shown in Fig. 3a. The rounded or conical forms represent the type of piers used in conjunction with multiple-span truss or girder bridges, and the square forms the type used with rigid-frame reinforced-concrete bridges. It is believed that the pier shapes used in the study represent the extremes of almost all the modern piers being built in Iowa. The testing of bulkier, older shapes has not been contemplated. In general these have either stood the test of time or failed completely - and therefore laboratory tests would be somewhat academic.

In a similar manner the abutment forms were reduced to those shown in Fig. 3b. The sloping form is typical of the modern stub abutment, in which the bridge seat is supported on piles and the approach fill is contained within sheet-piling. The vertical form is a typical gravity wall with the bridge seat contained in the abutment proper. Since high velocities might be expected at the sharp corners, a model in which these corners were rounded was also tested.

The most important geometrical relationship with the stream was included as an integral part of the tests: in the case of the piers, the angle of approach α of the stream; and in the case of the abutment, the relative length of the approach fill, or the contraction ratio β .

To overcome the difficulty of following the course of the scour without affecting the pattern, layers of colored sand were placed at known elevations below the original sand bed (Fig. 4). These layers permitted the observation of the scour pattern against time, and also served to delineate the contours of the hole of greatest extent. Photographs taken from a fixed relative position formed the final record.

The sorting effect usually inherent in the process of scour was eliminated by the use of a closely graded sand having the characteristics shown in Fig. 6. The colored sand was produced by dying the silica sand with an aniline dye (Sudan III) in a 1-percent benzene solution. The physical properties of the colored layers were therefore identical to those of the remainder of the sand bed. Figure 7 illustrates the techniques employed in preparing for a run. The model was first positioned and plumbed, then red layers 0.01 foot thick were introduced at intervals of 0.1 foot below the surface of the sand. Finally a sand bed extending from 20 feet upstream to 5 feet downstream was placed and leveled.

Prior to establishment of the standard operating procedure a series of runs was made with different model sizes, depths of flow, and velocities. As a result of this series the models shown in Fig. 3 were chosen and the following procedure for the tests on the piers adopted. With the tailgate in its highest position, the flow was fixed at 1.875 cubic feet per second - a condition which did not cause movement of the sand. The tailgate was then slowly lowered until a depth of flow of 0.3 foot was reached, the approach velocity then being 1.25 feet per second. The times of starting, of initial movement, and of water-surface establishment were recorded. As the scour hole increased in depth, the time of appearance of each layer was also noted. At the end of three hours the tailgate was raised until sand movement ceased. The intake valve was then closed and the water drained from the flume. Any slight excess of sand obscuring the red contours was removed and a standard photograph taken. The procedure adopted for the abutment tests was identical except that the single wide flume was used, and separate tests were run (a) with an approach velocity of 1.25 feet per second and (b) with a mean velocity in the contracted section of 1.25 feet per second.

Some progress has been made on an instrument to measure the scour depth electrically, although a satisfactory pilot model has not yet been perfected. The essential elements of the circuit consist of two vertical electrodes extending partially through the sand bed and partially through the water. The capacitance between the two depends on the relative depths of the two media surrounding the electrodes. Thus in Fig. 5 the capacitance of the circuit with the sand at position A is greater than with the sand at position B . The value of a technique of this type would lie not merely in its usefulness in the laboratory but also in its applicability to an automatic recording system for the field.

A diagram of the present circuit is shown in Fig. 8. Modification of some of the values would be necessary for the field, and perhaps the insertion of an amplifier before the recorder.

Interpretation of Experimental Results

A typical set of standard photographs is shown in Fig. 9. Similar photographs were used as the basis of Figs. 10 to 17, the scour patterns around the piers, and Figs. 18 to 25, the scour patterns around the abutments. The shape and relative depth of the scour holes are indicated by the contour intervals of 0.1 foot. Although these values cannot be interpreted in terms of actual depth of scour to be expected in the field, they nevertheless embody a comparative measure of scour tendency as a function of pier and abutment geometry.

Several general characteristics are common to all the scour patterns around the piers. The upstream portion of the hole has the approximate form of an inverted cone, sometimes distorted from the circular, with side slopes equal to the angle of repose of the sand. The zone of greatest depth is displaced slightly upstream from the face of the pier. Deposition which occurs in the low-velocity area behind the pier divides the downstream portion of the scour hole into two separate tails.

In the absence of a web, a separate scour hole is formed at each shaft of the pier. At small angles of approach (from 0 to 10 degrees) the downstream shaft is shielded by the one upstream, with an accordingly shallower scour hole. As the angle increases, however, not only is this protection lost, but the downstream shaft becomes subject to currents of higher velocity deflected by the shaft upstream; this results in a shift of the region of deepest scour to the downstream hole. At large enough angles, of course, the interference effect practically disappears.

When the pier as a whole is parallel to the flow, exactly the same pattern results whether or not the web is present. At increasing angles, however, basically different patterns obtain. The web then plays an increasingly more important role, a scour depth twice as great being attained at an angle of 30 degrees and two and one-half times as great at 45 degrees. Little if any local variation can be ascribed to shaft shape at maximum angles, both the flow and the scour pattern then approximating those which would occur around a simple flat plate.

The most pronounced difference between the effects of round and rectangular shafts is observable at the small angles, when local shape is important. As a consequence of the higher local velocities and greater resistance to flow resulting from the sharp corners of the rectangular shaft, the scour depth is increased some 15 percent beyond that for a cylinder of the same breadth. A comparison of the structurally equivalent round and rectangular piers (i.e., the round and the small rectangular) is difficult to make due to the change in width-depth ratio. It is believed, however, that the equivalent rectangular pier will produce a somewhat greater scour depth. The constancy of the pattern around the leading shaft of the round type in the absence of appreciable web influence is adequate proof that all experiments can be successfully duplicated.

Since a partial web extending down to low water is often used, a test (Fig. 16) was run with the web extending one-half the depth of flow below the surface. A scour depth intermediate between those for a full web and no web was obtained. With a greater depth of web it is likely that the increased velocity of flow under the web would result in scour as deep as that for the full web. By replacing the full web with a screen, the condition of a lattice or open-work web was simulated. Again the scour was less than that of the full web. While this construction might prevent large debris from lodging between the shafts, it would eventually become clogged with small debris, thus defeating its special purpose.

Another set of tests (Fig. 17) was made to indicate the effect of a footing which became exposed during the scour process. Although the footing was partially undermined at the higher settings, the difference in scour depth was not appreciable. Since the limitations of the present flume did not allow complete exploration of this condition, further tests are contemplated.

By analyzing the flow pattern around a typical pier, the progress of the scouring action and many features of the scour hole can be more clearly understood. At the outset, with the bed level, the flow around the pier is essentially two-dimensional - i.e., in horizontal planes. Although sediment transportation is then general, the capacity is nevertheless higher at points of high velocity such as the corners of the rectangular shaft (Fig. 26). Local scouring therefore at once begins, and two depressions centered on the corners are rapidly formed. These depressions are conical, since the material will not stand at a slope (Fig. 26c) greater than the angle of repose. As the scour progresses, the roller occurring across the upstream face (Fig. 26f) is intensified to the point of becoming the active scouring mechanism. The sides of the depression begin to slough as the depth increases, and this material is carried out of the hole by the spiral forming on the sides of the pier (Fig. 26e). Such action will continue at a progressively lower rate as the roller velocity decreases with increasing depth of scour.

The similarity between the flow pattern around immersed bodies and the scour patterns which they produce is evident in Fig. 27. Such a correlation might be expected, since it is the variation in velocity in the area around the obstruction which causes a change in the capacity for sediment transportation and thus results in the scour phenomenon. In much the same manner the drag on an immersed body is a direct result of the effect of that body on the velocity field. Special two-dimensional models of the piers with webs were tested in the low-velocity air tunnel of the

Institute in order to compare drag and scour values. The drag coefficients obtained are presented in Fig. 28; in the case of Model IIb the lift coefficients were also obtained. In Fig. 29 the correlation between drag and scour values is evident; in this plot the abscissa is the ratio of the drag coefficient to the coefficient at zero angle of attack, and the ordinate is the square of the ratio of the scour depth to the depth at zero angle of attack. It is readily apparent that within the experimental limits these two values are equal up to an angle of 45 degrees, when the scour depth begins to lag.

For the abutment forms, the history of the scour-hole formation is similar to that for the piers, the only essential difference being that the flow passes - and hence the scour occurs - on one side only. Although the velocity of approach was first held constant as the abutment length increased, the depth of scour thereby increasing, the contraction effect on the mean velocity was never sufficient to cause a general lowering of the bed. On the other hand, when the mean velocity in the contracted section was held constant, approximately the same depth of scour were obtained for all lengths of abutment, as is evident in Figs. 19, 21, and 23. Although there is a strong indication the latter velocity has primary significance, the proof is not yet conclusive. Noteworthy is the fact that the scour centered on the upstream corner of the abutment for all forms and conditions tested.

When piers and abutments are considered in combination, a multitude of geometrical possibilities are presented. For exploratory purposes, tests were made on a combination of the stub abutment, Model VI, and a full-webbed pier, Model IIb. Very little change can be noted in the scour adjacent to the abutment (Figs. 24, 25), but the scour pattern around the pier, although slightly deeper, is similar to that with the pier alone at an angle of 45 degrees to the current. It would seem then that the pier exerts little influence on the flow around the abutment, but that the abutment, in effect, swings the current against the pier. Although the importance of investigating combinations such as this is obvious, the plethora of possible combinations also makes it evident that the work should be postponed until more is known of the scour process.

Conclusions and Recommendations

Although the foregoing experiments on typical Iowa bridge piers and abutments necessarily indicate relative rather than actual depths of scour, the simplified conditions of the experimental program permit several conclusions of immediate practical significance to be drawn.

The danger of placing piers at an angle to the current is clearly illustrated, even small angles having an appreciable effect upon the scour. Predicting the direction of flow in a constantly changing river is assuredly not an easy matter. However, since the greatest danger occurs during flood flows, the valley line appears to be the primary factor to consider in determining pier alignment.

From the approximate relationship shown to exist between the drag coefficient of an immersed body and the relative scour depth, the desirability of a rounded or streamlined pier is obvious. In this connection, the influence of the web is predominant. Unfortunately, structural and debris requirements now lead to designs which are at odds with the hydraulic requirements. Future studies on the three-dimensional aspects of pier shapes leading to minimum scour must seek to reconcile these factors.

Most noteworthy in the abutment results is the position of the scour hole, which clearly indicates those portions of the abutment requiring the greatest protection. Evidently, the abutment need not be strengthened at all points, but only where the scour will occur. For the gravity type of abutment, it would probably be impractical to construct a concrete wall to a variable depth for this purpose. However, supplementary protection such as sheet-piling or sunken revetment could economically be applied. For the case of the stub type, on the other hand, the sheet-piling enclosing the approach could easily be driven to a variable depth, thereby providing maximum safety without undue expense. The paving or rip-rapping of the slopes should be planned in the same manner, the upstream corner and neighboring slopes receiving the greatest protection and the remainder being reduced accordingly.

The increase in safety which is afforded by rounding the upstream corner of the gravity abutment is apparent from the measurements. What further reduction in scour may be obtained by reshaping the wall should be determined in a companion study to that of reshaping the piers.

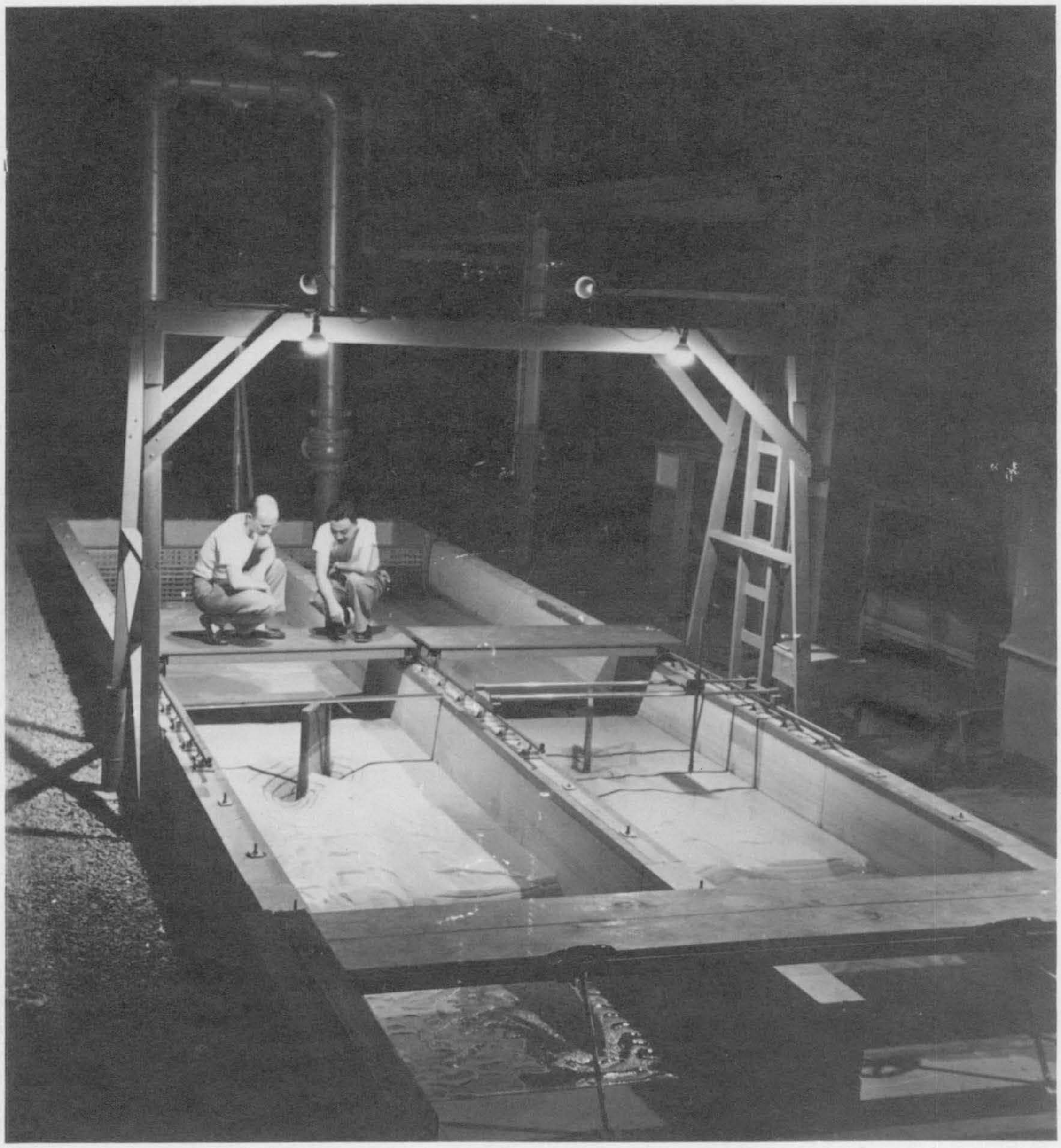


Fig.1 View of Flumes Looking Upstream

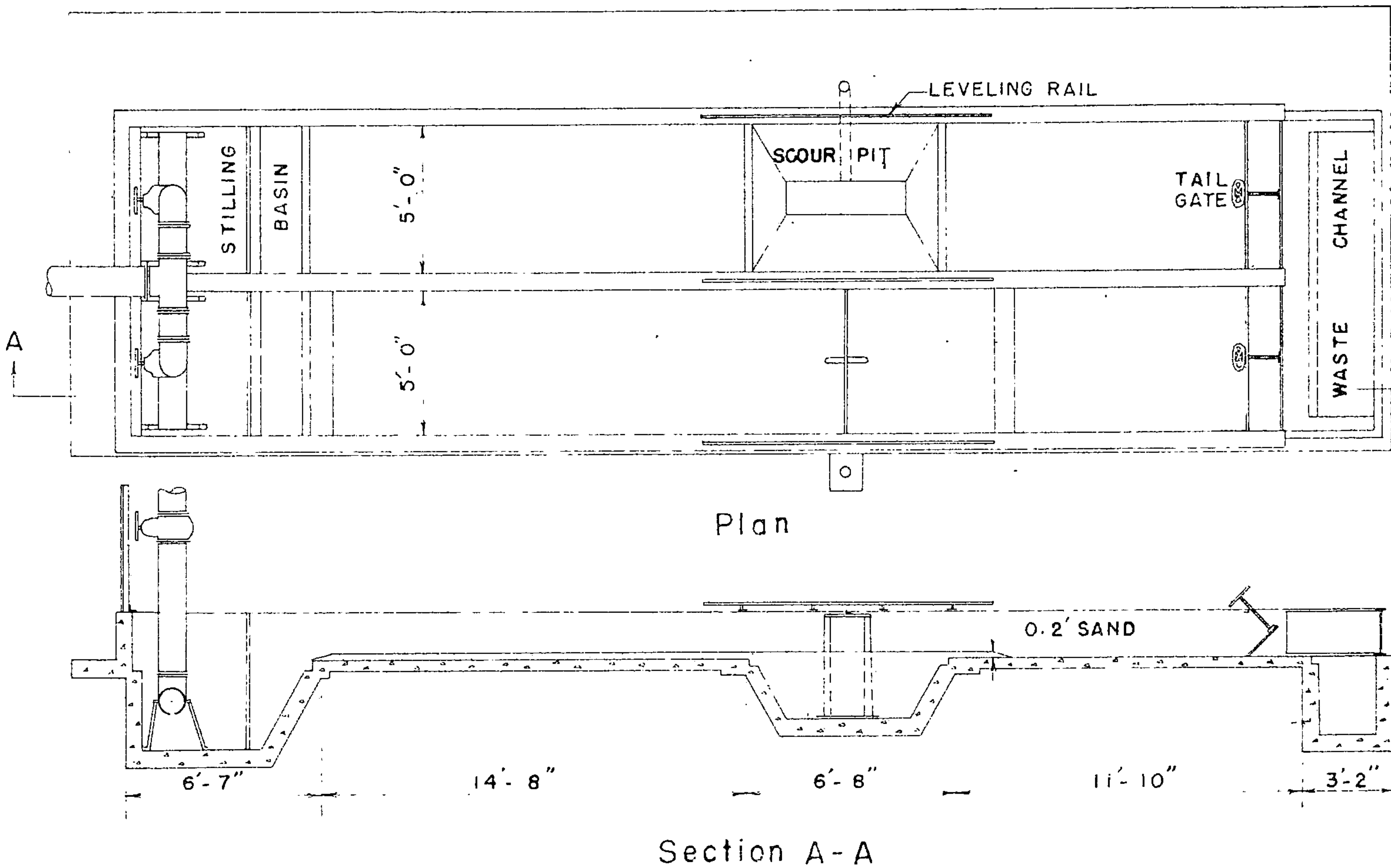


Fig.2 Layout of Flumes

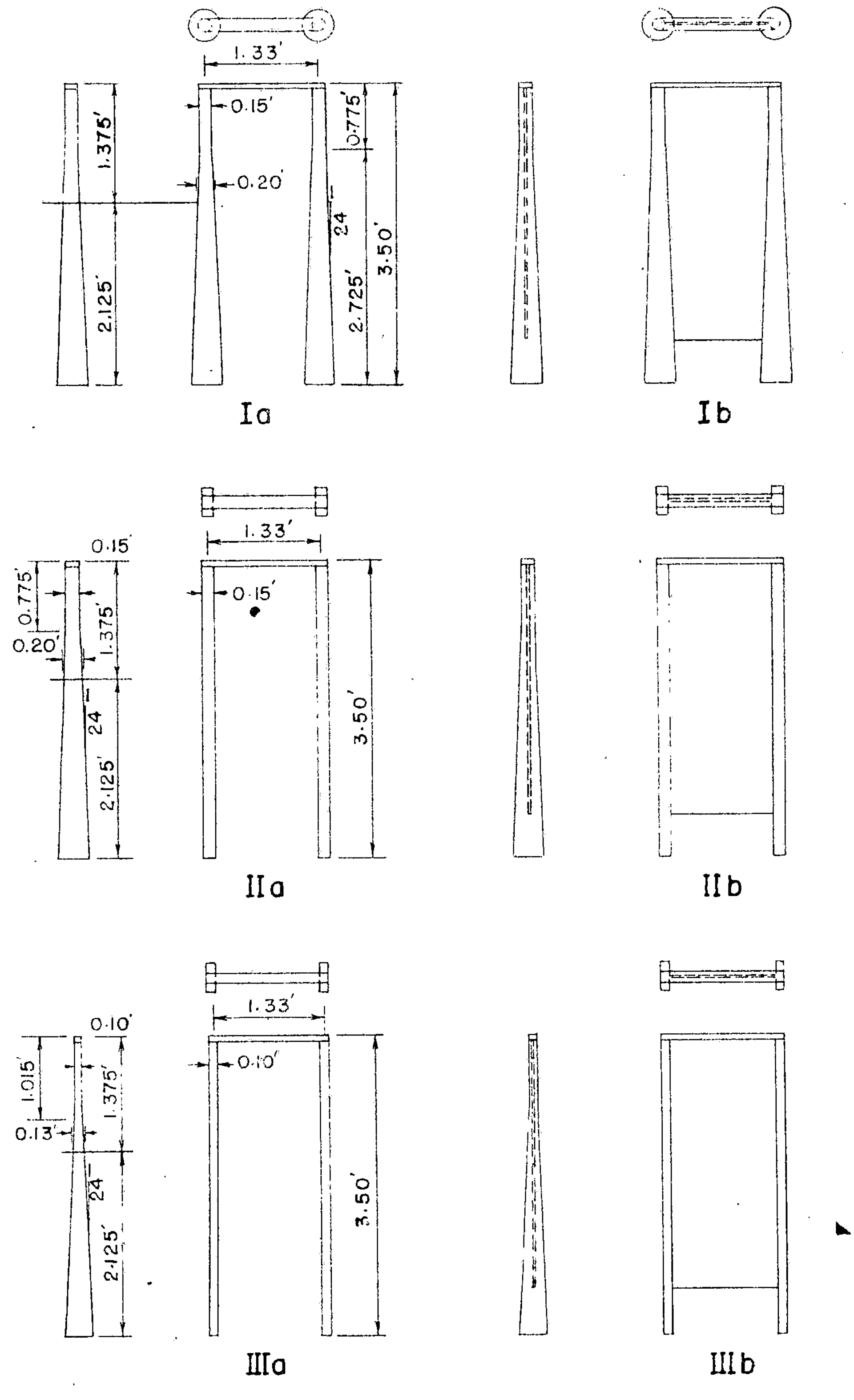


Fig. 3a Models of Basic Pier Shapes

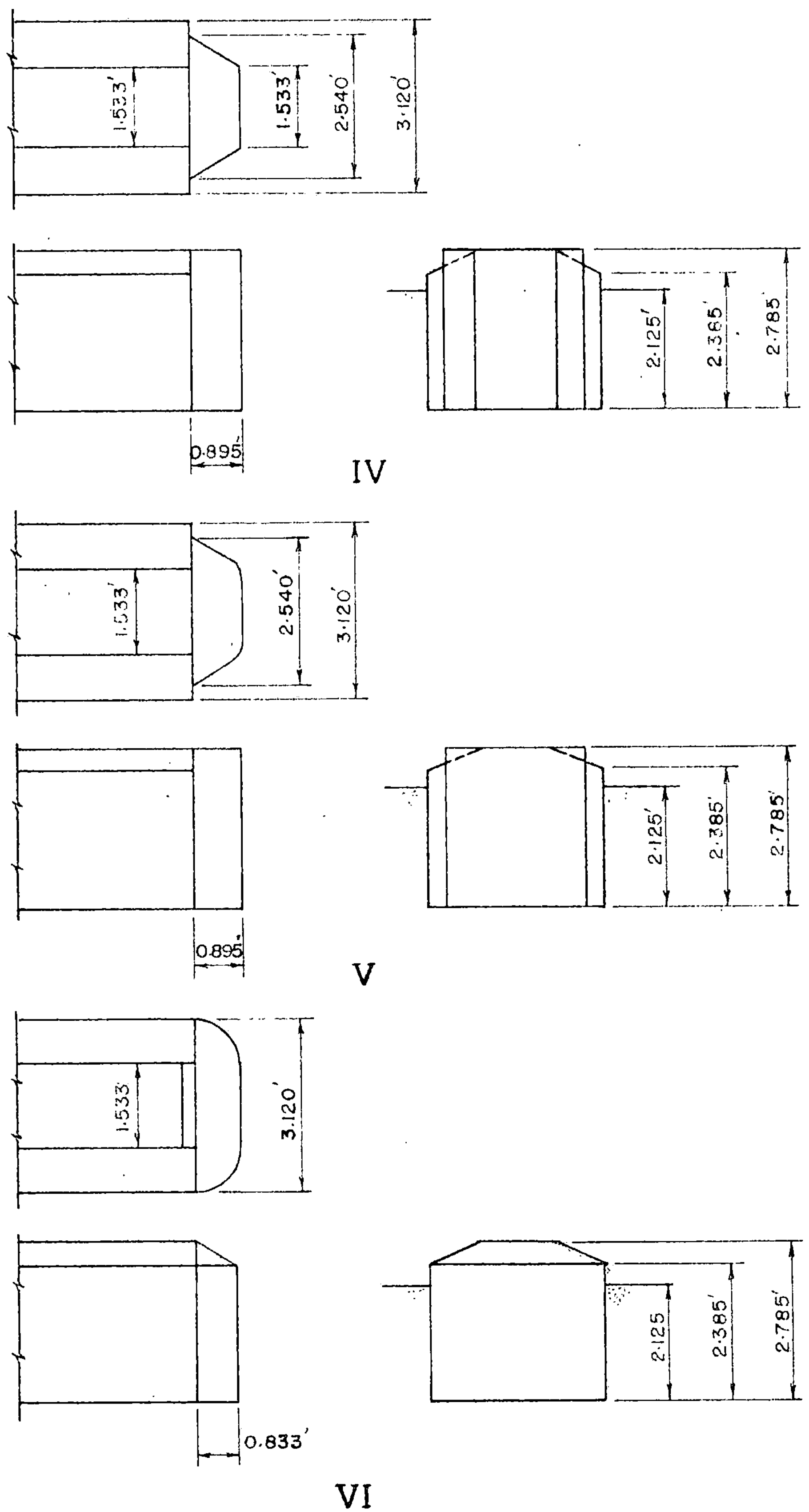


Fig. 3b Models of Basic Abutment Shapes

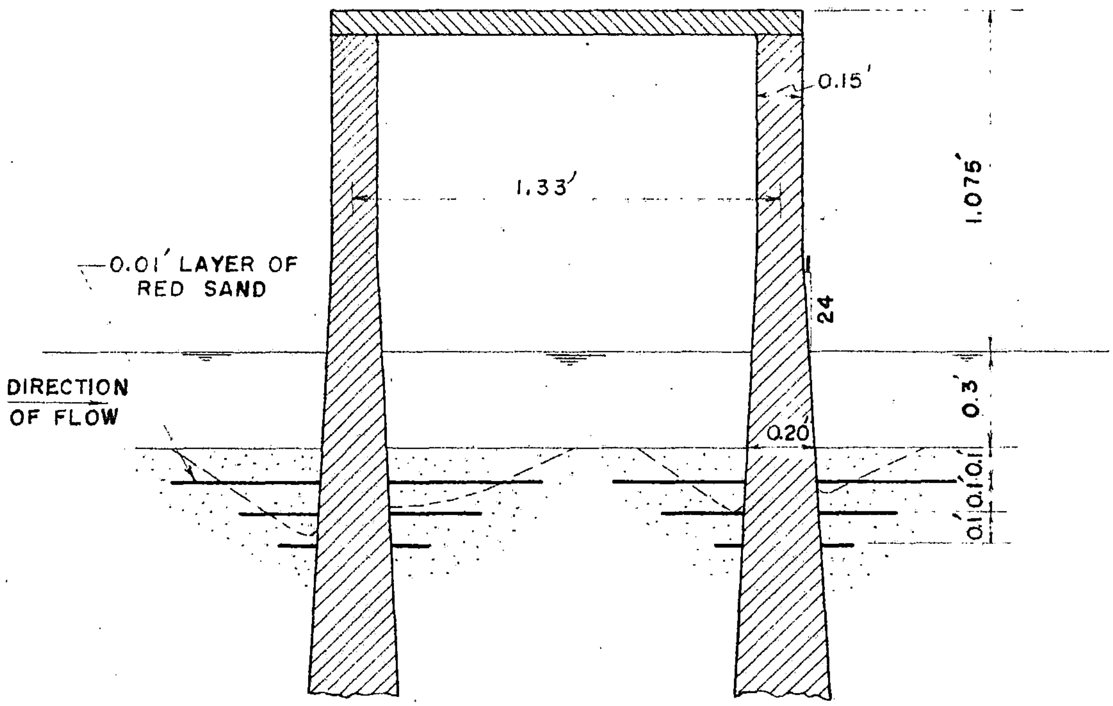


Fig. 4 Sketch of Red Layers

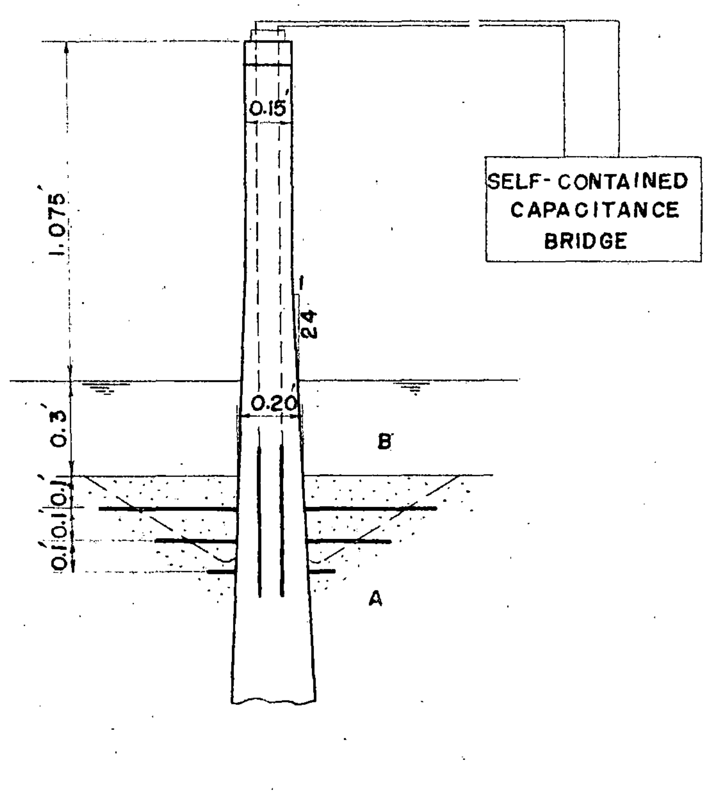


Fig.5 Schematic Layout of Depth Meter

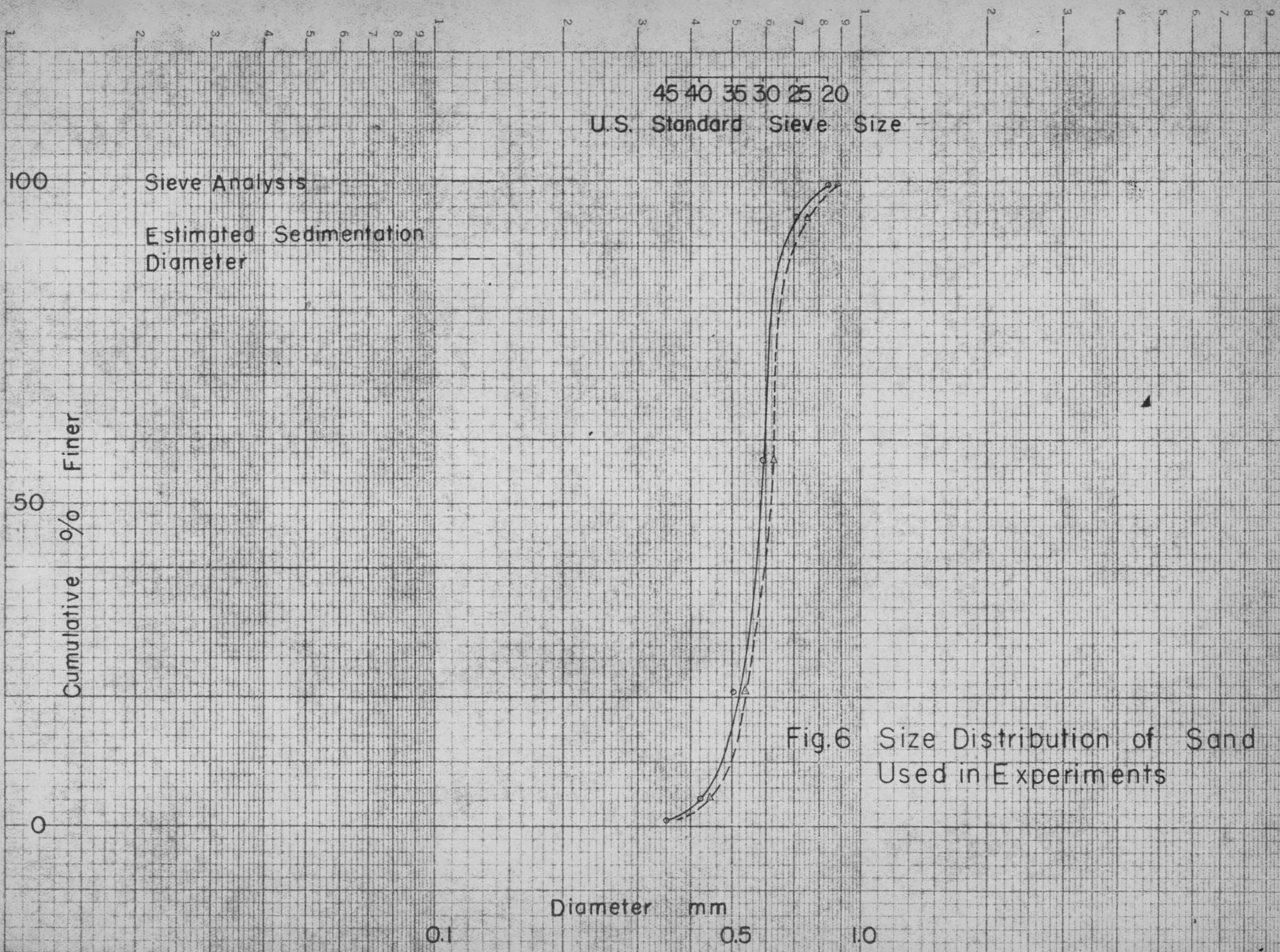
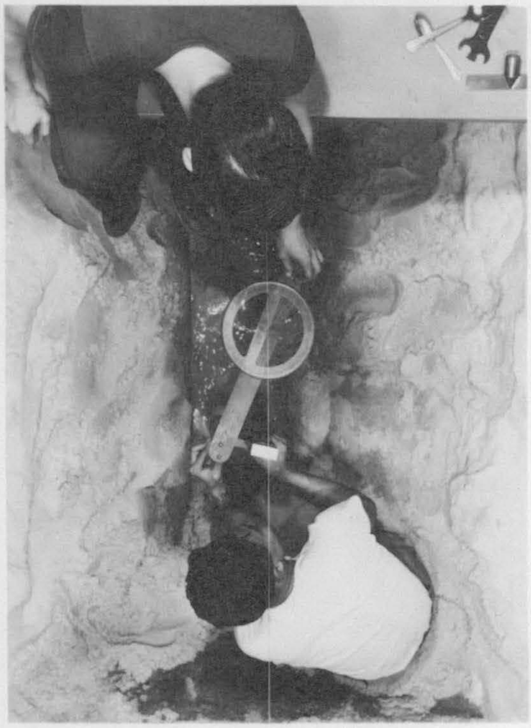
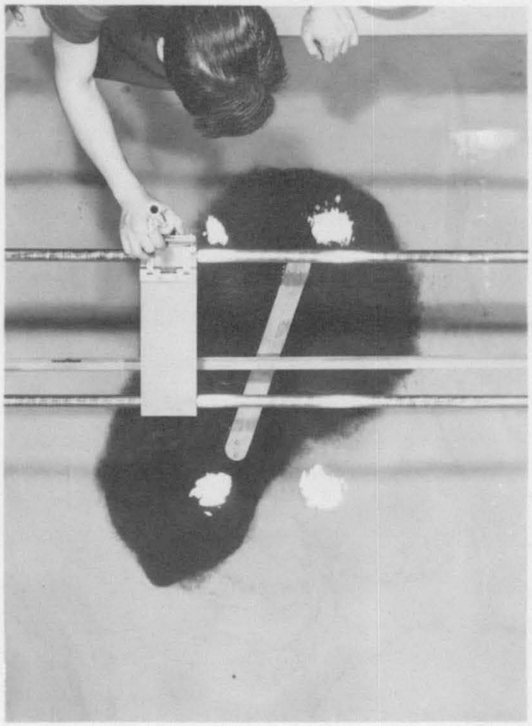


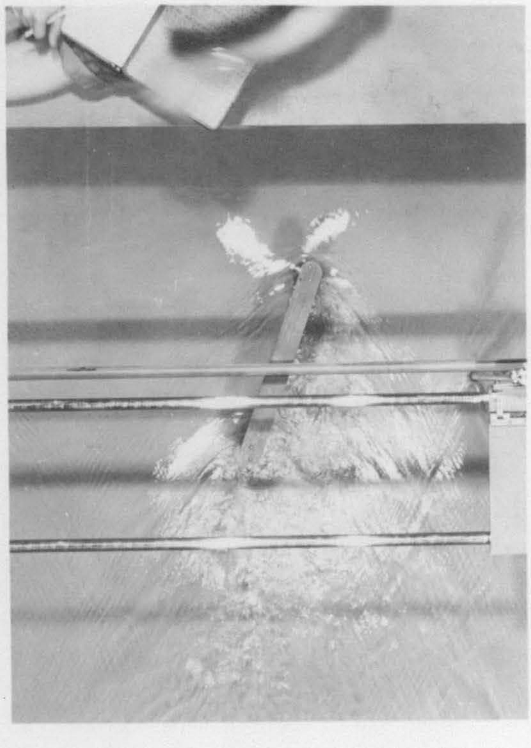
Fig.6 Size Distribution of Sand Used in Experiments



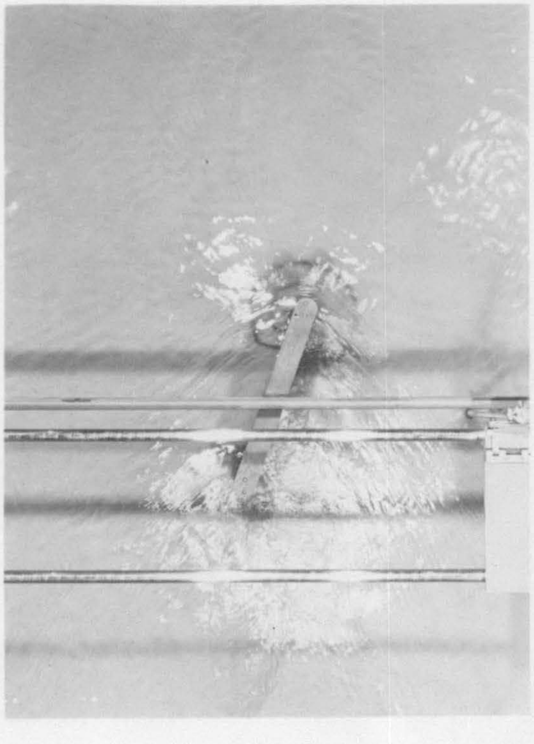
Positioning Model



Placing Final Red Layer

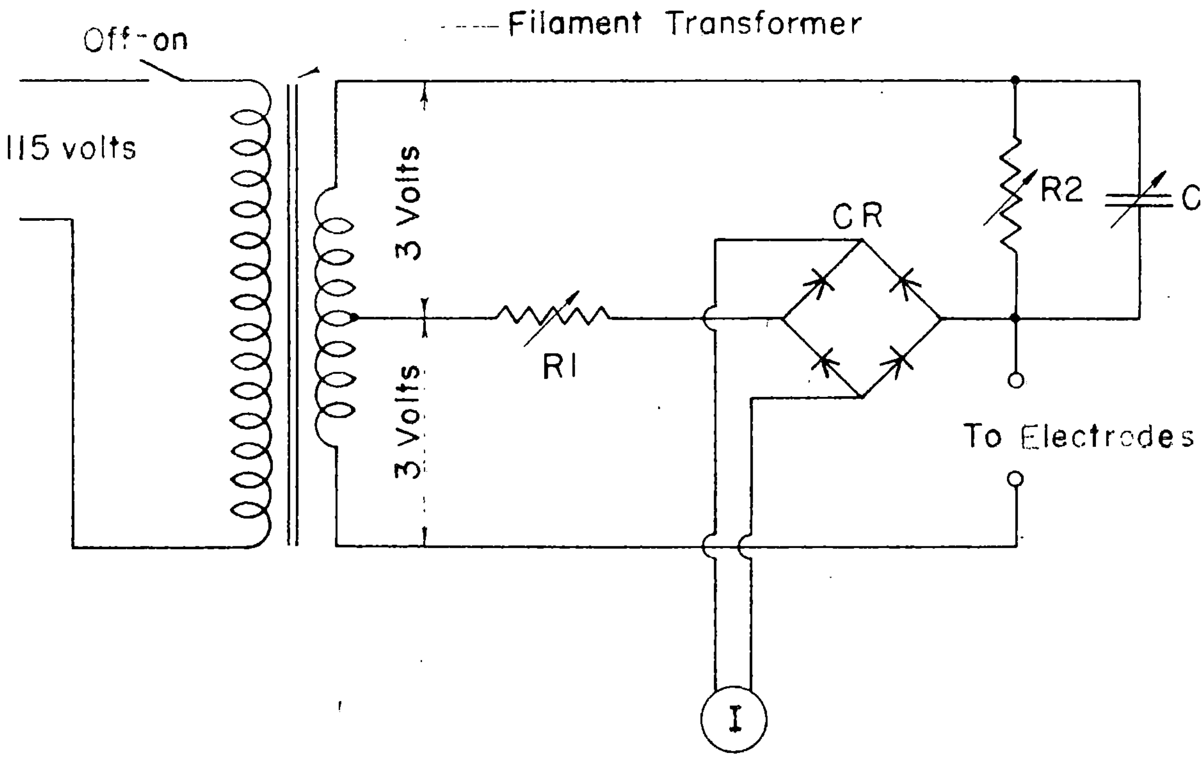


Beginning of Run



Intermediate Condition

Fig. 7 Steps in Preparing and Running a Test



R1 — Sensitivity Control (20,000 Ohms)

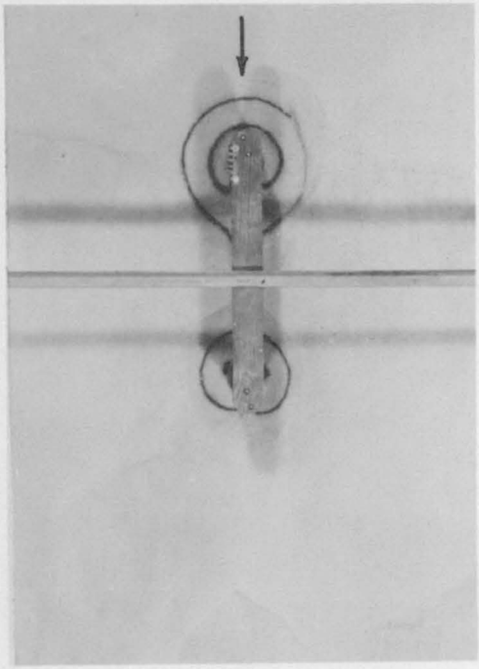
R2 — Balance Rheostat (5000 Ohms)

C — Balance Capacitor (0 to 1mfd)

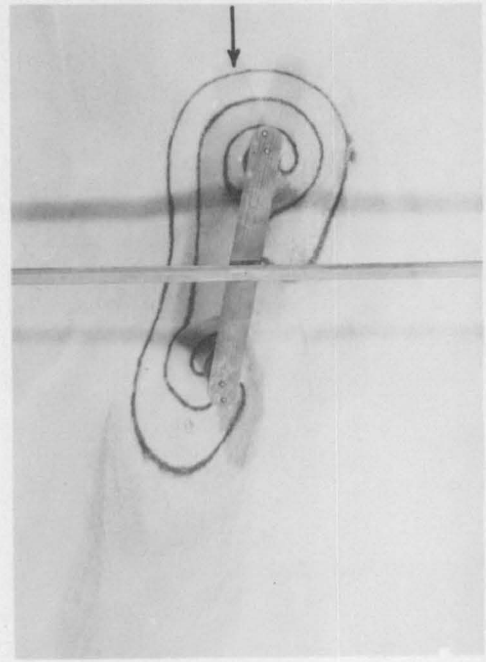
CR — Copper Oxide Rectifier Bridge

I — 0 to 50 Microampere Meter (Sensitive Amplifier and Recorder Could be Used)

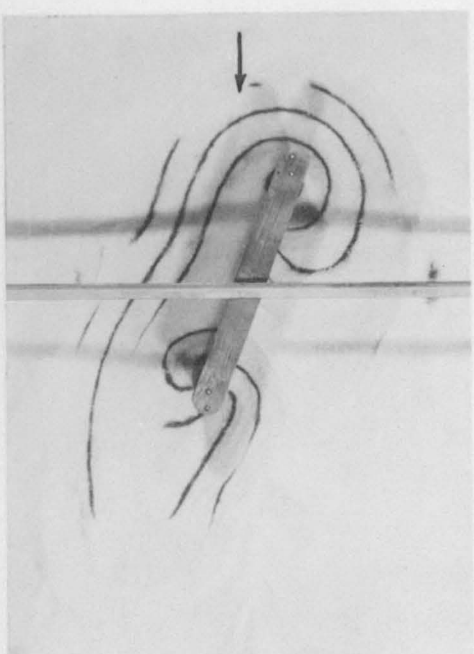
Fig. 8 Circuit Diagram of Electrical Scour Indicator



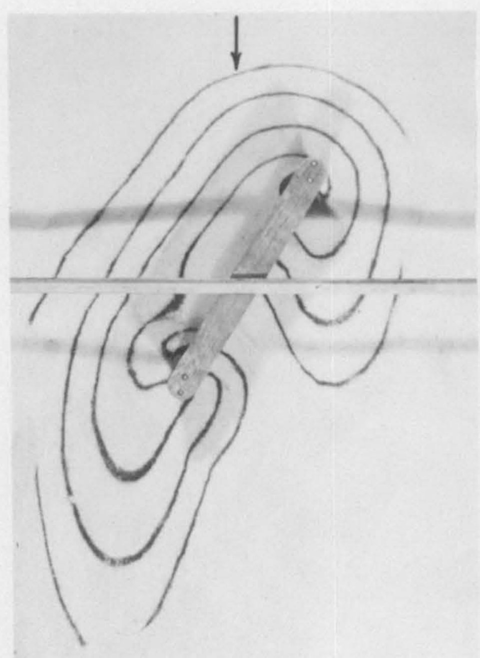
$\alpha = 0^\circ$



$\alpha = 10^\circ$



$\alpha = 20^\circ$



$\alpha = 30^\circ$

Fig. 9 Scour Pattern Around Model Ib

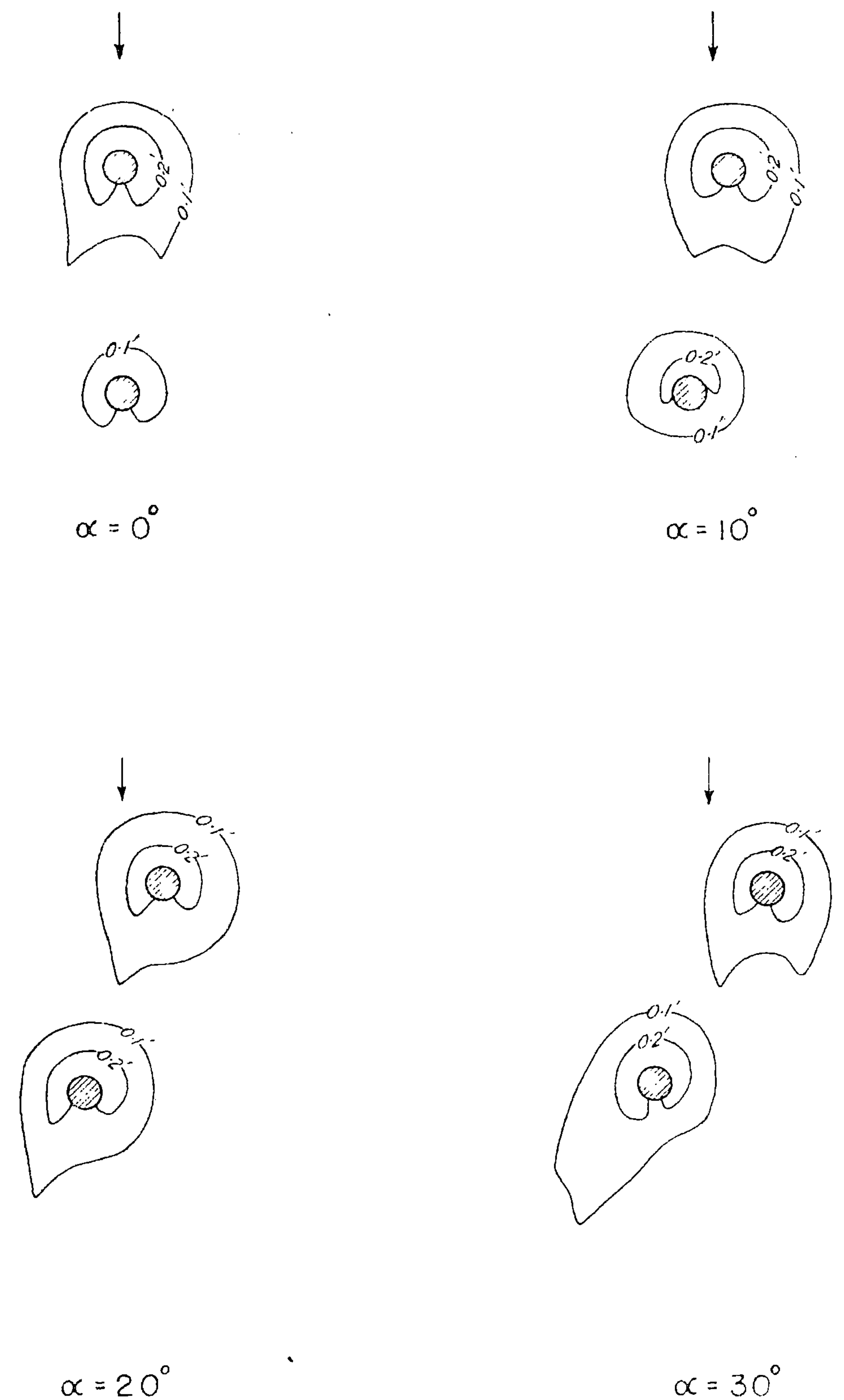


Fig. 10 Scour Pattern Around Model Ia

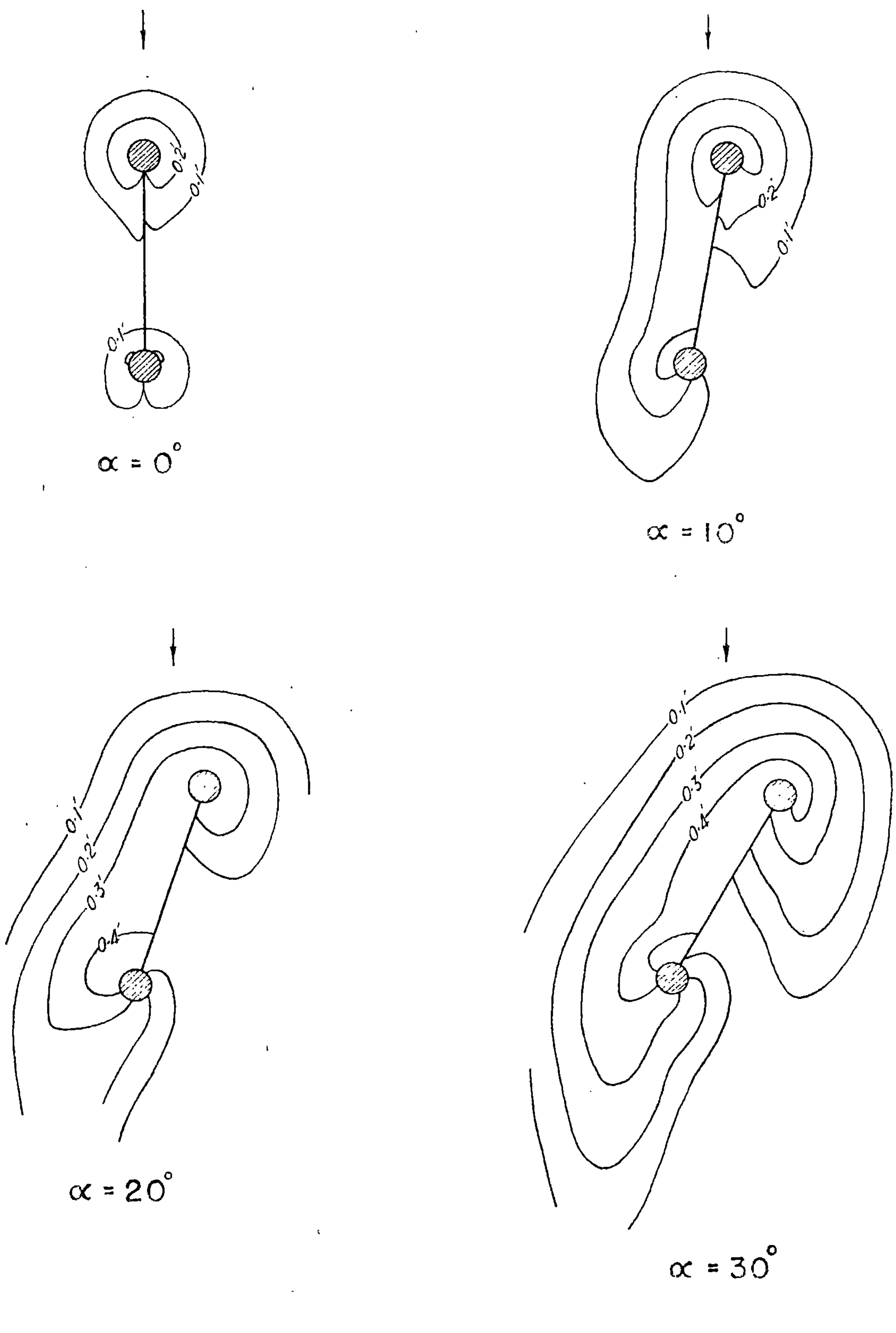


Fig. 11 Scour Pattern Around Model Ib

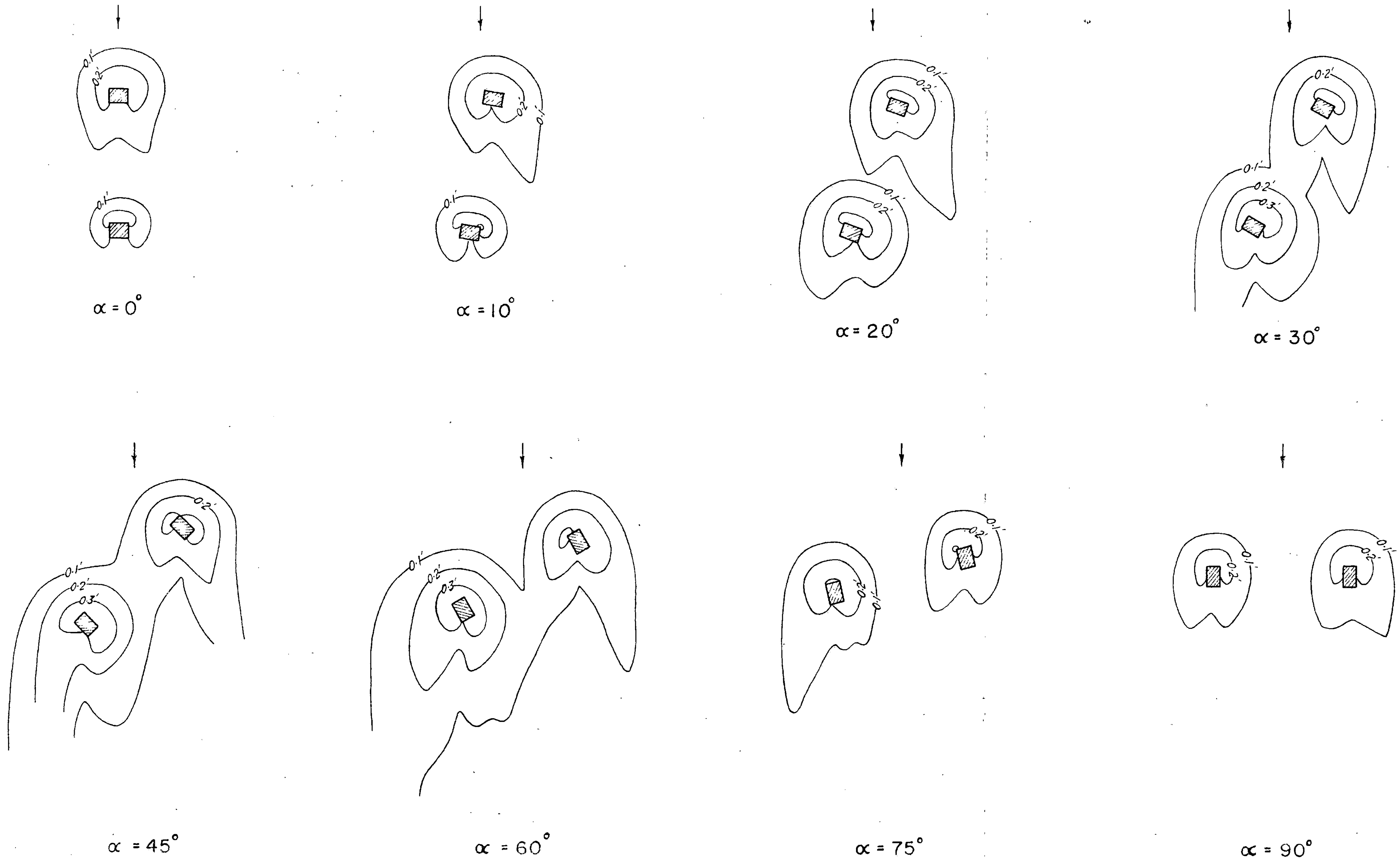


Fig. 12 Scour Pattern Around Model IIa

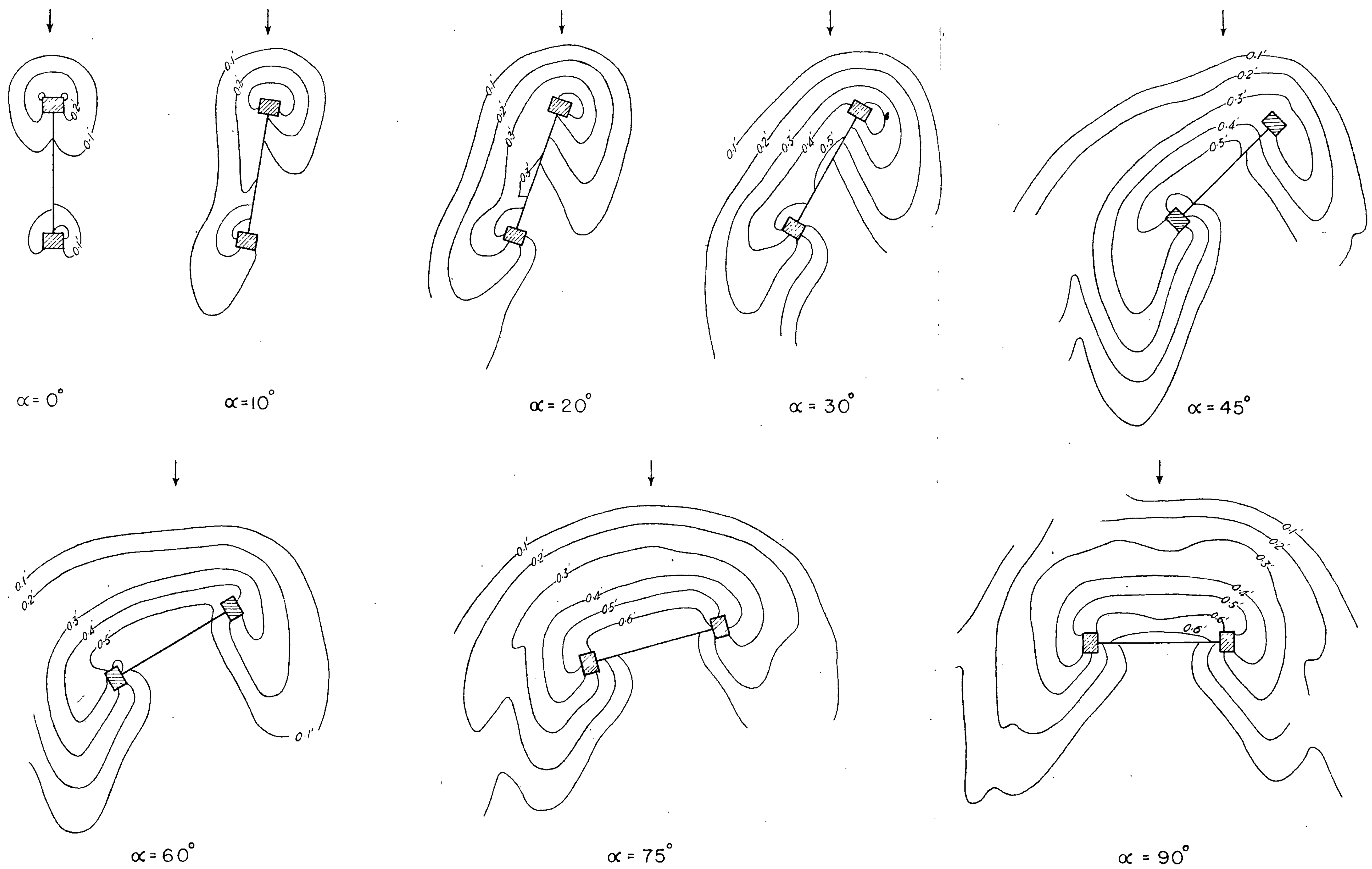


Fig. 13 Scour Pattern Around Model IIb

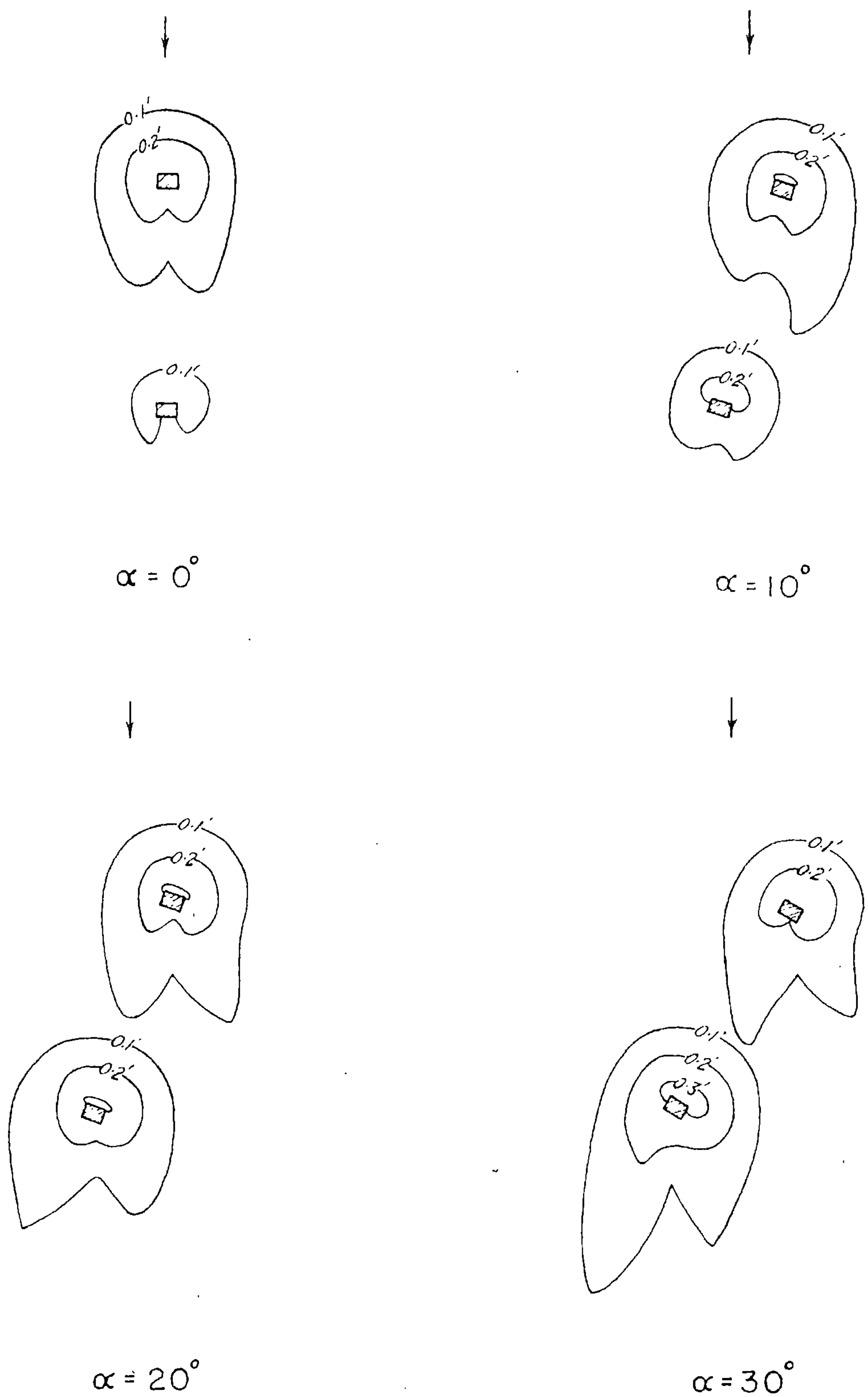


Fig.14 Scour Pattern Around Model IIIa

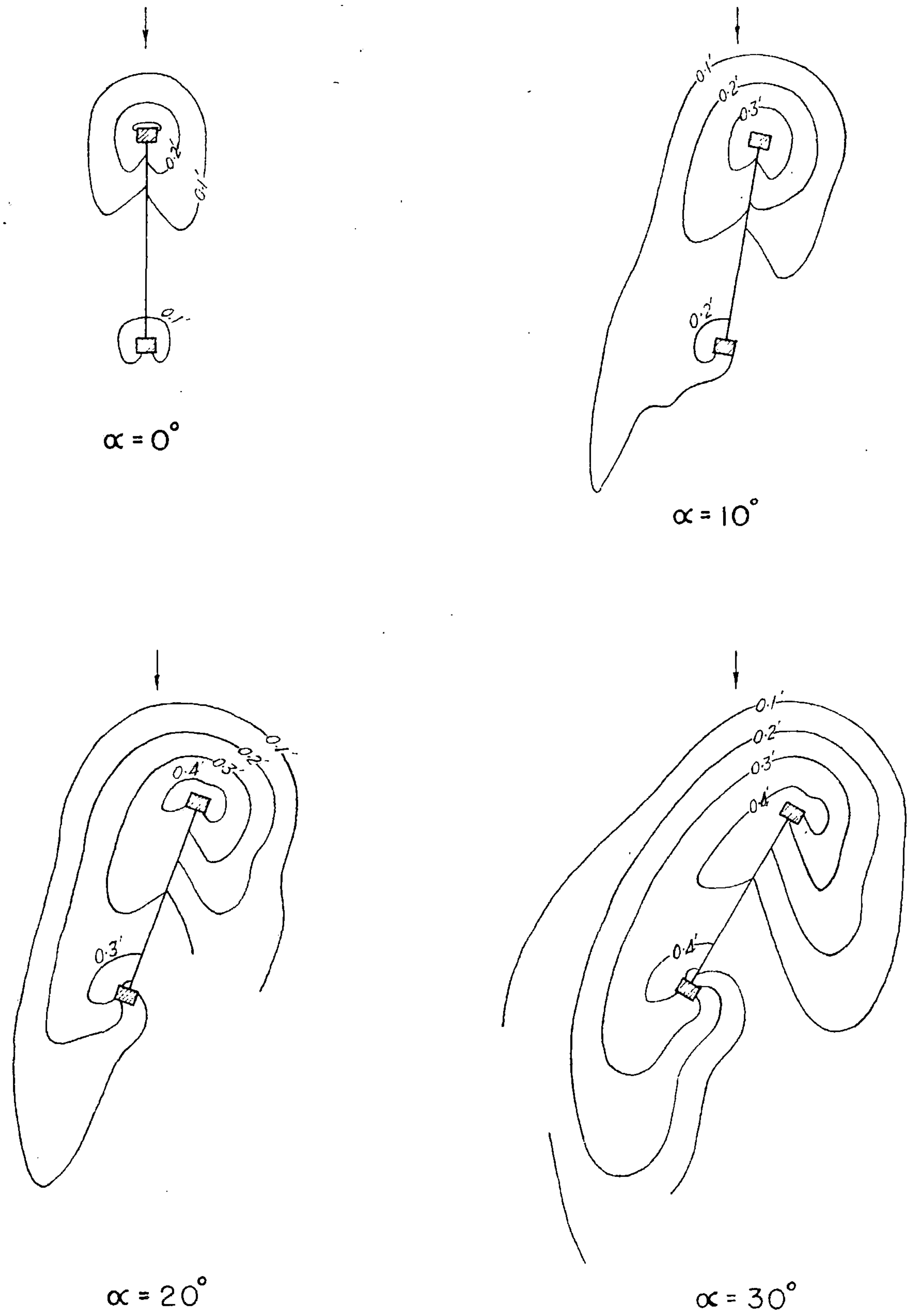
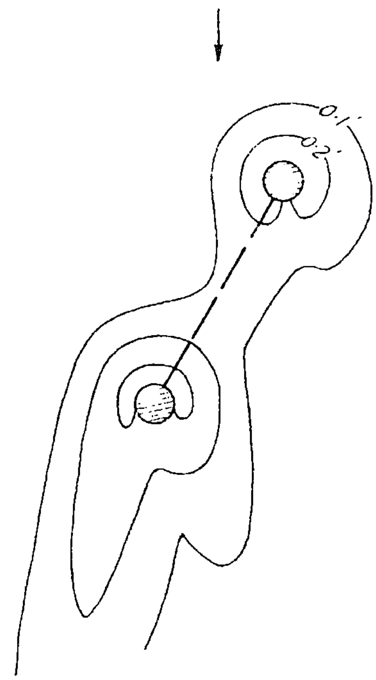
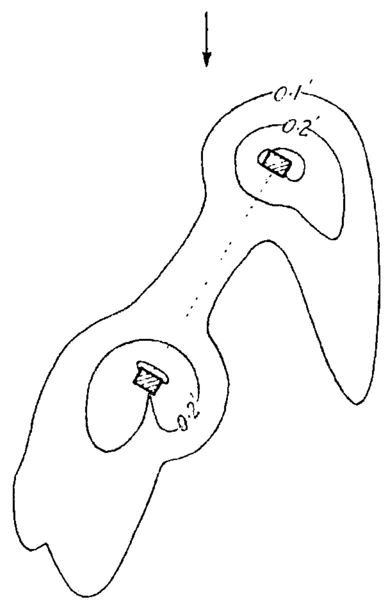


Fig. 15 Scour Pattern Around Model IIIb



Model Ib (Half Web)



Model IIIb (Screen Web)

Fig. 16 Effect of Partial Webs on Scour

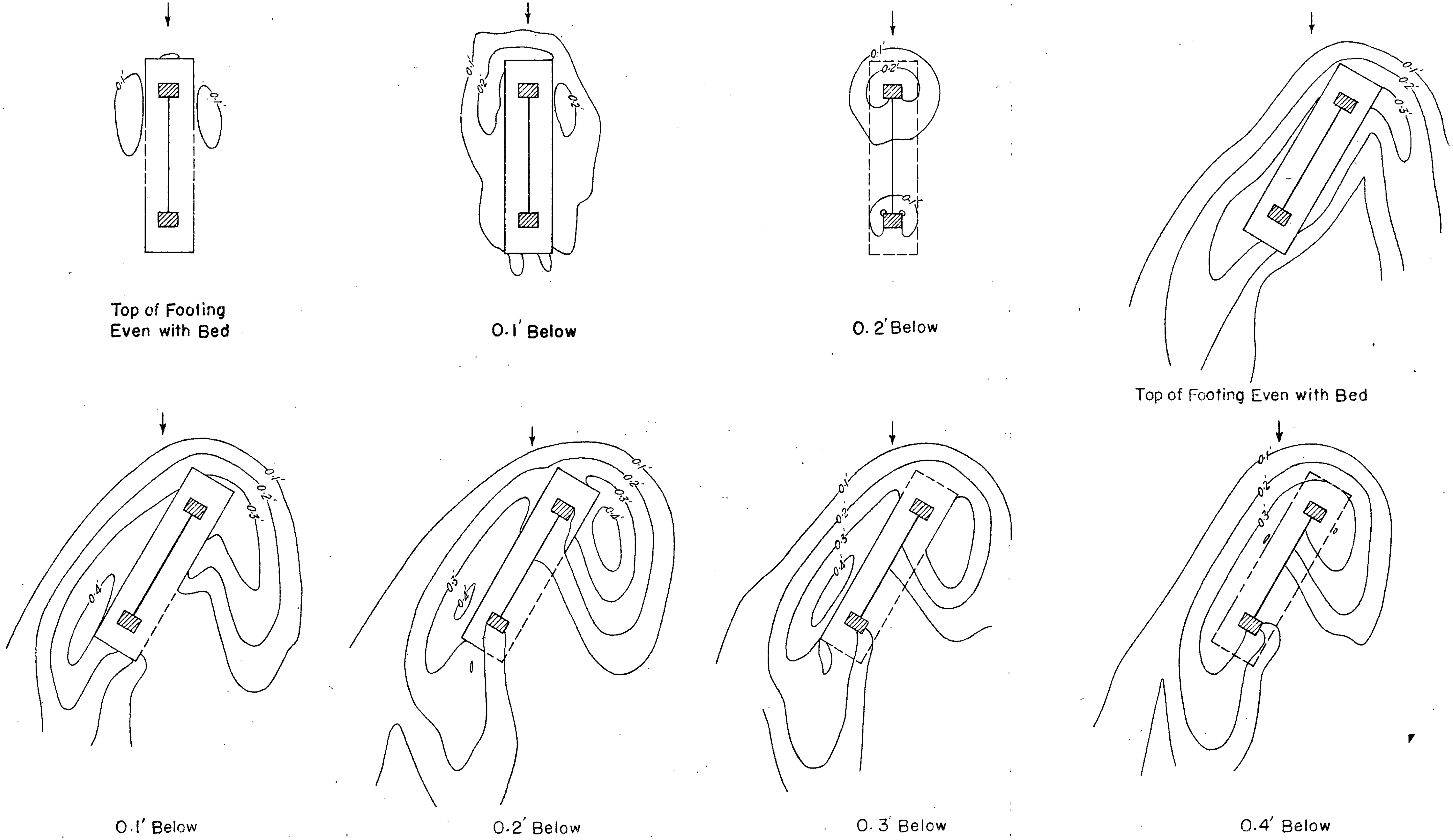


Fig. 17 Effect of Footing Elevation on Scour

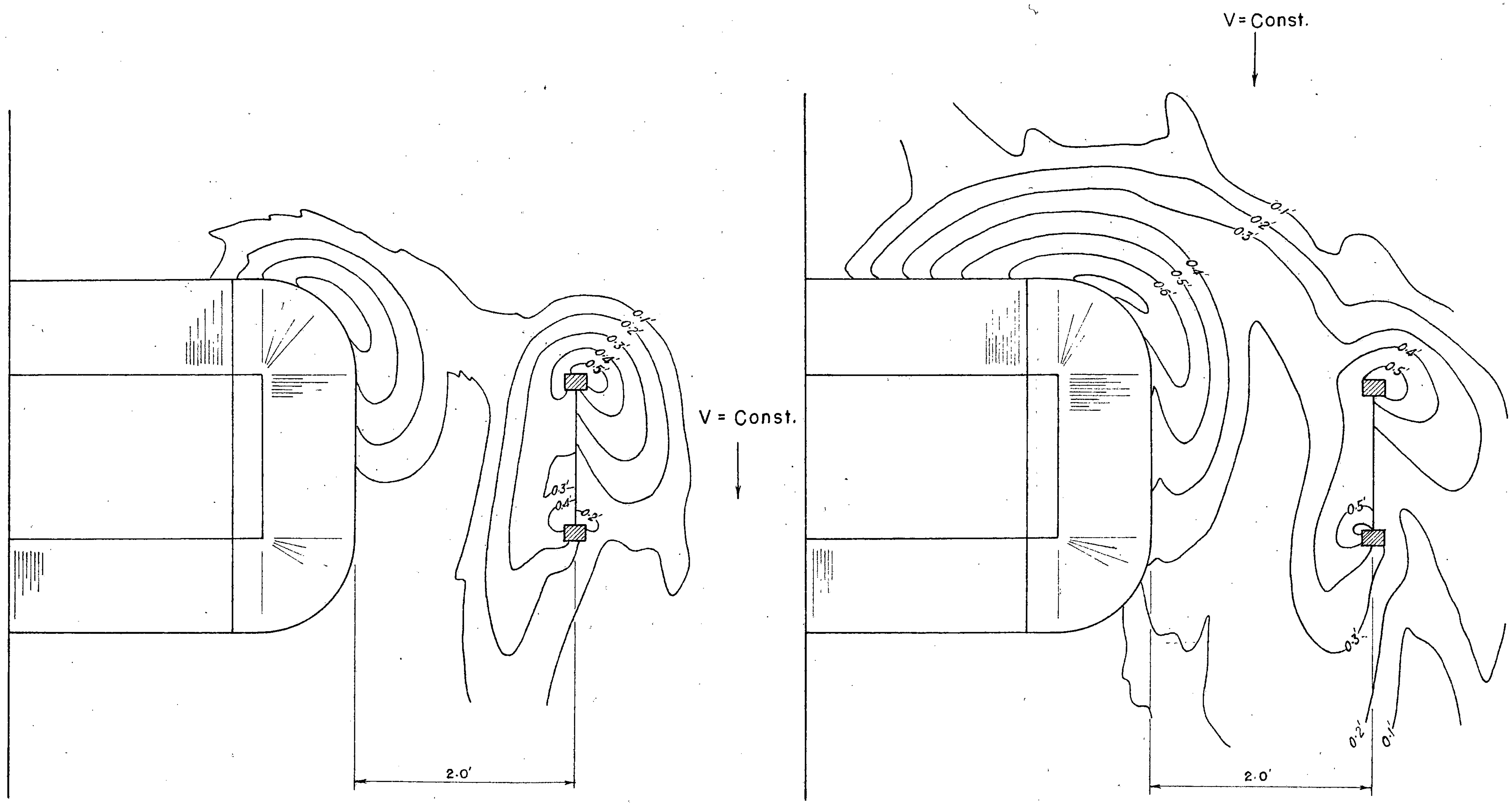


Fig.24 Scour Pattern Around Combination of Models IIb and VI

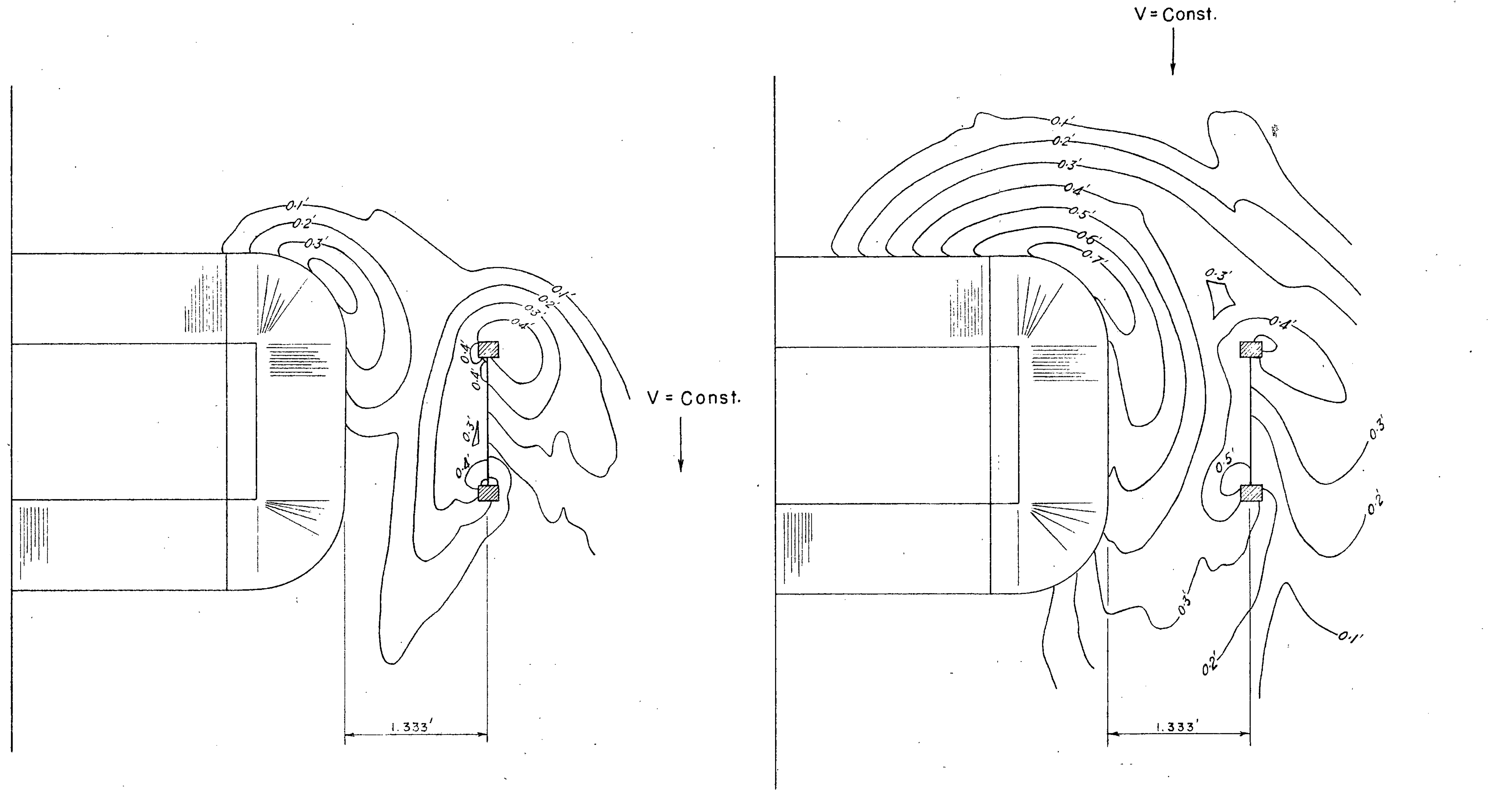


Fig. 25 Scour Pattern Around Combination of Models IIb and VI

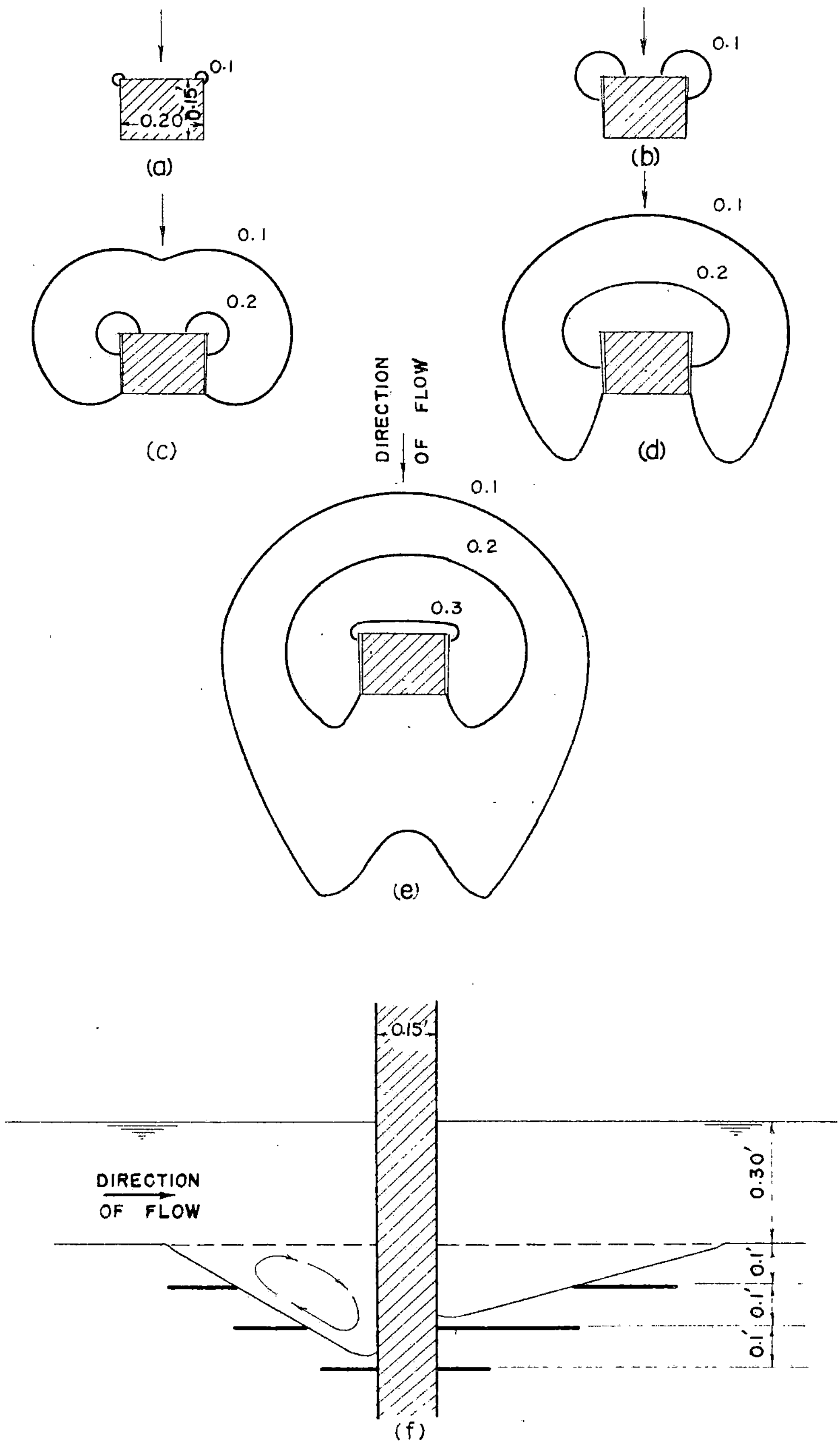
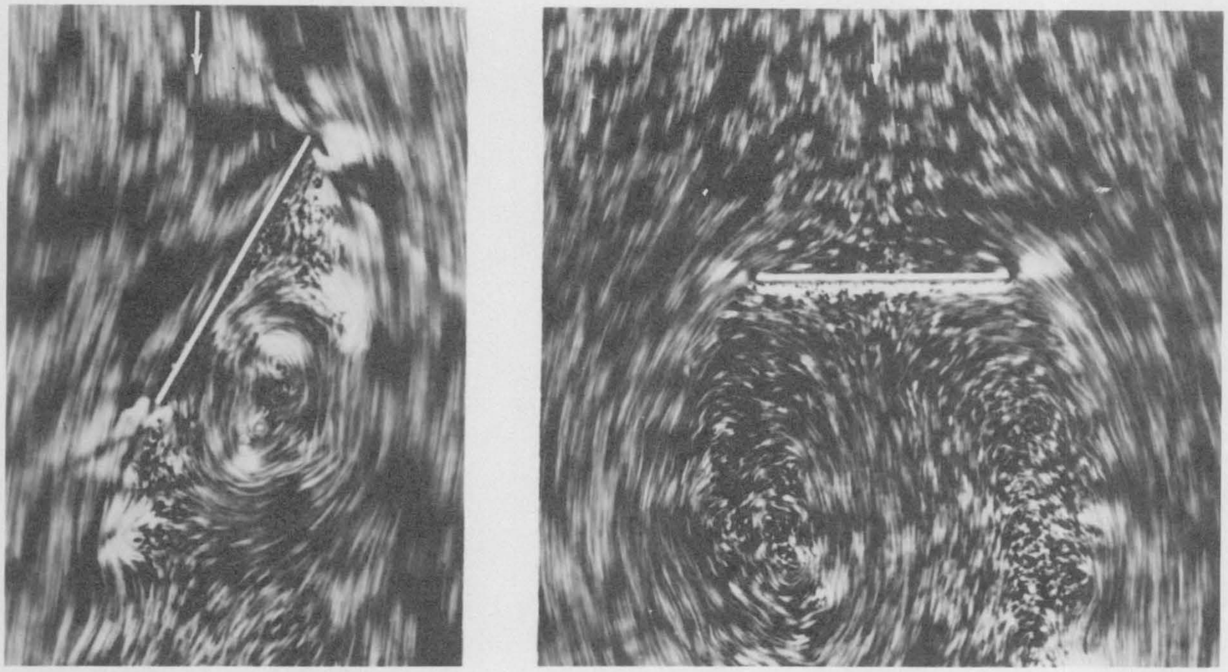
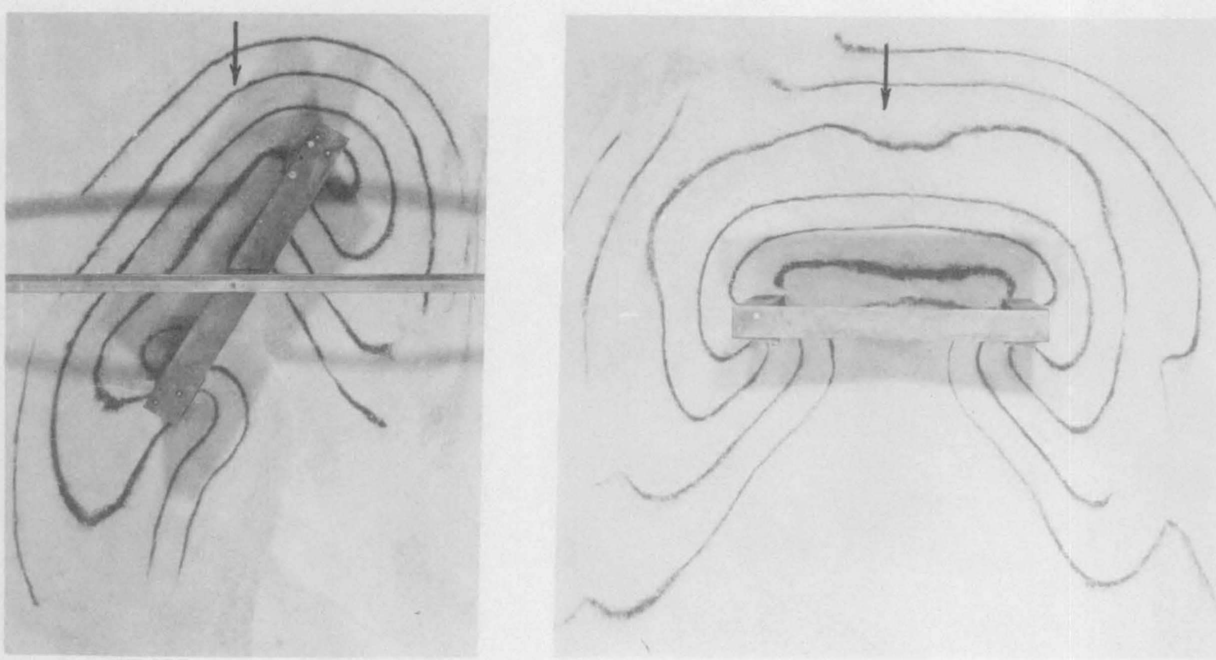


Fig. 26 Sketch of Process of Scour



Flow Pattern Around a Flat Plate



Scour Pattern Around Model IIb

Fig. 27 Similarity Between Flow and Scour Patterns

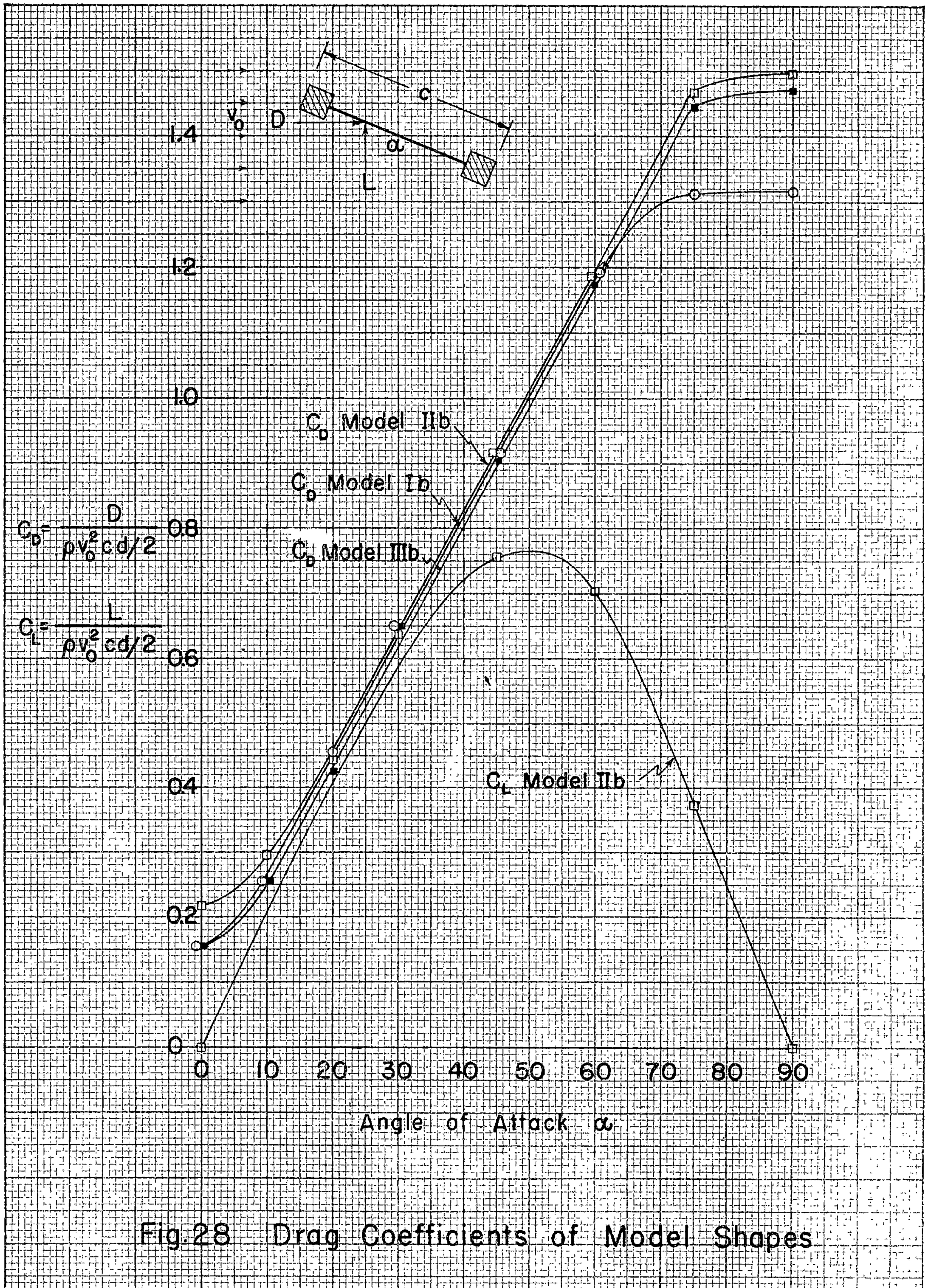


Fig.28 Drag Coefficients of Model Shapes

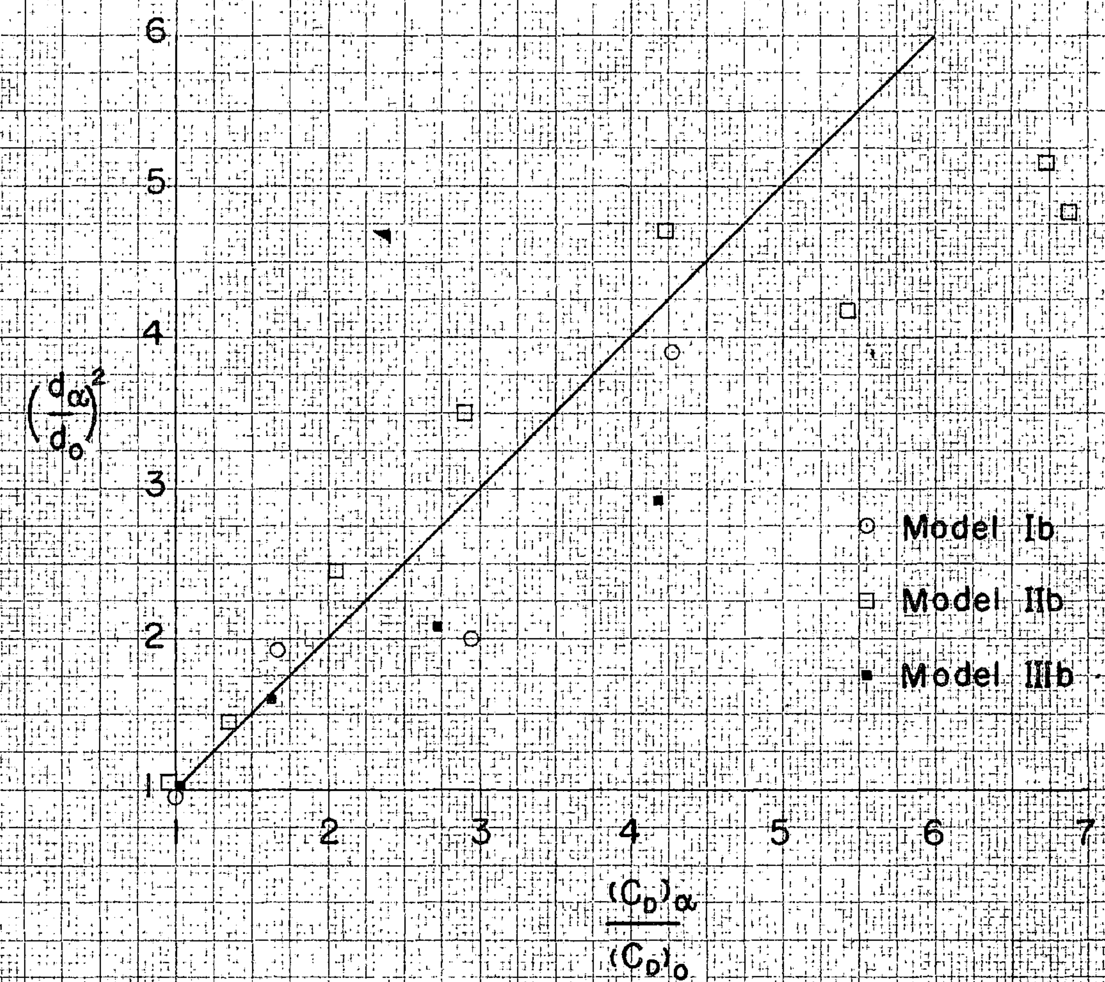


Fig.29 Relationship Between Drag Coefficients and Scour Depths