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CHANNEL WIDTHS IN BENDS AND STRAIGHT REACHES BETWEEN BENDS FOR PUSH TOWING

Hydraulic Model Investigation

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This investigation was concerned with the development of parameters that could be used as a guide in the layout and design of shallow-draft waterways, particularly bends and straight reaches between bends. Results are based largely on model studies using different linear scales and some limited prototype tests.

In negotiating a bend or making a turn, tows occupy a greater channel

(Continued)

20. ABSTRACT (Continued).

width than in straight reaches. The width of channel required depends on the deflection or drift angle which varies with the size of tow, radius of the bend or turn, length of the bend up to about 90 deg, alignment and velocity of currents, weather conditions, direction of travel (upstream or downstream), draft of tow with respect to channel depth, alignment and location of the tow when entering the bend, and maneuverability of the tow. If the deflection angle assumed by a tow in negotiating a bend is known, the width of channel required can be computed using one of the equations from this study. Results include curves showing the deflection angle assumed by tows of various sizes in bends of different curvatures with and without currents. Also covered are bends consisting of compound curves, bends with irregular bank lines, and lengths of straight reaches required between alternate bends. Principal results have been included in OCE Engineer Manual EM 1110-2-1611, Layout and Design of Shallow-Draft Waterways, 31 December 1980.

PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army, in November 1974 and was designed to obtain information that could be used in the layout and design of inland waterways for commercial traffic. The study was conducted in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) periodically during the period January 1975 to December 1980. The prototype tests described herein were conducted by the U. S. Army Engineer District, Vicksburg (LMK), with the assistance of WES during November 1978.

The model investigation was conducted under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and F. A. Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory; and under the direct supervision of J. E. Glover, Chief of the Waterways Division. The engineer in immediate charge of the investigation was Mr. L. J. Shows, Chief of the Navigation Branch, assisted by R. T. Wooley, C. M. Myrick, C. R. Ellerbe, J. L. McGregor, and D. P. George. The prototype tests were conducted under the general supervision of Mr. R. O. Smith, Chief of the Hydraulics Branch (LMK), and the direct supervision of Messrs. P. G. Combs and J. E. Bardwell, Chief and Assistant Chief, respectively, of the Hydraulics Section (LMK). Captains of the M/V Lipscomb and M/V Key Woods during the tests were Henry C. Muirhead and Clifford Paul, respectively, also of LMK, who assisted materially in the conduct of the tests. This report was prepared by Messrs. Shows and J. J. Franco.

Some of the results of this investigation were included in EM 1110-2-1611, "Layout and Design of Shallow-Draft Waterways," Office, Chief of Engineers, dated 31 December 1980.

Commanders and Directors of WES during the course of the investigation and the preparation and publication of this report were COL G. H. Hilt, CE, COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTORMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
miles per hour (U. S. statute)	1.609344	kilometres per hour

CHANNEL WIDTHS IN BENDS AND STRAIGHT REACHES BETWEEN BENDS FOR PUSH TOWING

Hydraulic Model Investigation

PART I: INTRODUCTION

Background

1. The layout and design of shallow-draft waterways involve the solution of many problems that could affect the development of traffic on the waterway. Some of these problems are concerned with factors that could adversely affect the safe and efficient movement of traffic. Unless these factors are considered and adequately resolved, hazardous conditions or delays could occur to such an extent that commercial traffic would not be economically competitive with other modes of transportation or the traffic potential of the waterway would not be fully developed.

2. Reliability of the waterway will depend to a large extent on the channel dimensions available, alignment of the channel, and effects of currents and weather conditions. Shallow-draft waterways are developed mostly in natural streams that provide either open-river navigation or navigation with locks and dams. However, some waterways utilize land-cut canals in connection with those in natural streams. Natural streams tend to meander, and the alignment usually consists of a series of alternate bends and straight reaches between bends and is affected by currents and movement of sediment. Although land-cut canals are man-made, their alignments could also consist of some bends as required to take advantage of existing lakes or low areas or to bypass existing structures on highly developed areas.

3. Dimensions of the required channel will vary depending on the amount and type of traffic to be accommodated, alignment of the channel, effects of currents and weather, and whether one-way or two-way traffic will be required. The size and maneuverability of a tow, particularly

in negotiating a turn, can be some of the most important factors in determining channel widths in bends. Crosscurrents and crosswinds can also be significant factors in the width of channel that might be required.

Need and Purpose of Model Study

4. Section 5 of the Rivers and Harbors Act approved 4 March 1915 outlines the basis for channel dimensions as follows: "The channel dimensions specified will be understood to admit of such increases at entrances, bends, sidings, and turning places as may be necessary to allow free movement of boats." The towboat is located at the back end of the tow, usually a considerable distance from the head of the tow, and controls the movement and direction of the tow by means of its propellers and rudders. When a towboat and tow change direction, the action of the rudder moves the stern of a forward-moving tow in a direction opposite that of the turn. The pivot point of the turn varies from some point forward of the midpoint to some distance beyond the head of the tow, depending on the speed of the tow and the alignment and velocity of currents in relation to that of the tow.

5. The above explains why the stern of the tow does not generally follow the same path as the head when making a turn, going around bends, or overcoming the effects of adverse currents. Because of this effect, the tow occupies a greater width of channel when making a turn than when moving in a straight line. The width of channel occupied varies with size of tow, rate of change in direction, and effects of currents and, in some cases, wind. The effects have been recognized, but there has been little information that could be used by the design engineer in determining the channel widths required under different conditions. Although some attempts have been made with full-scale tests to determine the widths of channel required in bends, results have been too limited and inconclusive. A model study was considered necessary to establish some relationship between the channel widths required and such variables as size of tow, radius of bend, length of curve, and currents. In the

model, the factors involved could be varied and controlled, and a sufficient number of conditions could be established to permit the development of general criteria that could be used in the design of waterway navigation projects. This study also included some special tests conducted on the Ouachita River by the U. S. Army Engineer District, Vicksburg (LMK), in coordination with the U. S. Army Engineer Waterways Experiment Station (WES).

PART II: THE MODELS

Description

6. The facilities used for this study were designed to permit the modeling of a large number of typical bends with minimum initial construction cost and cost of modifications required to incorporate the many variables involved. Accordingly, the facilities consisted essentially of a concrete flume filled with sand that could be molded and reshaped to provide the conditions required for the study and to vary the linear scale relationship. A large number of bends of various curvatures with straight reaches or crossings between bends were modeled in the flume. The models were not reproductions of any existing stream or waterway but consisted of a series of typical alternate bends, consisting mostly of simple curves with straight reaches between bends, generally tangent to the curvatures of the bends.

7. The channel bed was not free to move under the model velocities but could be readily modified to reproduce typical cross sections based on channel alignment and on what could be expected in an alluvial stream with the conditions imposed. Before tests were undertaken in each model, the cross-sectional areas in the reach were modified to some extent until they reproduced realistically the alignments and velocities of currents that would be expected, based on the channel alignment used (Figures 1 and 2).

Scale Relations

8. The models used in this investigation were constructed to undistorted linear scales varying from 1:120 to 1:70, model to prototype. The largest scale that could accommodate the size of channels and bends needed was used in each case. In other words, the smaller channel and bends were tested with models having the larger scale. Some channels and bends were reproduced to different scales to determine if results might be significantly affected by the scale relations used. The

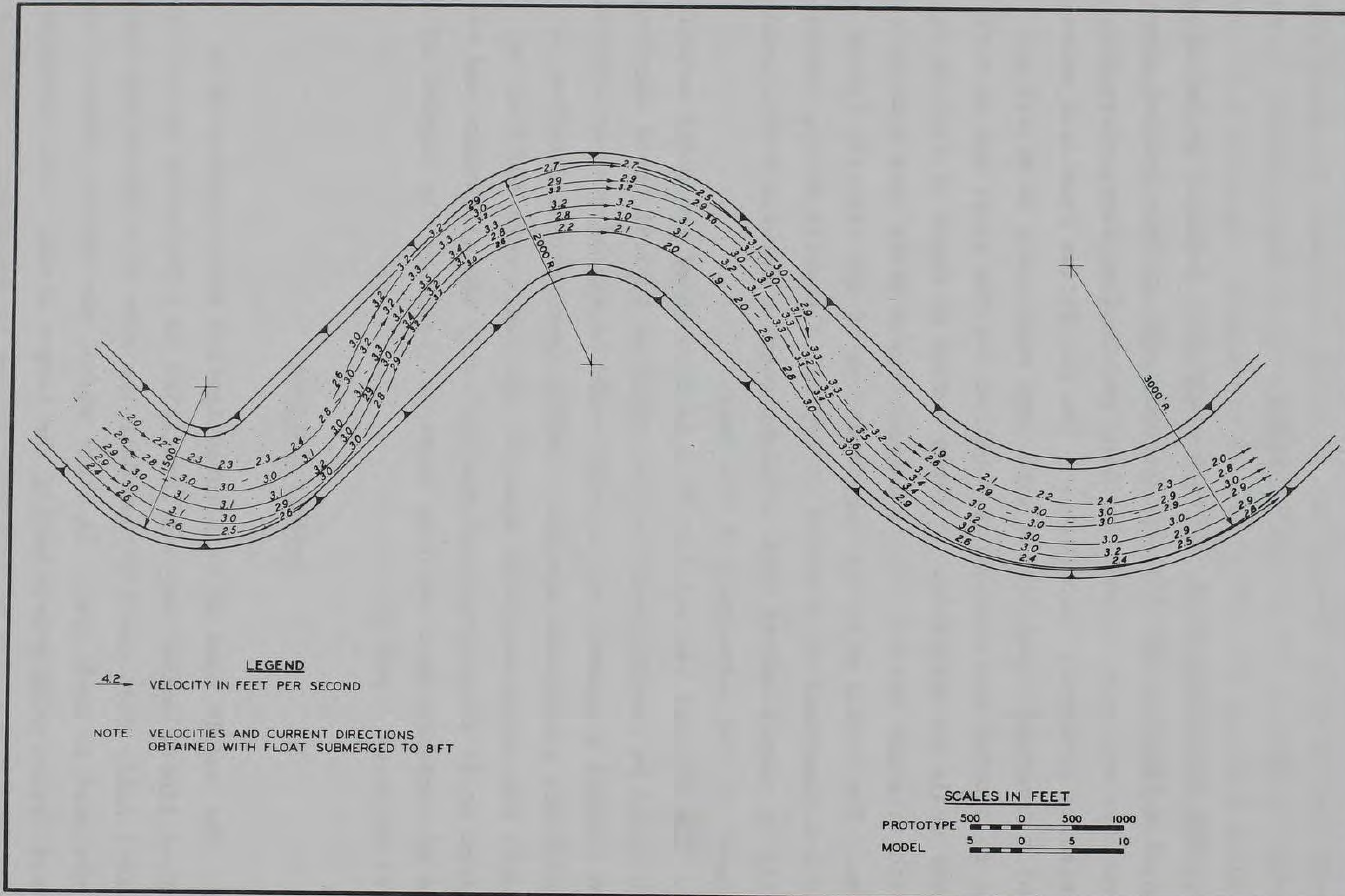


Figure 1. 1,500-, 2,000-, and 3,000-ft-radius bends, average velocity approximately 3 fps

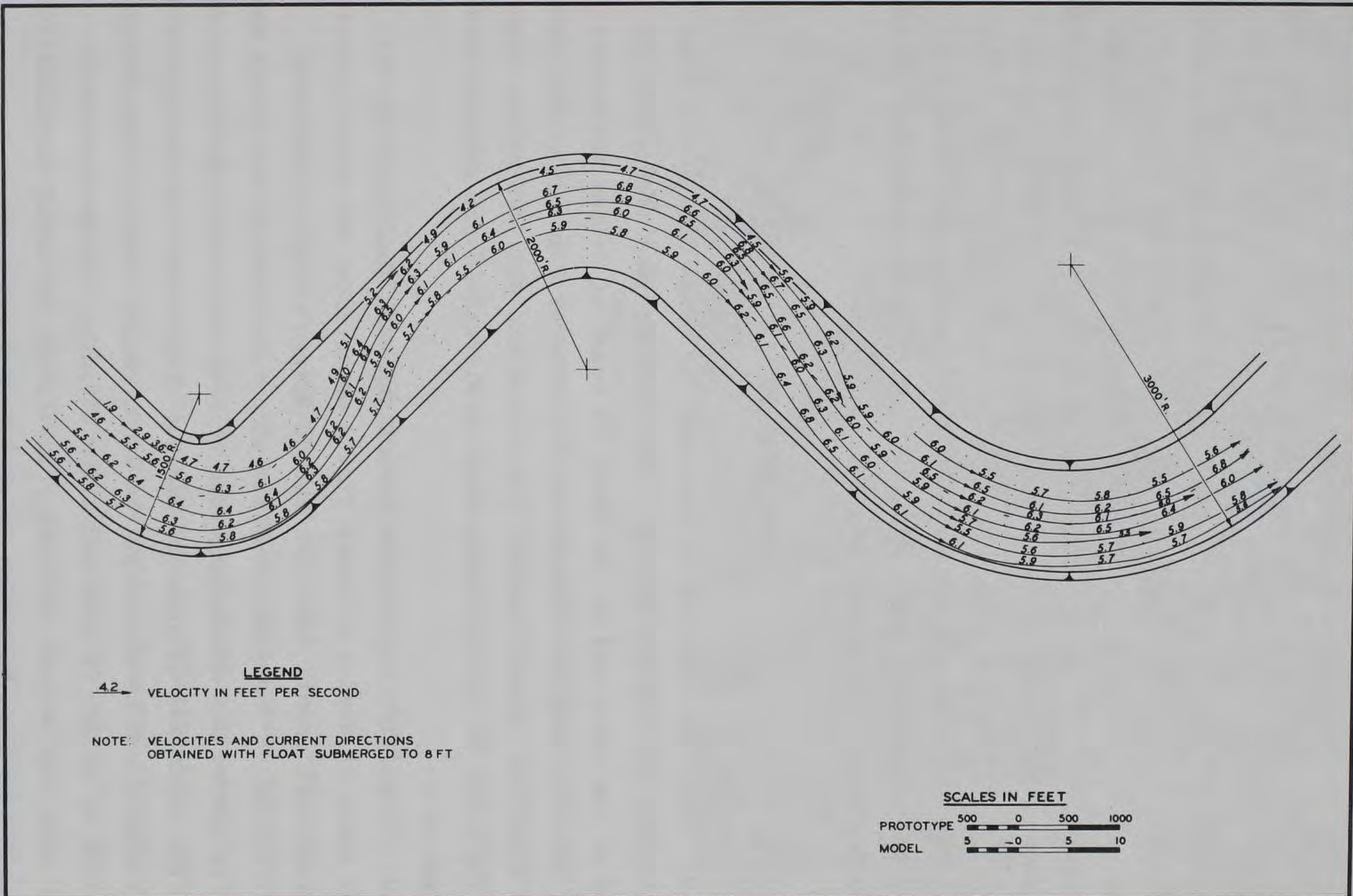


Figure 2. 1,500-, 2,000-, and 3,000-ft-radius bends, average velocity approximately 6 fps

linear scales used for the various models and other scale relations resulting from the linear scales were as shown below:

	Model Linear Scales			
	1:120	1:100	1:80	1:70
Area	1:14,400	1:10,000	1:6,400	1:4,900
Velocity	1:10.95	1:10	1:8.94	1:8.37
Time	1:10.95	1:10	1:8.94	1:8.37
Discharge	1:157,743	1:100,000	1:57,243	1:40,996
Roughness (Manning's n)	1:2.22	1:2.15	1:2.08	1:2.03

Measurements of discharge, water-surface elevations, and current velocities can be transferred quantitatively from model-to-prototype equivalents by means of these scale relations.

Appurtenances

9. Water was supplied to the model by means of a 10-cfs pump operating in a circulating system. The discharge was controlled and measured at the upper end of the model by means of valves and venturi meters; water-surface elevations were measured by means of point gages located along the channel banks. A tailgate was provided at the lower end of the model to control water-surface elevations for the different discharges used.

10. Velocities and current directions were determined in the model by means of wooden cylinder floats weighted on one end to simulate the maximum permissible draft for loaded barges using the waterway (8 ft prototype). Two model towboats with tows of different sizes were used to determine and demonstrate the effects of currents on tows moving through the bends and in straight reaches (Figure 3). The overall sizes of the towboats and tows used in the study ranged from 35 ft wide and 480 ft long up to 105 ft wide and 1,200 ft long. The towboats were equipped with twin screws and were propelled by two small electric motors operating from batteries located in the tows; the rudders and speeds of the tows were remote-controlled. The towboats could be

Figure 3. A downbound model towboat and tow negotiating a typical bend

operated in forward or reverse. The power and speed were adjusted by means of a rheostat and limited to the maximum that would be comparable to that of tows of the sizes that would normally use the waterways.

Calibration of Model Towboats with Tows

11. Before tests were undertaken with the model towboats and tows, the tows were calibrated to determine their speeds in miles per hour (mph) with each tachometer setting used during the tests. The calibration was conducted in slack water in an unrestricted channel (constant depth and width) and operated over a measured distance with various settings on the tachometer and straight rudder. The tows were permitted to attain full speed before reaching the test section. Data obtained during these tests included the tachometer setting and time required to negotiate the measured distance for each tow size. This

information was then used to determine speed in actual feet per second which was later converted to mph based on the model linear scale relation used. A number of runs were made with each setting to eliminate any unusual deviation that might have occurred in the tachometer setting or the time of travel. The spread in the speed varied from about 5 to 10 percent with the biggest spread occurring with the low speed setting. A typical calibration curve developed from these tests is shown in Figure 4.

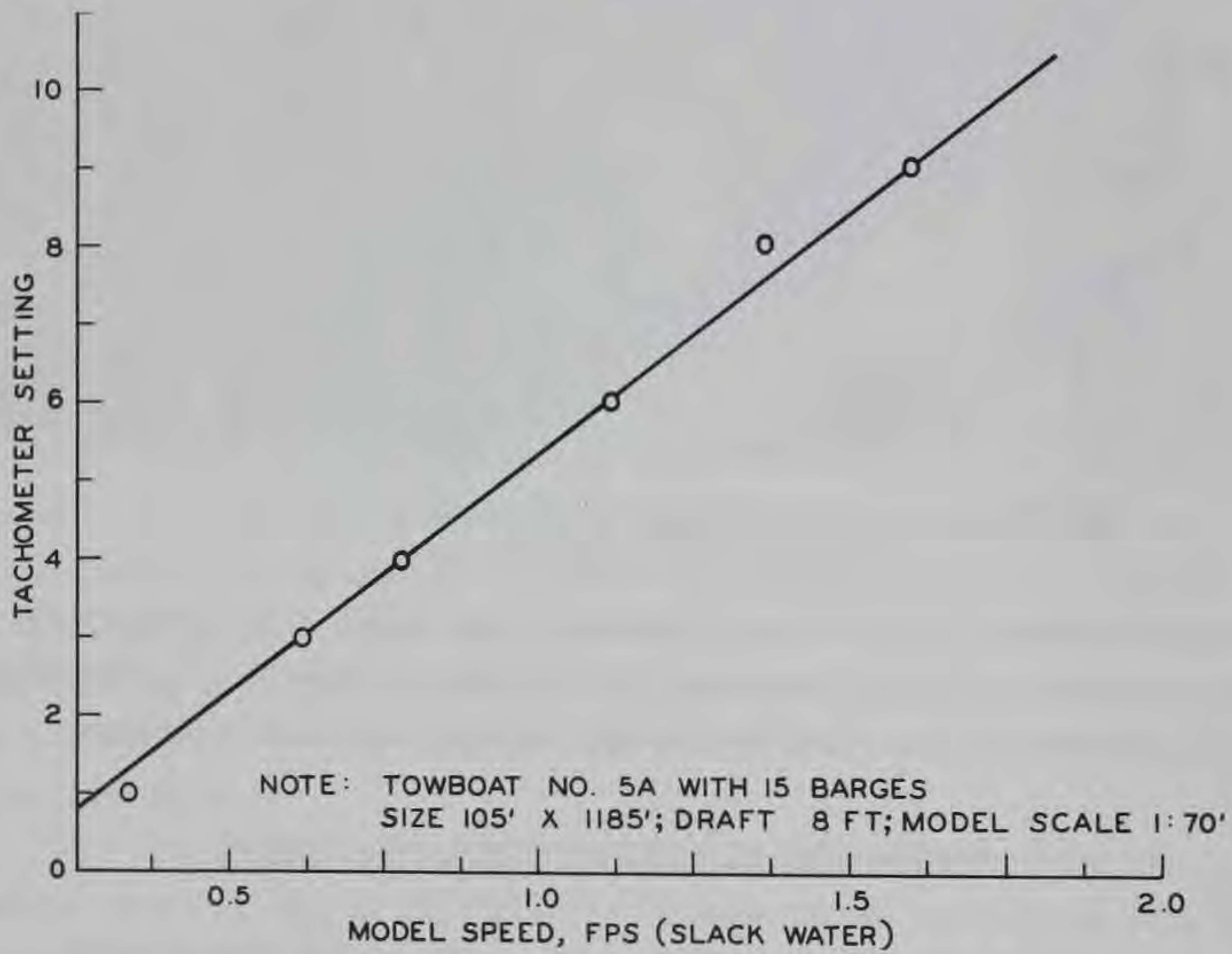


Figure 4. Typical speed calibration curve for model tow

12. Tests were also conducted to determine the turning radius of various sizes of tows with different rudder setting and speeds based on the calibration curves mentioned in paragraph 11. Tests were conducted to establish some of the characteristics of the model tow, for possible comparison with the characteristics of tows in use on the various waterways, and to determine if there would be any significant differences in the results obtained with models of the different linear scales used.

The size tows used during these tests were 35 and 70 ft wide by 480 and 685 ft long, and 105 ft wide by 600, 900, and 1,100 ft long. These tests were also conducted in an unrestricted channel and based on the tows making a complete circle (360 deg) with each tachometer setting and size of tow. Tests were conducted with rudders set at 22, 30, and 45 deg, and results were based on the average of several runs with each setting. The error in returning to the initial starting point of the turn to complete the circle varied from about 2 to 4 percent with the largest error occurring with the shorter radius of turn. During these tests, it was noted that the width of tow had no appreciable effect on the radius of turn and that the radius of turn would be increased somewhat as the speed on the tow was increased. Since this study was primarily concerned with minimum-powered tows, a tow speed of 2 mph was used as standard for these tests. This was the lowest speed at which accurate control of the tow could be maintained based on slack-water calibration with straight rudder. Turning radius for the different lengths of tows and model scales are shown in Figure 5. These data indicate that the differences in scale effect from linear scale ratios from 1:70 to 1:120 would be small and within the accuracy of measurements.

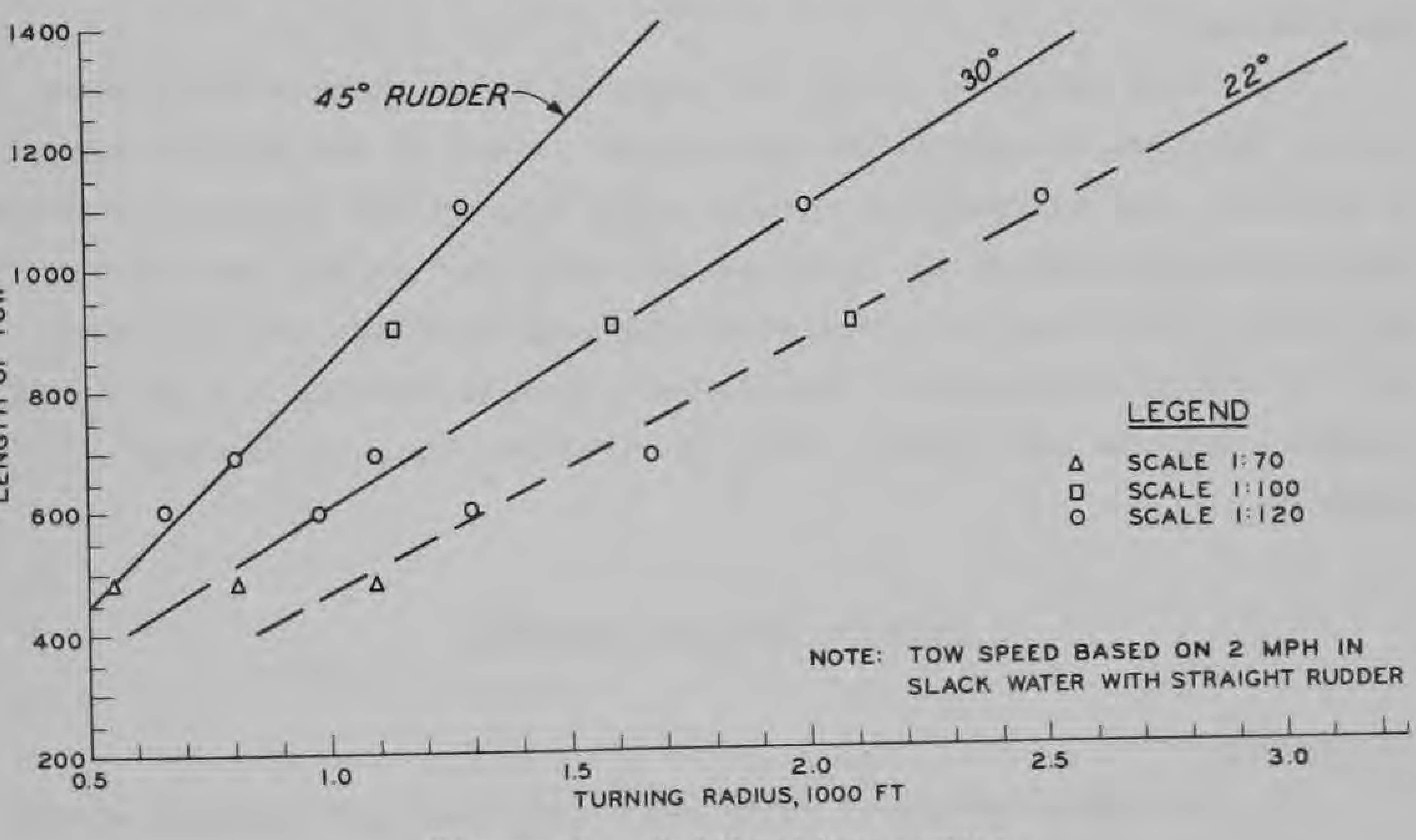


Figure 5. Calibration curves

PART III: MODEL TESTS AND RESULTS

Test Procedures

13. Tests were conducted with models of three different scales and different sizes of tows loaded to a draft of 8 ft based on channels having project depths of 9 ft. The channels used in these tests were of uniform width bank-to-bank and their alignments included bends of various curvatures and straight reaches between bends that were generally tangent to the curvature of the bends. Tests were conducted with no flow (slack water) and with flows producing average velocities of 3 and 6 fps.

14. Each test was conducted with the rudder angle required to negotiate the bend without exceeding the maximum angle (45 deg) and with the minimum speed required to maintain rudder control with the size of tow used and currents. A sufficient number of runs were made with each condition to assure that the results were consistent and typical of what could be expected under normal operating procedures. All tests were conducted with tows driving through the bend without flanking or unusual maneuvering.

15. Data obtained during the tests included channel width occupied by the tows in negotiating each bend, radius of the curve followed by the tows, and multiexposure photographs showing the progressive movement and orientation of the tow through the bend. In the case of two-way traffic, two tows were used simultaneously with one tow downbound and the second tow upbound. Results were used to develop a relationship between tow sizes and channel width required for bends of various curvature.

Bends of Uniform Curvature

Description

16. The first series of tests were concerned with channel widths required in bends with smooth banks consisting of a simple curve with

straight reaches approaching and leaving the bend tangent to the curve of the bend. The bends made a turn of 90 deg. The tests were generally conducted in the model with the largest scale that could accommodate the size of bend required to cover the range of conditions to be studied. However, a number of conditions were tested in each of the three models to determine the effects of model scale on results.

17. It was realized that in order to determine the channel width required in bends, it was necessary to determine the position and orientation of the tow in negotiating bends. The orientation of the tow is best defined by its drift or deflection angle with respect to the channel alignment (Figure 6). The width of channel required in bends is a direct function of the deflection angle assumed by the tow and the length and width of the tow. Factors that could affect the deflection angle include current alignment and velocity, speed of tow with respect to that of the currents, direction of travel (upstream or downstream),

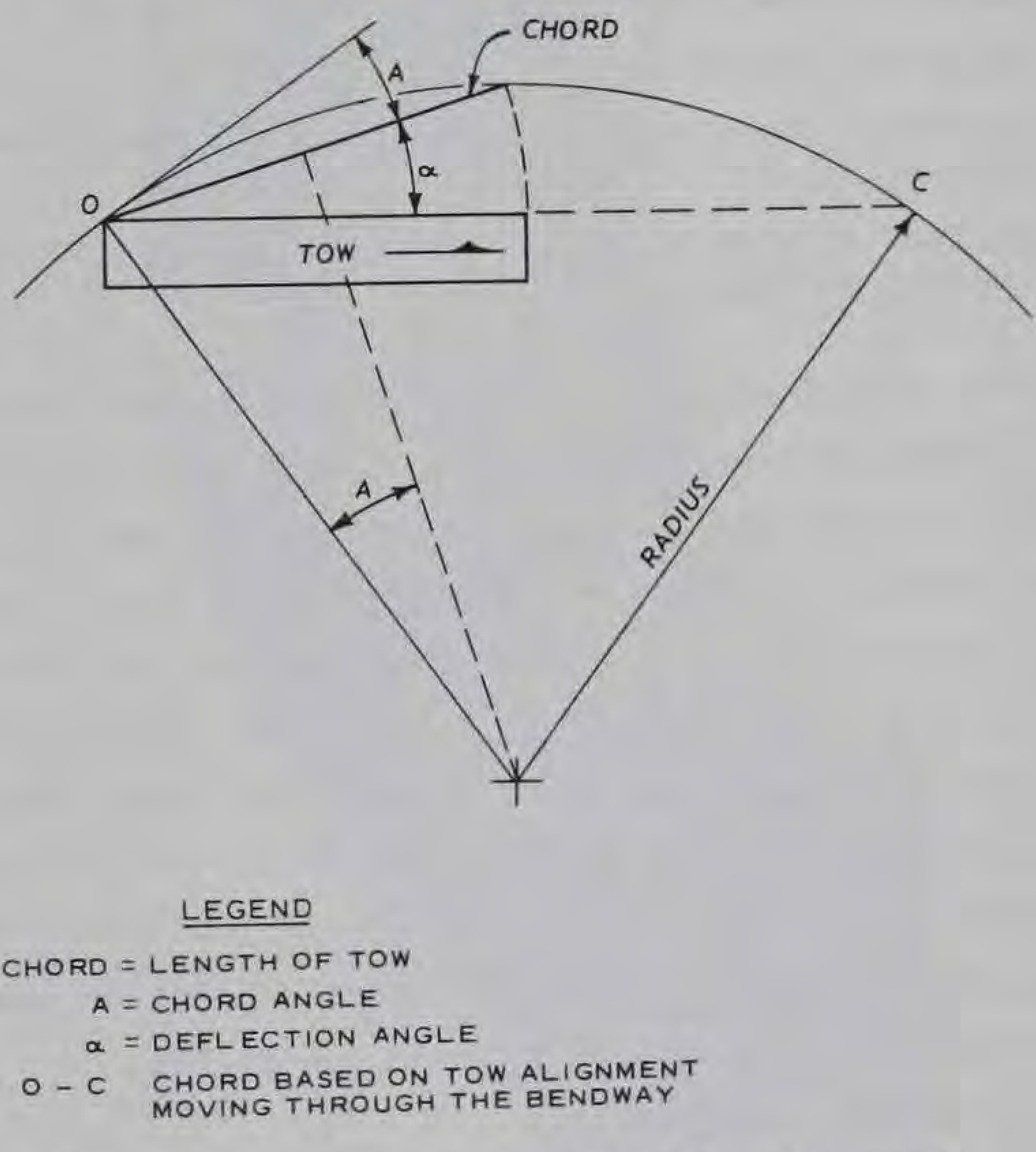


Figure 6. Description of deflection angle

tow driving or flanking when downbound, draft of tow with respect to channel depth, and weather conditions.

18. If the deflection angle assumed by a tow in moving through a bend is known, a reasonably accurate channel width required can be determined from one of the following two equations:

$$CW_1 = (\sin \alpha_d \times L) + W + 2C \tag{1}$$

$$CW_2 = (\sin \alpha_u \times L) + W + (\sin \alpha_d \times L) + W + 2C + C_t \tag{2}$$

where

CW_1 = channel width required for one-way traffic, ft

CW_2 = channel width required for two-way traffic, ft

α_d = maximum deflection angle of a downbound tow, deg

α_u = maximum deflection angle of an upbound tow, deg

L = length of tow, ft

W = width of tow, ft

C = clearance required between tow and channel limit for safe navigation, ft

C_t = minimum clearance required between passing tows for safe two-way navigation, ft

Therefore, tests were designed to determine the deflection angles for various conditions and size of tows. Since the deflection angle would be difficult to measure while the tow is moving through the bend, measurements were taken that could be used to compute the deflection angle based on the above formulas. Measurements included the channel width occupied by the tow and radius of curve followed. The path was carefully marked with pins and the test with each condition repeated to assure that results were consistent. Results were also recorded by means of multiexposure photographs (Figure 7). These tests were conducted with the minimum power required to maintain rudder control on the tows which was about 2.0 mph greater than the current velocities.

Results

19. Results of these tests were used to determine the deflection

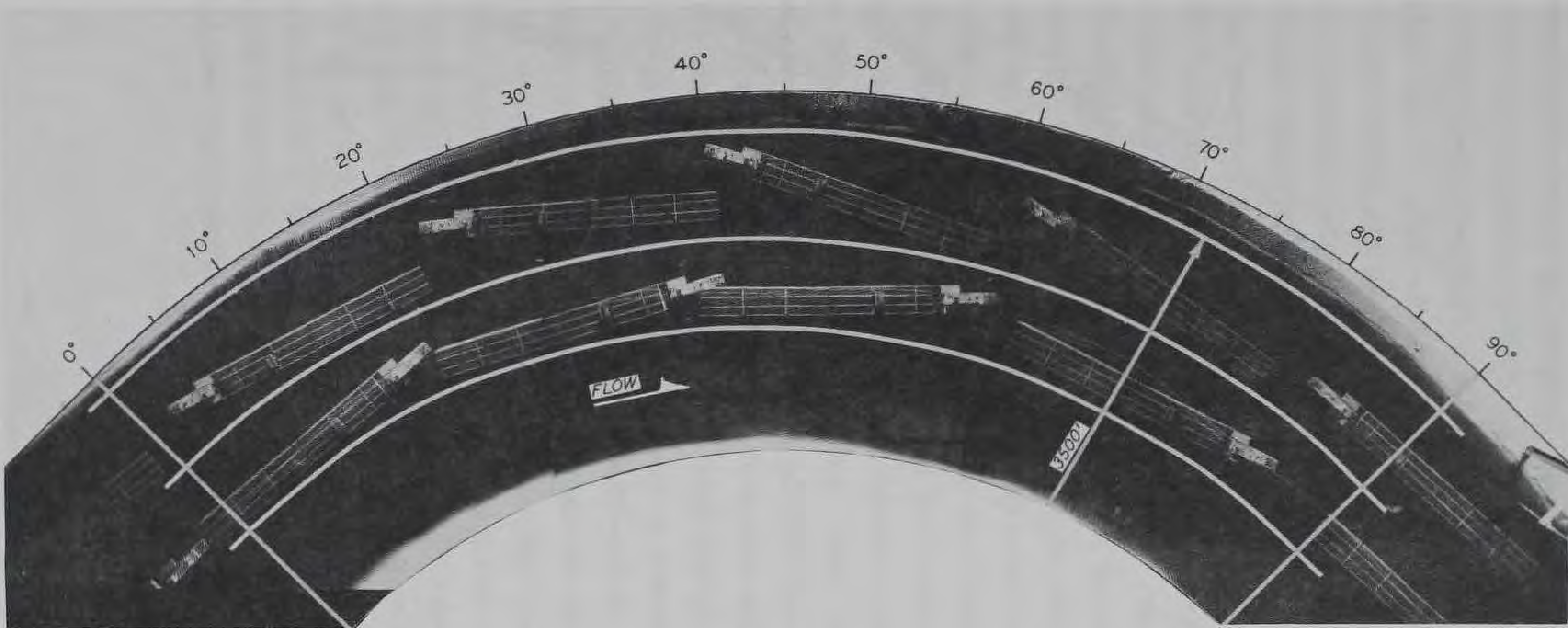


Figure 7. Multiexposure photograph showing paths and orientations of an upbound and a downbound tow (each 105 by 1,200 ft) negotiating a 3,500-ft-radius bend with average velocity of 3 fps

angles for various size tows operating in bends of different curvature and are included in Plates 1-6. Typical variations in the deflection angle assumed by downbound tows of different sizes and the channel width required for each are shown in Figure 8. Some of the conditions were tested in models of two and in some cases three different linear scales. A comparison of the results obtained with the different scale models indicates little difference that could be attributed to model scale used (Figure 9). The differences are too small to have any appreciable effect on the results, particularly when differences in the alignment of the currents and orientation of tow entering the bend are considered.

20. Results of these tests indicate how the deflection angles and the required channel widths vary with the size tow, curvature of the bends, and current velocities. The greatest channel widths will be required for downbound tows driving through the bend without flanking or maneuvering and because of greater rudder control, particularly when currents are involved, upbound tows assume a deflection angle smaller than that for downbound tows. For these reasons, less channel width would be required for two-way traffic if the downbound tow moved along the concave bank side where the radius of the bend would be longer than for the upbound tow moving on the side away from the concave bank. Also, the deflection angle assumed by tows is affected by the included angle of the bend up to about 90 deg--the smaller the included angle or amount of change in direction through the bend, the smaller the deflection angle assumed by the tow, and the less channel width required (Plates 1-6). When currents are involved, downbound tows could flank around the bend using about the same channel width as required for an upbound tow in that bend. The makeup of a tow could have a significant impact on channel capacity, particularly in short-radius bends. A four-barge tow (two barges wide), 480 ft long, moving through a bend having a radius of 1,500 ft would occupy about 215 ft of channel width while a single-line, three-barge tow, 685 ft long, in the same bend would occupy about 300 ft of channel width (Plates 2 and 3).

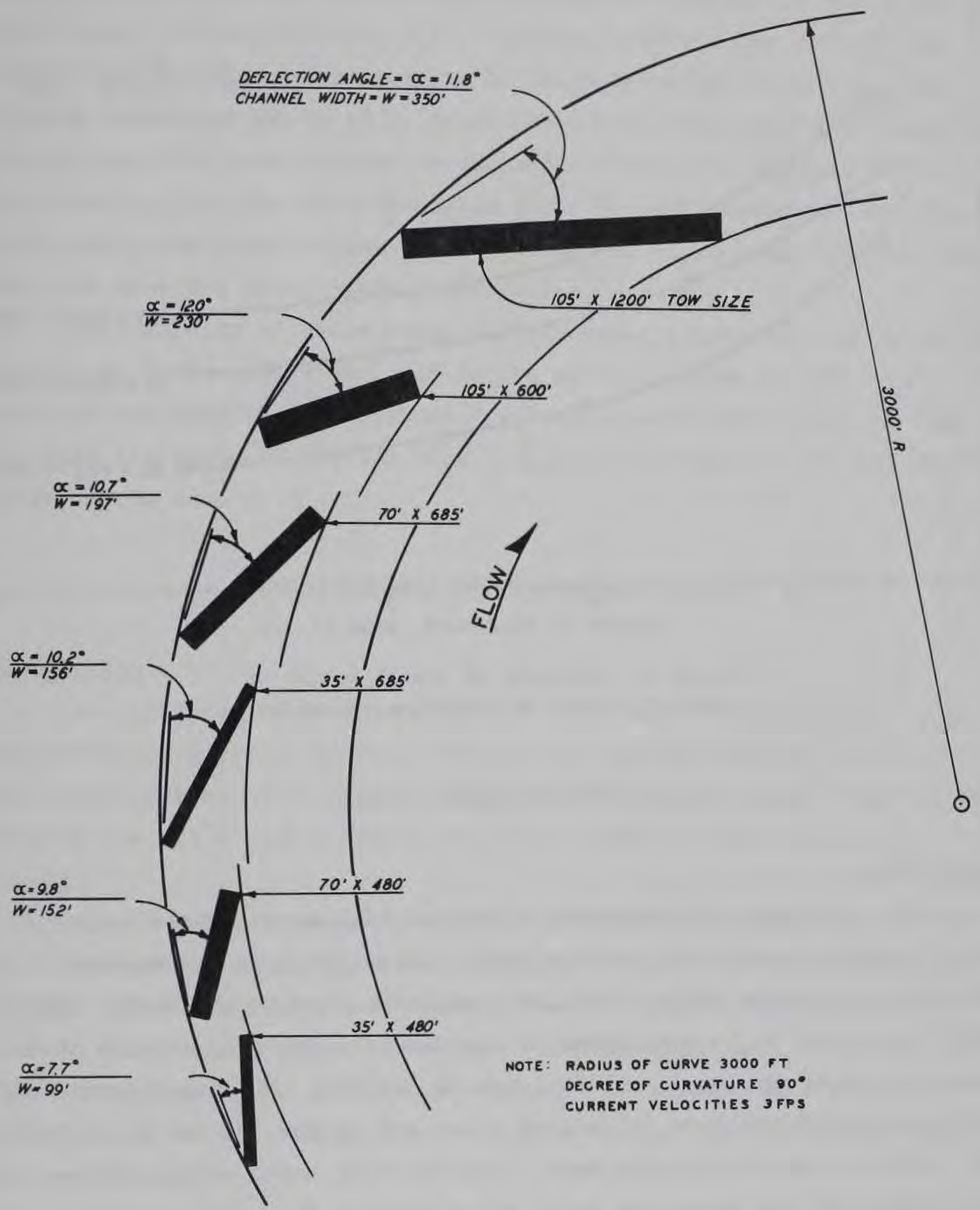


Figure 8. Variation of deflection angle and channel width with tow sizes for downbound tows

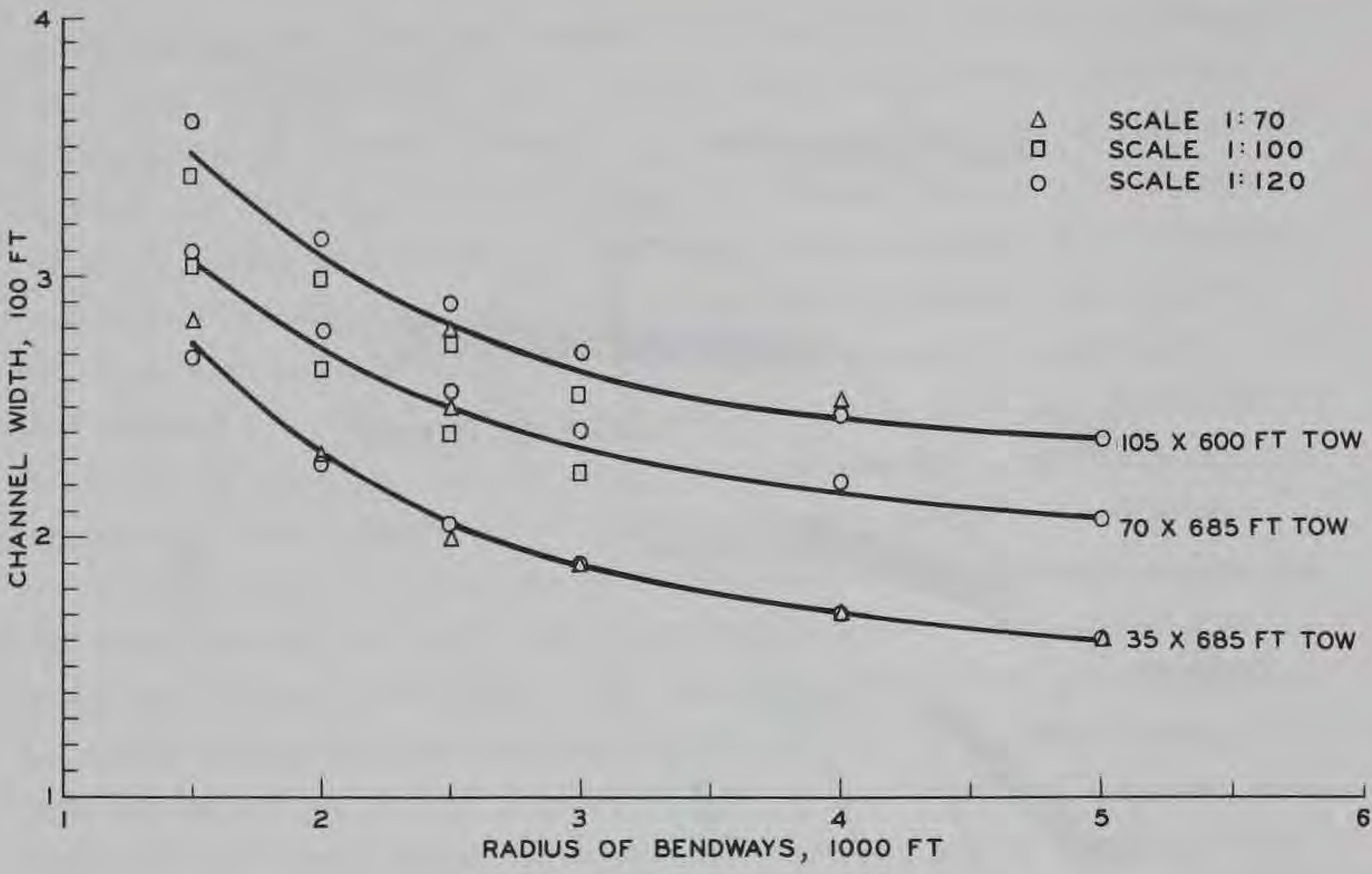


Figure 9. Effects of model scale on channel widths with 3-fps velocity

Irregular Bank Lines

Description

21. A number of tests were conducted with bends consisting of a simple curve but with the concave banks having scallops or landward bulges to determine their effect on navigation through the bend. This condition would be in simulation of conditions in natural streams that might be caused by local bank failures or erosion. The irregularities tested included scallops of various sizes and depths located at different points along the concave bank. Results were based mostly on the observation of the model tow as it moved through the bend.

Results

22. Results of these tests indicate that small irregularities in the concave bank line would have little or no effect on navigation through the bend. The effect on navigation in the bend would depend

upon the amount of flow and currents moving into and out of the scalloped area. Since there would be a greater tendency for currents to move into a scalloped area located in the lower reach of a bend, the effects on navigation would generally be much greater than when scallops of the same size were located in the upper reaches of the bend. Currents moving into the scalloped area could cause a downbound tow moving close along the concave bank to be grounded or be in danger of hitting the bank near the lower end of the scallop.

23. Results of these tests indicate that conditions for downbound tows could be hazardous when the length of the scallop in the lower reach of the bend is at least one tow length and extends into the bank at least the width of the tow with a depth of at least 75 percent of the draft of the tow.

Bends Consisting of Compound Curves

Description

24. Limited tests were conducted with half of the bend (45 deg) consisting of a simple curve of one radius and the other half of a different radius. The larger radius curve was in the upper reach of the bend in one set of tests and in the lower reach in the second set.

Results

25. Results of these tests indicate that when the portion of the bend having the shorter radius of curvature is in the lower reach, the channel width required should be based on the shorter radius as developed in tests with bends consisting of uniform curvature. However, when the shorter radius is in the upper reach, the channel width could be varied based on the radius of each segment with a suitable transition between widths.

Crossing Between Alternate Bends

Description

26. Crossings are relatively straight reaches between alternate

bends and are common in meandering streams. Tows leaving one bend, usually from along the concave bank, have to move toward the opposite bank to approach the channel along the concave side of the next alternate bend. Tests were conducted to determine the length of channel required to make the crossing downbound without flanking for various size tows and channel widths. The tests were conducted with the moving tow located along the concave bank of one bend before starting the turn toward the opposite bank. The channel between the bends was molded to a uniform trapezoidal-shaped cross section. Currents with velocities averaging about 3 and 6 fps were generally parallel to the bank lines. The speed of the tow was maintained constant with the minimum power required to maintain rudder control.

Results

27. Results of these tests, shown in Plate 7, indicate that the length of channel required by a downbound tow to make a crossing without flanking or unusual maneuvering depends on the size of tow, width of channel, and alignment and velocity of currents. Results presented are based on conditions imposed and could be affected by other conditions not tested such as weather conditions, different alignment and velocity of currents, and tows flanking or tows with greater maneuverability. Also, in most crossings, particularly during low water, currents tend to cross from the concave bank of one bend toward the concave bank of the opposite bend, whereas currents in the study were generally parallel to the bank line. In such cases, tows could make the crossing in less distance than indicated by this study. Because of greater rudder control, upbound tows can make the crossing in much less distance than that required for downbound tows; therefore, downbound distances control.

PART IV: PROTOTYPE TESTS

28. In connection with the improvement of navigation on the Ouachita River, special field tests were conducted in the vicinity of Monroe, Louisiana, to obtain data on the movement of tows in some of the critical reaches and to correlate the results with those of the model study described above. These studies were conducted by LMK with the assistance of representatives of WES concerned with the model studies of navigation in bends and straight reaches between bends. The Ouachita River was particularly suited for these tests, since it contains many short-radius bends, relatively straight reaches, limited channel widths, and a number of bridges with small navigation spans and short distances between some of the bridges.

Equipment Used

29. The prototype tests were conducted with two Corps of Engineers towboats moving barges each 35 by 195 ft. The M/V Lipscomb is 126 ft long and 32 ft wide with maximum horsepower of 1,600; the M/V Key Woods is 64 ft long and 24 ft wide with maximum horsepower of 825. The towboats were operated by master pilots with many years of experience, although one of the pilots had never operated on the Ouachita River. One of the pilots operated both towboats during some of the tests. The Lipscomb operated with four barges (two abreast) for a total dimension of 516 by 70 ft and with three barges in line for a total dimension of 711 by 35 ft. The Key Woods handled three barges in line for a total dimension of 649 by 35 ft.

Test Procedures

30. Velocity ranges were established at various locations within the test reach and velocity measurements obtained. These measurements indicated that the average velocities in which the tow was operated were about 2 fps. Current alignments were not determined; however,

observations indicated that flow was generally concentrated along the concave side of most bends. Towboats and tows were operated through a number of bends of different curvature in both upstream and downstream directions. Towboats were operated with minimum power required to maintain rudder control and continuous driving without flanking or maneuvering comparable to conditions used in the model tests. Location and orientation of the tows while moving through the reaches were recorded by photographs taken from a low-flying aircraft (Photo 1) and by photographing images on the radar scope (Photo 4).

Results

31. Typical results obtained during prototype tests are shown in Photos 2-4. Prototype measurements of channel widths required by a 35-ft-wide by 711-ft-long tow for two different 1,189-ft-radius bends varied from 263 to 279 ft (Photos 2 and 3). The channel width required by a 70-ft-wide by 516-ft-long tow for a 2,020-ft-radius bend was 185 ft (Photo 4). Using model data reported herein and extrapolating the deflection angle to match prototype test conditions mentioned above, the channel width computed was about 290 ft for the 35-ft-wide by 711-ft-long tow and 168 ft for the 70-ft-wide by 516-ft-long tow. This width is about 19 ft more than the average prototype width observed for the two bends with the longer tow and about 17 ft less than the channel width for the shorter tow, or within ±10 percent for both tows. Considering the lack of control on the alignment of the tow entering the bend, imprecise determination of current velocity, lack of data on the current pattern, and the degree of accuracy with which the prototype width measurements were made, the prototype tests provided a reasonable confirmation of the model determinations.

PART V: DISCUSSION OF RESULTS AND CONCLUSIONS

Limitations of Model Results

32. In evaluation of results of this investigation, it should be considered that the models used reproduced only the general characteristics of an alluvial stream and were not actual reproductions of a prototype stream. Alignment of the channel consisted of a series of bends with uniform curvature and typical cross sections that could be expected based on the channel alignment. The model bed was not free to move with the currents imposed and did not change with changes in discharge as usually occurs in most alluvial streams.

33. Results were based on a study of the movement of the tows under the various conditions established to permit the development of the relationships needed to assist the engineer in the layout and design of shallow-draft waterways for commercial traffic. Model towboats used had twin screws, with Kort nozzles and rudder on each. However, the screws were operated together at the same speed in all cases. Also, the tests were conducted with the minimum speed required to maintain rudder control. Tows with greater maneuverability, such as operating the screws independently or using special steering devices, can negotiate turns easier and occupy less channel width in bends or require less channel lengths in making a crossing.

34. In spite of the limitations, the model study was sufficient to provide data required in the layout and design of inland waterways based on the minimum-powered traffic normally using the waterway. Limited prototype tests indicated that the model results are close to conditions that can be expected in a natural stream and provide the best guide available at this time. Effects of weather conditions were not considered and could be an important factor.

Summary of Results and Conclusions

35. Results of the investigation indicate the following:

a. In negotiating a bend or in making a turn, tows occupy a greater channel width than when moving in a relatively straight alignment. The width of channel occupied by the tow in making a turn will depend on the angle assumed by the tow with respect to its direction of travel. If this angle referred to as the deflection angle is known, the channel width required by the tow can be computed.

b. The deflection angle and the width of channel required vary with the size of tow, curvature of the bend (radius), included angle of bend up to about 90 deg, and alignment and velocity of currents. Other factors that affect the deflection angle assumed by the tow and channel width occupied include speed of tow, direction of travel (upstream or downstream), and location of the tow on entering a bend.

c. When moving through a bend, tows moving upstream require less channel width than tows moving downstream. Downbound tows flanking would require about the same channel width in a bend as tows moving upstream in that bend.

d. With two-way traffic in bends, less total channel width would be required with the downbound tow moving along the concave bank side of the bend and the upbound tow moving on the side away from the concave bank.

e. In bends consisting of compound curves, the channel width required should be based on the requirement for the shorter radius curve, particularly if the shorter radius curve is in the lower reach of the bend. In long bends with the shorter radius curve in the upper reach, separate channel widths could be provided for each section with a suitable transition between the different widths.

f. Shorter and wider tows usually require less channel widths in bends than long narrow tows carrying the same load, particularly in short radius bends.

g. Channel widths required also depend on the amount of turn involved up to about 90 deg. Shorter bends with less change in direction would require less channel width depending on the length of the bend.

h. Irregularities in the concave bank line of a bend could produce conditions that might be hazardous to downbound tows moving close along the bank. Generally, small irregularities along the bank would tend to have little or no effect on the movement of tows in the bend. However, when a scallop or indentation in the bank is as long as or longer than the length of tow and extends into the bank at least the width of the tow with a depth of at least 75 percent of the draft of the tow, currents moving into the area could cause downbound tows moving close along the bank to be grounded or be in danger of hitting the bank at the lower end of the scallop. The tendency for current to move into a scalloped area and its effect on tows are much greater when the area is in the lower reach of the bend than in the upper reach.

i. In reaches between alternate bends, a sufficient length of straight reach would normally be required to permit tows to move from along the concave bank of one bend toward the concave bank of the next bend on the opposite side. The length of channel required to make the downbound crossing without flanking or special maneuvering would depend on the size of tow, the width of channel, and the alignment and velocity of currents.

j. Model results on the length of channel required between alternate bends are based on a downbound tow with limited power moving from along and adjacent to the concave bank of the upper bend before starting the turn toward the next bend with currents generally parallel to the bank lines. This should give a somewhat conservative estimate since currents in most natural stream crossings tend to move from along the concave bank of one bend toward the concave bank of the next bend, particularly during low flows.

k. Model results on channel width compared reasonably close with the limited results obtained during the prototype tests.

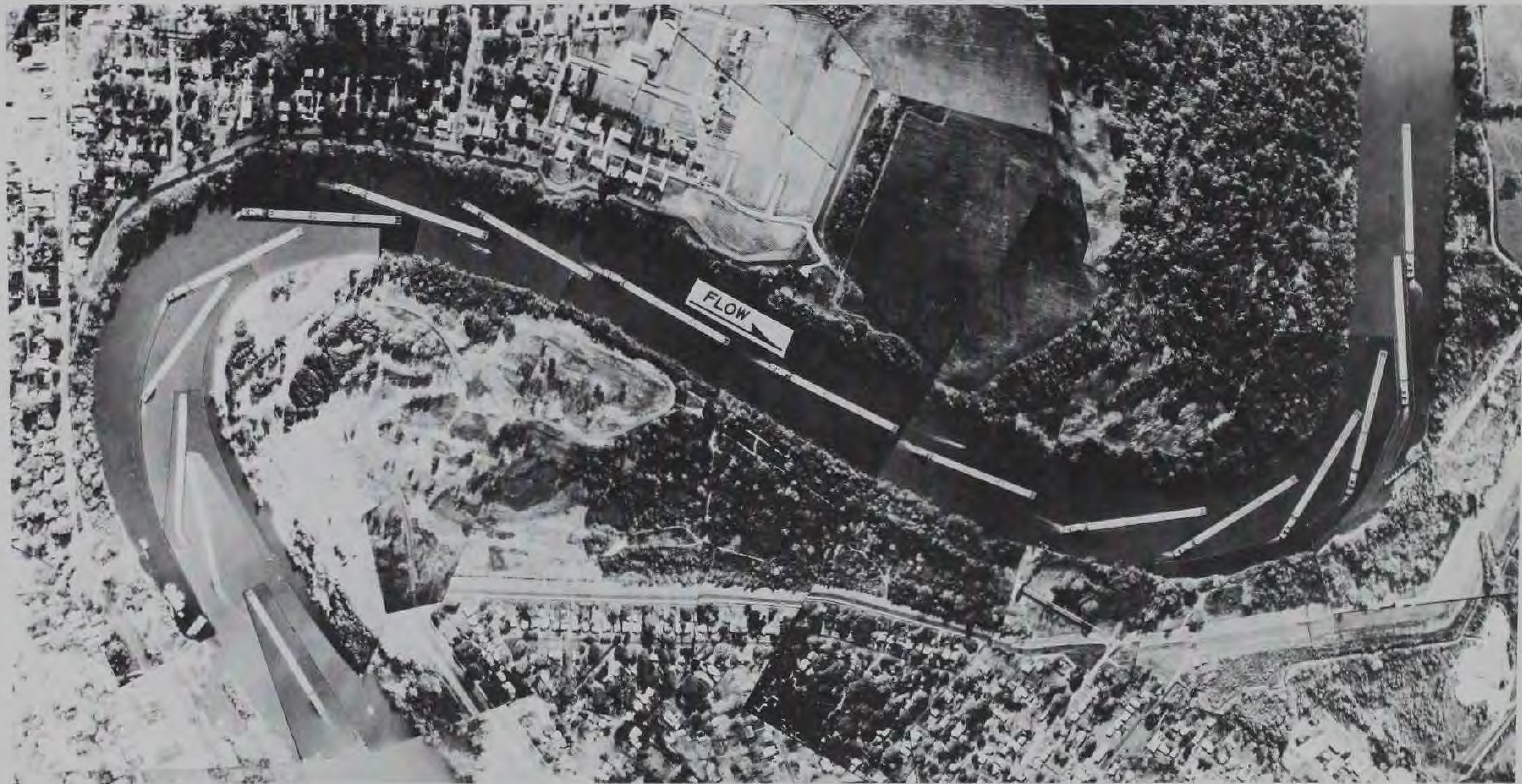


Photo 1. Mosaic showing path of a 35- by 711-ft tow moving through a reach of the Ouachita River with average current velocity about 2 fps

Photo 2. Mosaic showing progressive location and orientation of a 35- by 711-ft downbound tow negotiating a rather sharp bend in the Ouachita River with average current velocity about 2 fps

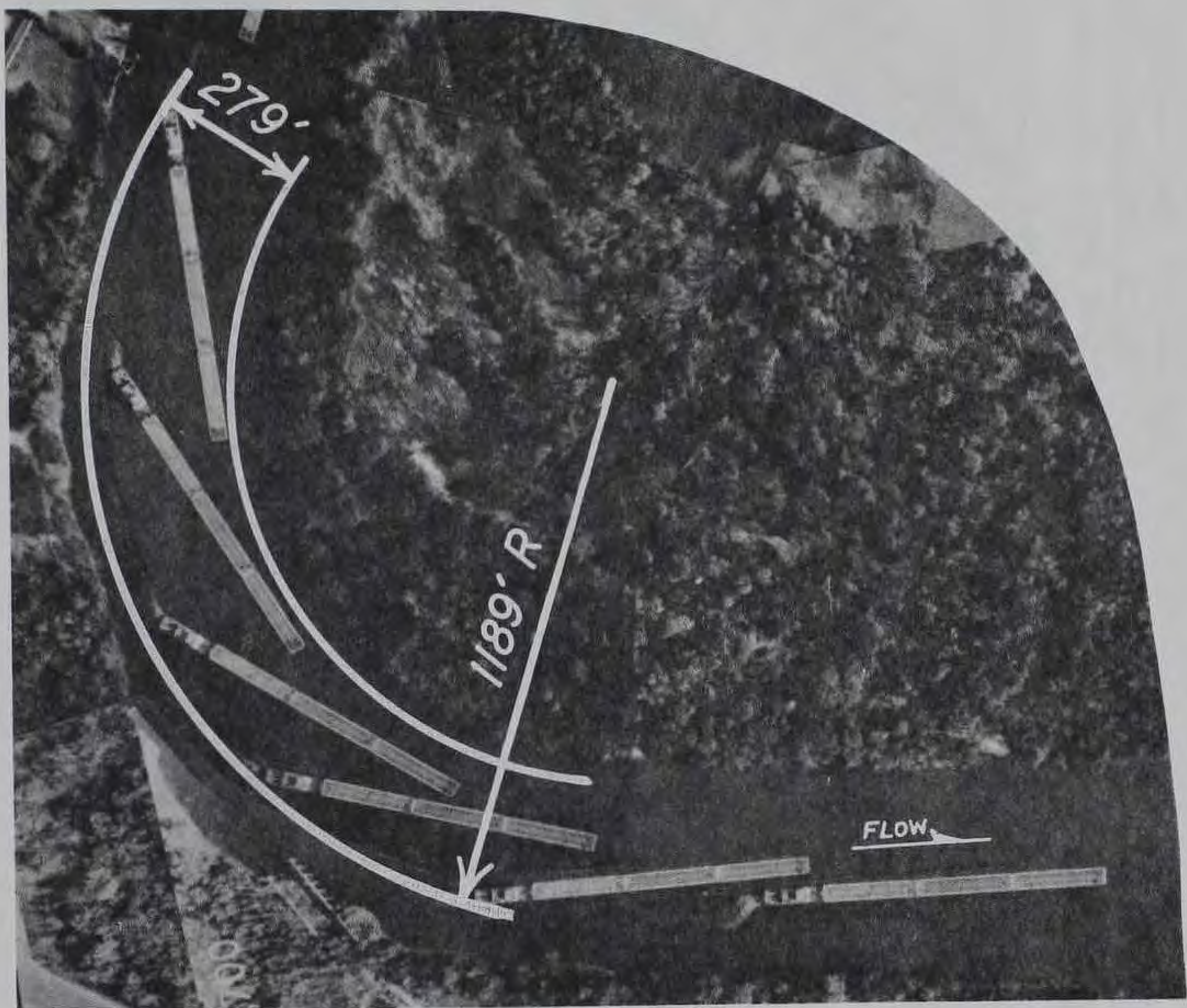


Photo 3. Mosaic showing progressive location and orientation of a 35- by 711-ft downbound tow negotiating a rather sharp bend in the Ouachita River with average current velocity about 2 fps. Note the slight difference in channel width occupied compared with Photo 2

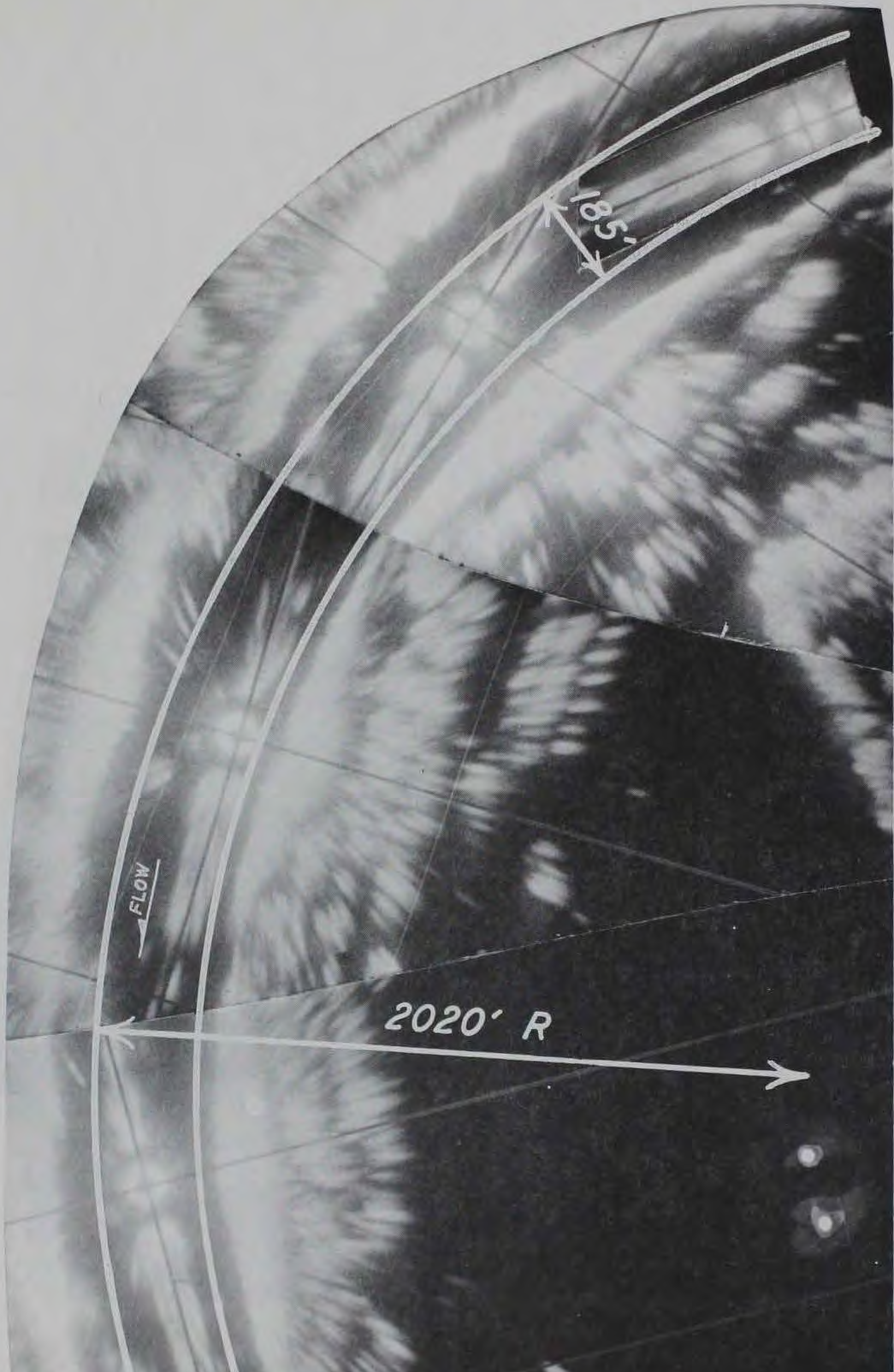
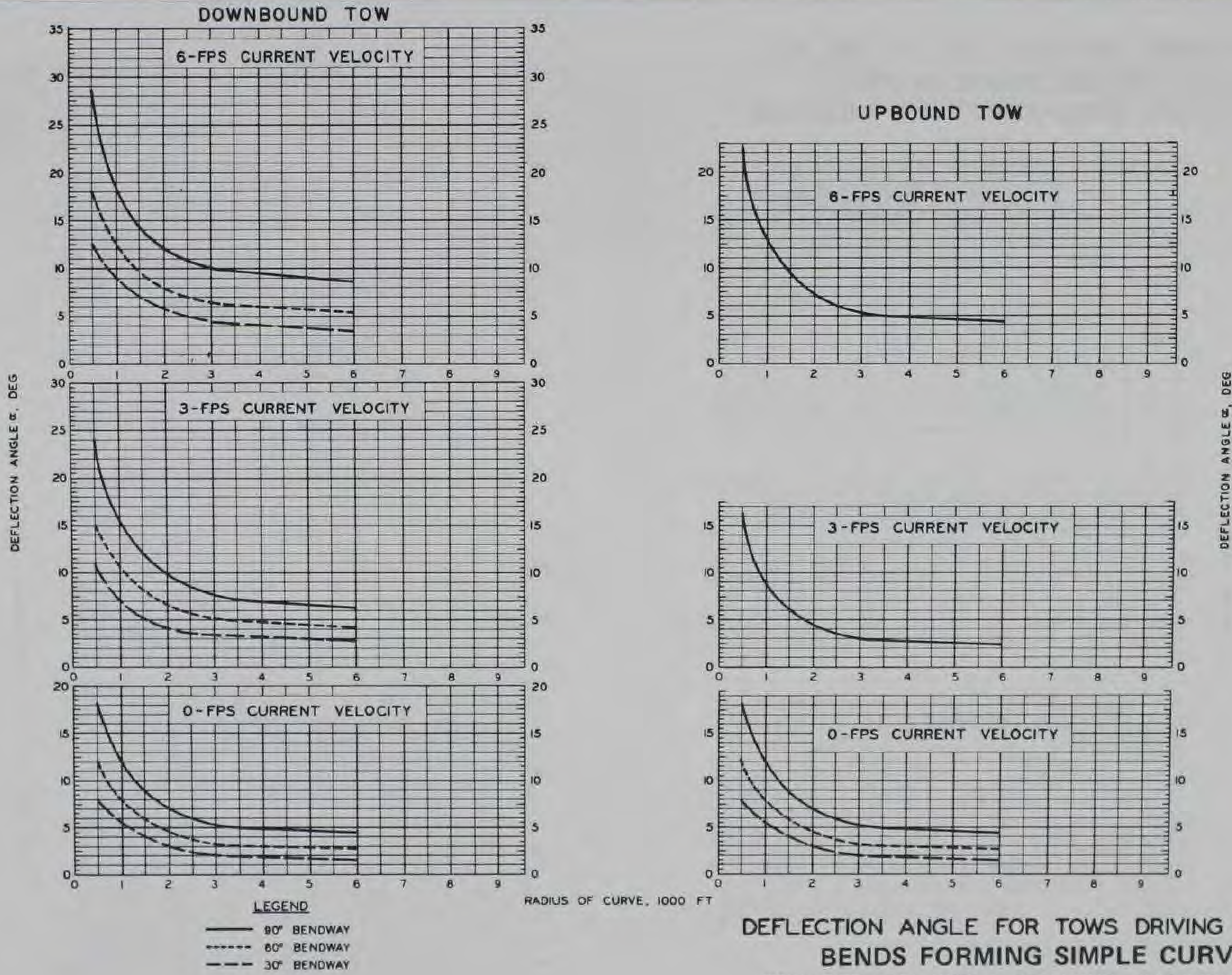


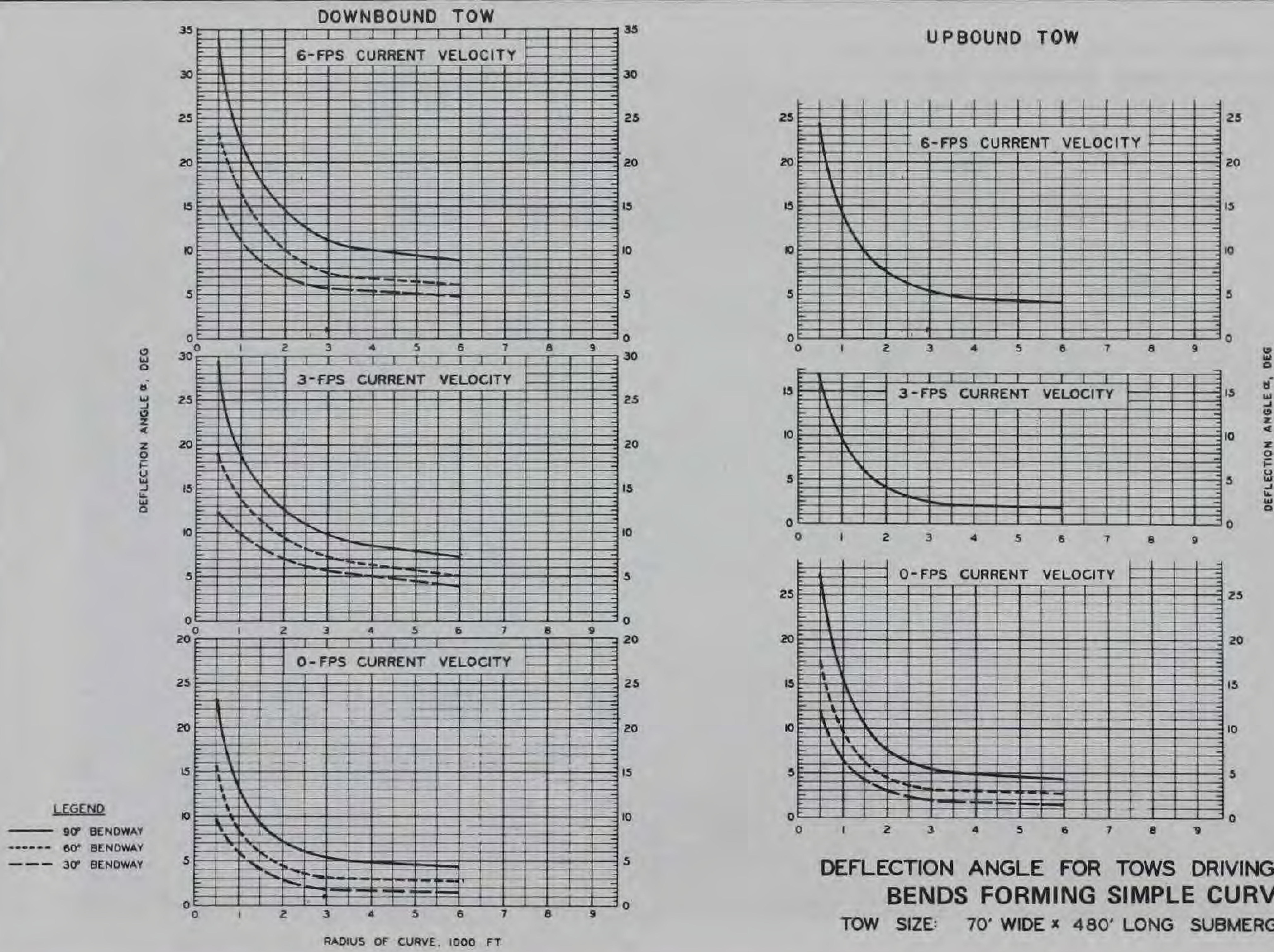
Photo 4. Mosaic of radar image showing progressive location and orientation of a 70- by 516-ft downbound tow negotiating one of the larger radius bends in the Ouachita River with average velocity about 2 fps



DEFLECTION ANGLE FOR TOWS DRIVING THROUGH BENDS FORMING SIMPLE CURVES

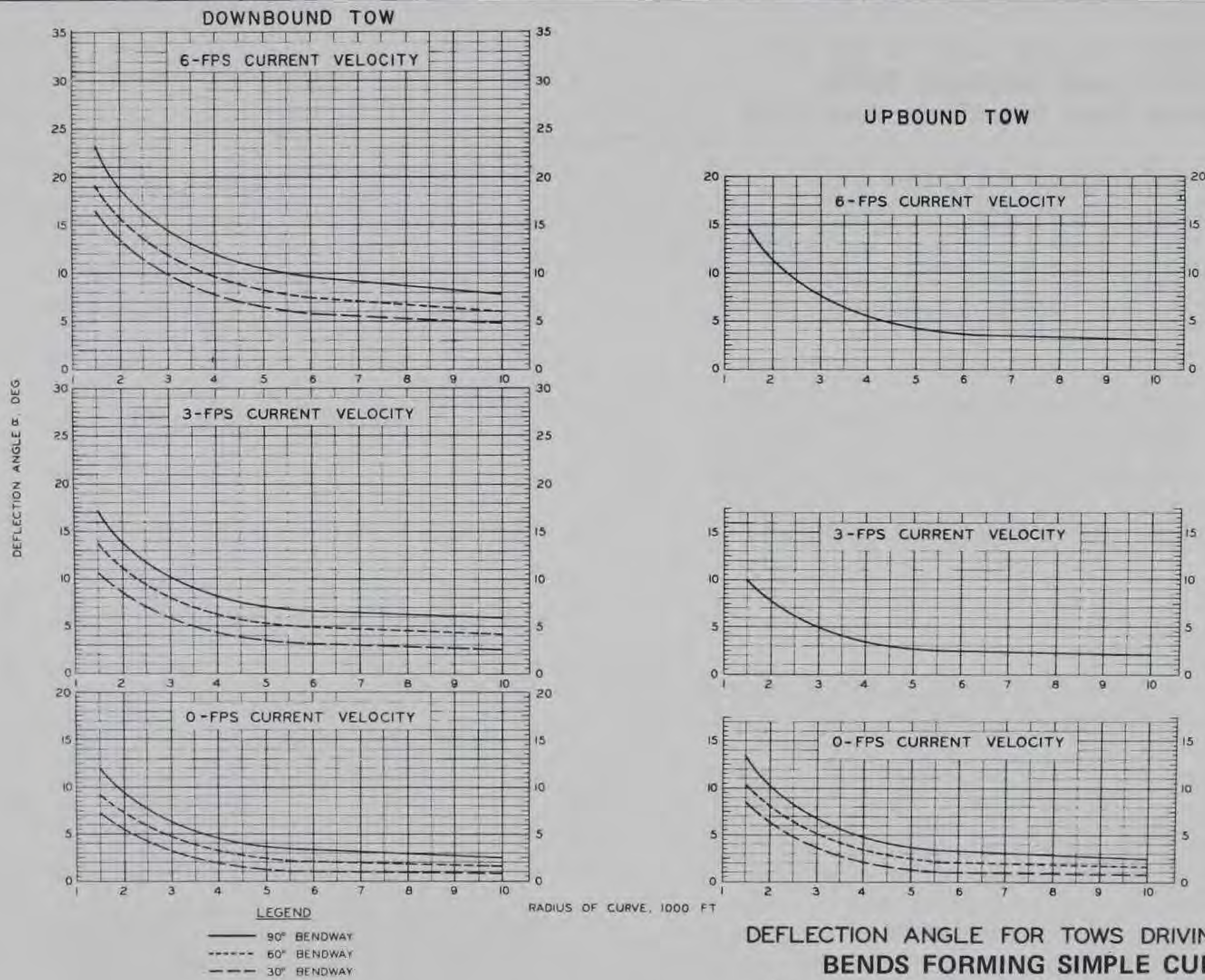
TOW SIZE: 35′ WIDE × 480′ LONG SUBMERGED 8 FT

PLATE 1



DEFLECTION ANGLE FOR TOWS DRIVING THROUGH BENDS FORMING SIMPLE CURVES

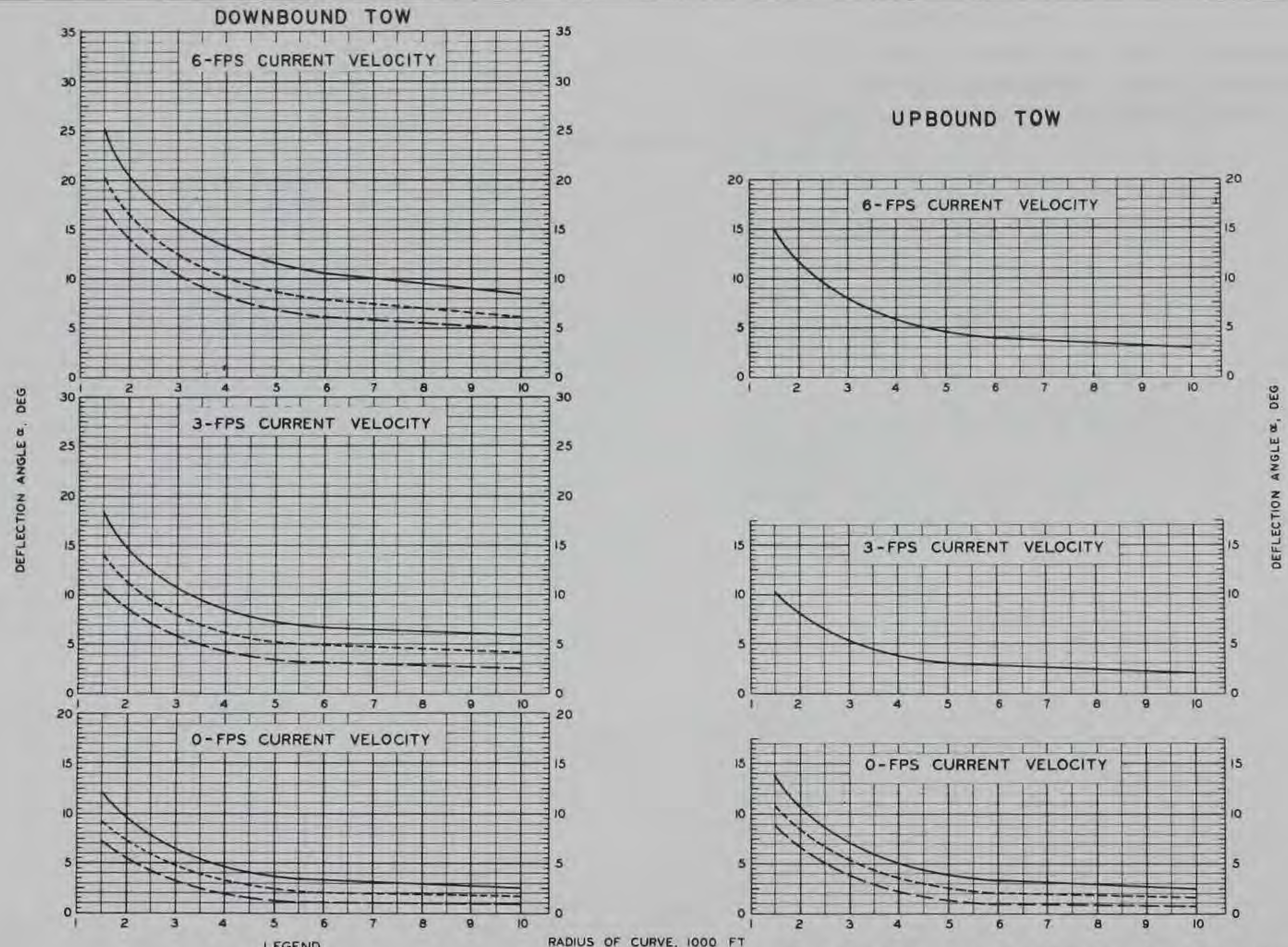
TOW SIZE: 70' WIDE × 480' LONG SUBMERGED 8 FT



DEFLECTION ANGLE FOR TOWS DRIVING THROUGH
BENDS FORMING SIMPLE CURVES
TOW SIZE: 35' WIDE × 685' LONG SUBMERGED 8 FT

PLATE 3

PLATE 4



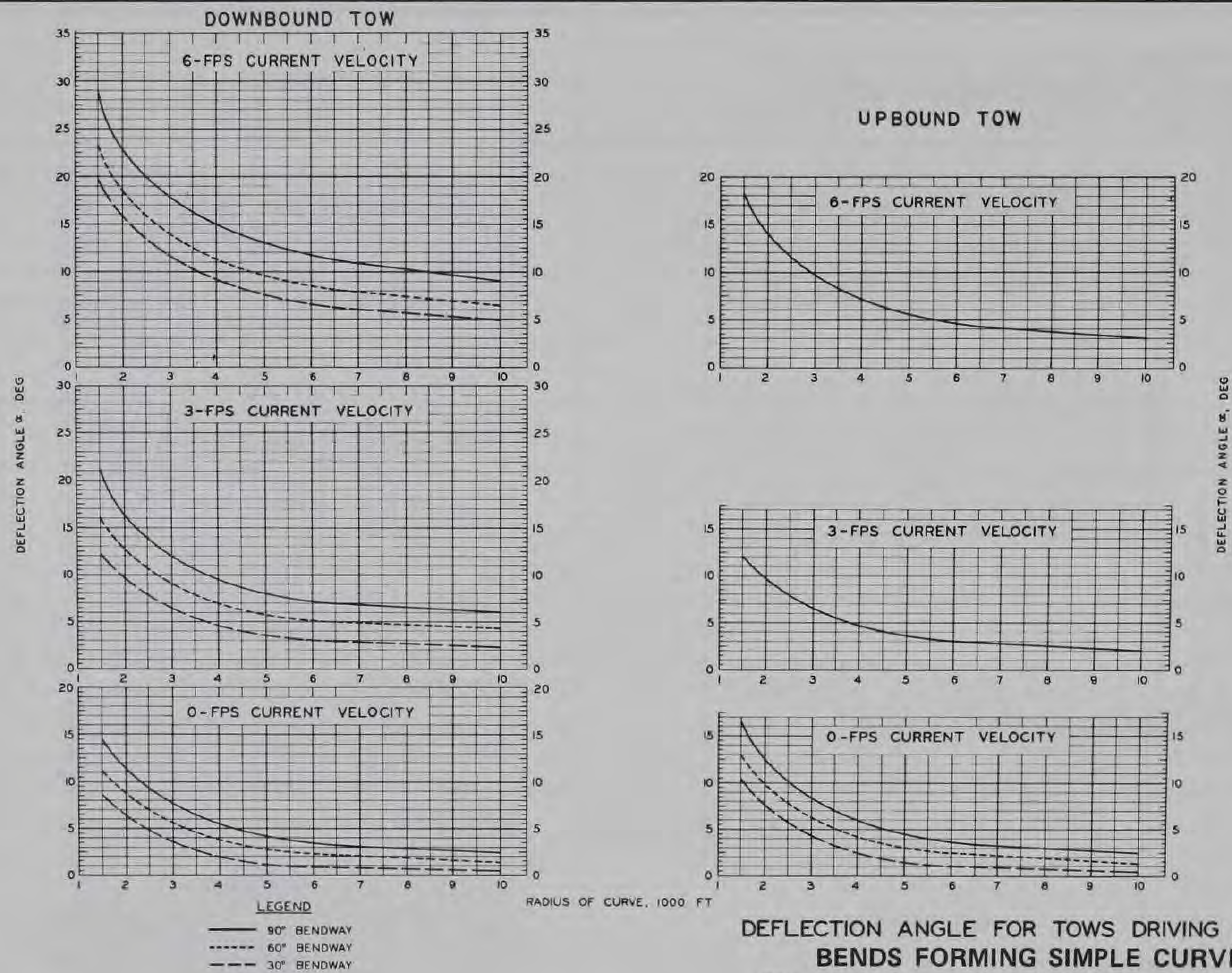
LEGEND

- ——— 90° BENDWAY
- - - - - - 60° BENDWAY
- — — — 30° BENDWAY

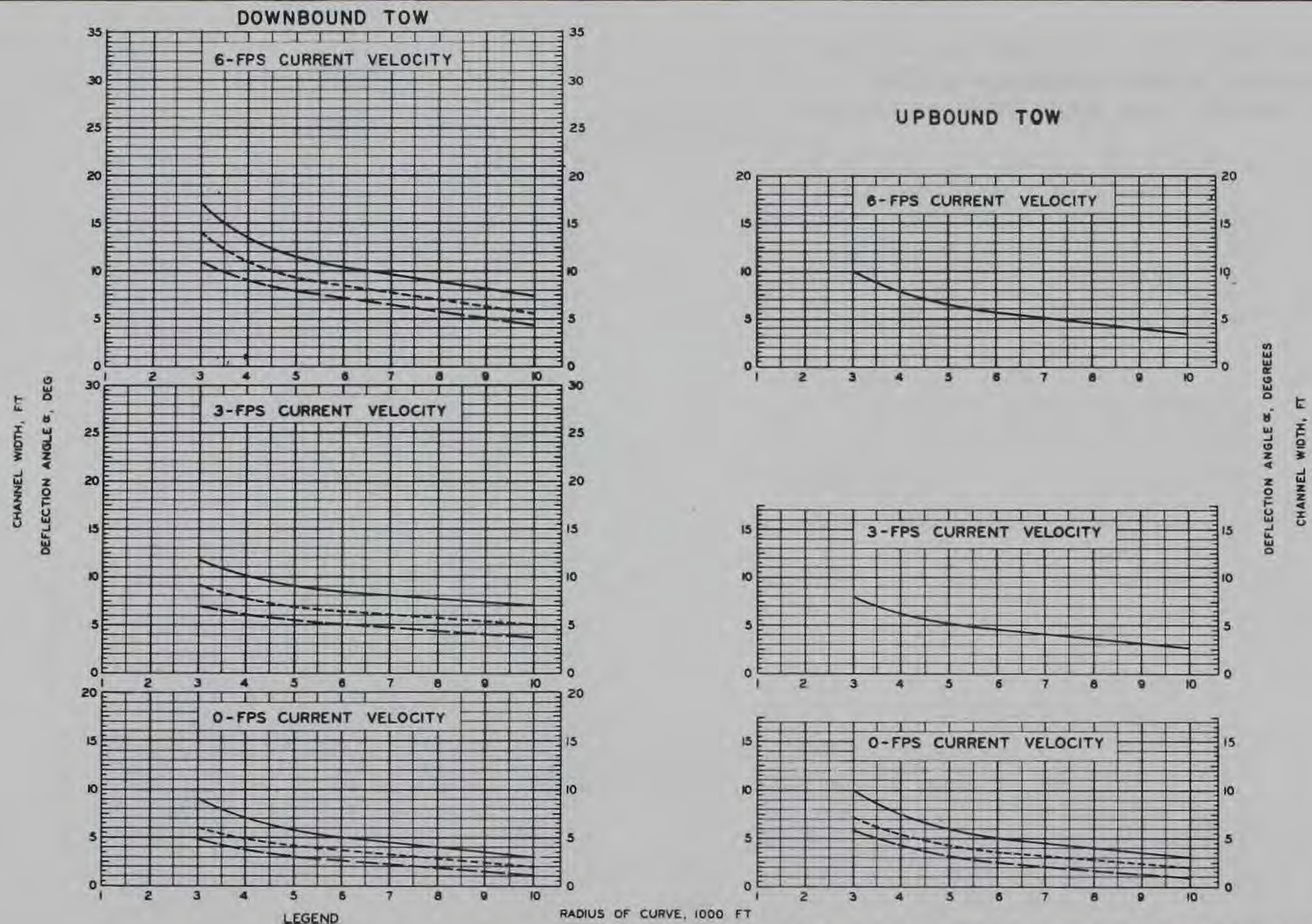
DEFLECTION ANGLE FOR TOWS DRIVING THROUGH

BENDS FORMING SIMPLE CURVES

TOW SIZE: 70' WIDE × 685' LONG SUBMERGED 8 FT



DEFLECTION ANGLE FOR TOWS DRIVING THROUGH
BENDS FORMING SIMPLE CURVES
TOW SIZE: 105' WIDE × 600' LONG SUBMERGED 8 FT

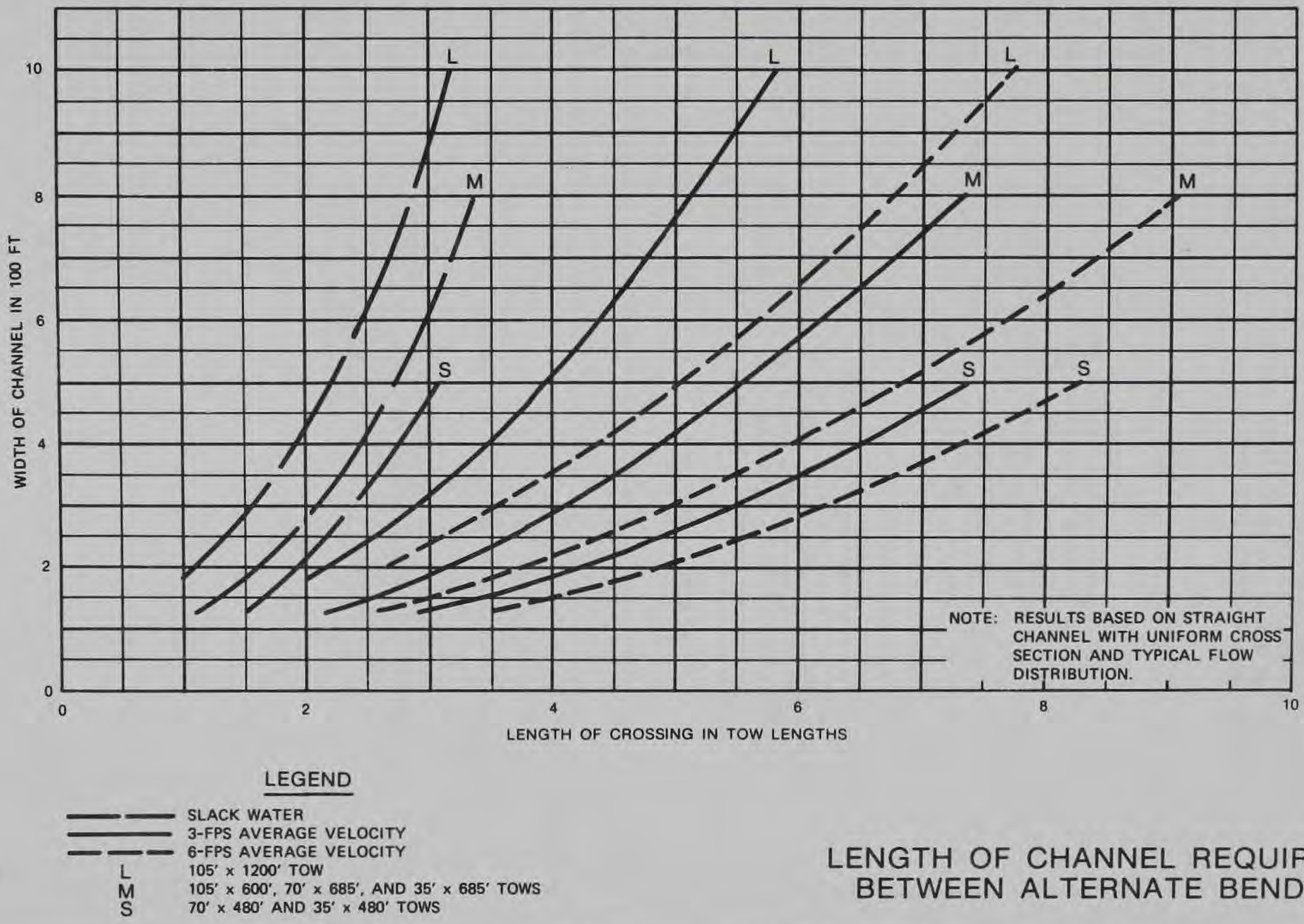


LEGEND

- ——— 90° BENDWAY
- - - - - - 60° BENDWAY
- — — — 30° BENDWAY

DEFLECTION ANGLE FOR TOWS DRIVING THROUGH BENDS FORMING SIMPLE CURVES

TOW SIZE: 105' WIDE × 1200' LONG SUBMERGED 8 FT



LENGTH OF CHANNEL REQUIRED BETWEEN ALTERNATE BENDS