MISSOURI RIVER

DESIGN STUDY

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REPORT NO. 5

LABORATORY INVESTIGATION OF THE KANSAS RIVER BEND AND KANSAS CITY REACH

MEAD HYDRAULIC LABORATORY
MEAD, NEBRASKA

U. S. ARMY ENGINEER DISTRICT, OMAHA
U. S. ARMY ENGINEER DISTRICT, KANSAS CITY
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This report describes the tests and results of a model study conducted at the Mead Hydraulic laboratory of the Kansas City Reach and the Kansas River Bend of the Missouri River. The study was performed by personnel of the Hydro-Sediment Section of the Omaha District, Corps of Engineers, under the general supervision of the Kansas City District and the Missouri River Division.

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DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

LABORATORY INVESTIGATION OF THE KANSAS CITY REACH AND KANSAS RIVER BEND

Conducted at
Mead Hydraulic Laboratory
Mead, Nebraska

U. S. Army Engineer District, Omaha, Nebraska
U. S. Army Engineer District, Kansas City, Missouri
Missouri River Division, Omaha, Nebraska

December 1971

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2. Missouri River Division, Corps of Engineers, "Operation and Function of the Mead Hydraulic Laboratory." MRD Hydraulic Laboratory Series Report No. 1, March 1969.

3. Missouri River Division, Corps of Engineers, "Laboratory Investigation of Underwater Sills on the Convex Bank of Pomeroy Bend." MRD Hydraulic Laboratory Series Report No. 2, November 1966.

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LABORATORY INVESTIGATION OF THE KANSAS CITY REACH AND KANSAS RIVER BEND

INTRODUCTION

This report describes the tests and results of a model study conducted at the Mead Hydraulic Laboratory of the Kansas City Reach and the Kansas River Bend of the Missouri River. The study was performed by personnel of the Hydro-Sediment Section of the Omaha District, Corps of Engineers, under the general supervision of the Kansas City District and the Missouri River Division.

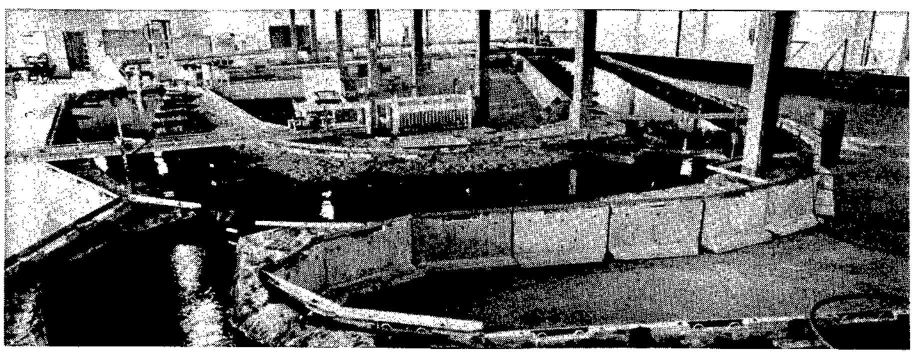


Figure 1. Photograph of Model Taken While Operating.

Attempts to improve and control the Missouri River have been in progress for many years. Dikes, sills, and revetments of various arrangements have been constructed to control the overall river alignment and to insure a river channel of adequate depth and width to permit navigation. The channel alignment of the Missouri River between Sioux City, Iowa and its mouth at St. Louis, Missouri, has in general been established with the shape of each major bend controlled by a combination of spur dikes and bank revetments. However, many times problems still appear within this general alignment. Maintaining an adequate navigation channel through the Kansas City Reach and the Kansas River Bend is a typical problem.

DESCRIPTION OF THE KANSAS CITY REACH AND THE KANSAS RIVER BEND

This river reach is located within the Kansas City city limits and extends from Missouri River mile 363.5 to 368. The reach selected for the model extended from river mile 363 to 369 as shown on Figure 2. The concave (outer) banks are completely revetted with rock, wood piling, or concrete retaining walls and are therefore stable boundaries. The convex bank, or inside of the bend, is controlled by a series of spur dikes spaced intermittently throughout the reach. "L-Head" dikes have been constructed from the ends of some of the spur dikes. At normal river stages, the dikes are above water surface elevation. The "L-heads," however, have generally been constructed to the established Construction Reference Plane (CRP) which is 2 to 3 feet below normal water surface elevation. As of October 1966, sills (also constructed to CRP) existed on the first and third dikes above the Kansas River Bend. These sills confined that portion of the river to about 600 feet. The channel width in the Kansas City Reach remained at about 800 feet. The only significant inflow within the limits of this reach is the Kansas River which enters the Missouri River on the right bank of the Kansas River Bend at Missouri River mile 367.5. A location map of the study reach is shown on Figure 2, while Plate 1 shows the location of all existing control structures as of October 1968.

A review of hydrographic surveys reveals that a deep and narrow channel generally exists on the right bank of the Kansas River Bend, and a point bar often develops directly across from the mouth of the Kansas River. This restriction frequently results in a split channel at the confluence of the two rivers, with neither channel having dimensions suitable for navigation. The channel remains narrow throughout the remainder of the Kansas River Bend. Immediately below this bend in the upper segment of the Kansas City Reach near the Broadway Bridge (river mile 366.1), the flow leaves the right bank and a more uniform cross-section developes. Continuing downstream, the channel meanders between the banks leaving scattered sand bars throughout the remainder of the Kansas City Reach.

PURPOSE OF STUDY

Design criteria for the effective control of river reaches similar to the Kansas River Bend and the Kansas City Reach are very limited. "L-heads," low elevation sills both level and sloping, dike extensions, and vane dikes are types of control that may be effective. Each type of structure may have several successful combinations of structure length, elevation, orientation and slope. Because of the many possible solutions and the unknown results of each, the above reaches were selected for a detailed laboratory investigation. Emphasis was placed upon the selection of an effective system of structures that would develop the desired navigation channel both through the Kansas River Bend and the Kansas City Reach.

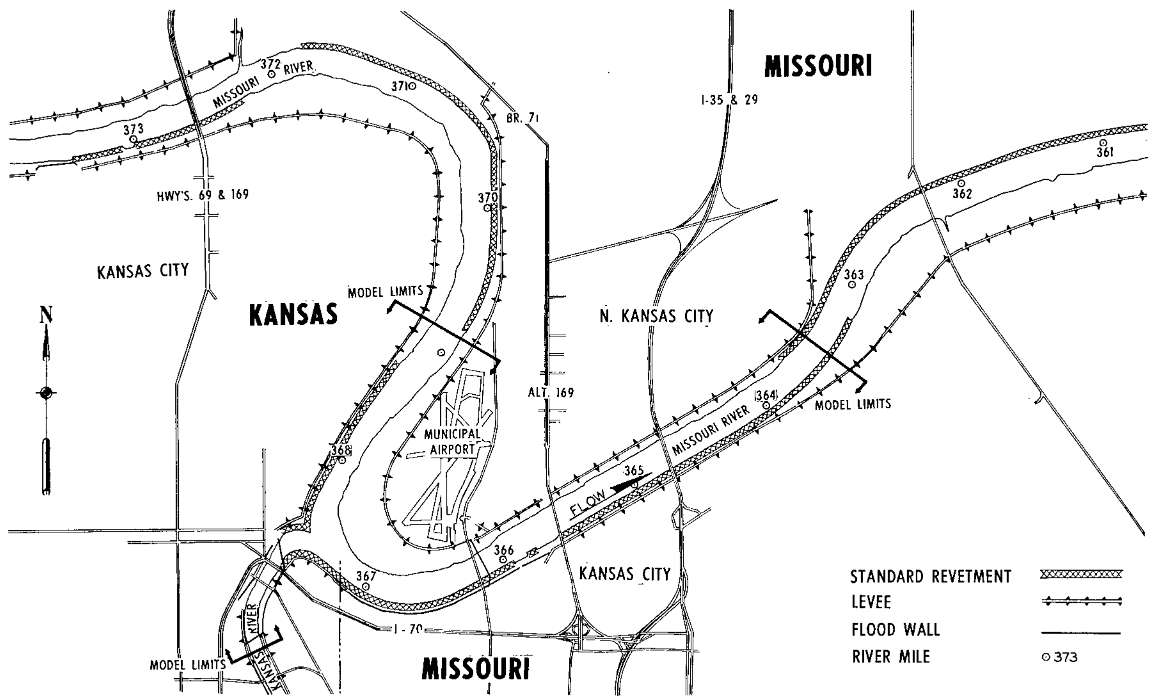


Figure 2. Location Map of Study Reach.

MODEL DESIGN AND VERIFICATION

The bed material for this model, like previously completed studies at the Mead Hydraulic Laboratory, was finely ground walnut shells. The gradation and particle shape of this material is very similar to the sand found in the bed of the Missouri River, as illustrated in Figures 3 and 4. This material resembles and responds very much like sand, but has a specific gravity of only 1.33 compared to 2.65 for sand. This light-weight bed material permitted the model to be operated at low flow velocities, and still maintain a relatively high suspended sediment load which resulted in a desirable time-scale ratio. The bed material was transported both as bed and suspended load.

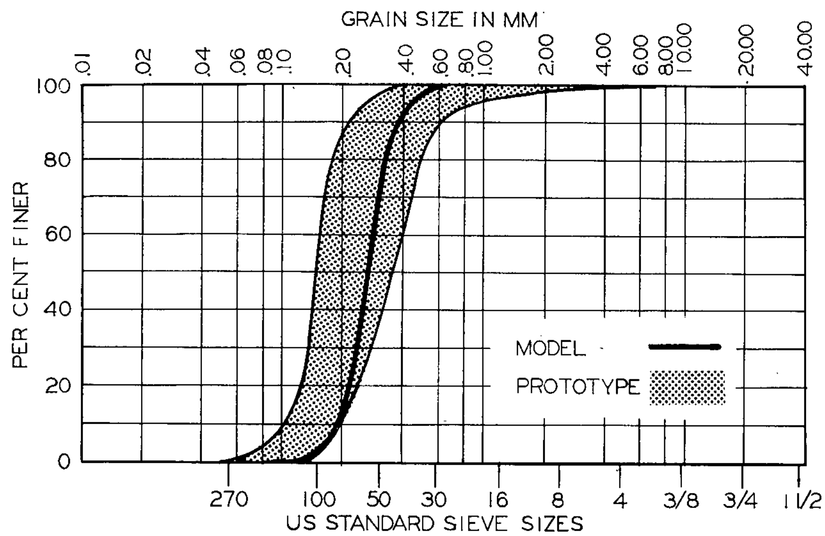
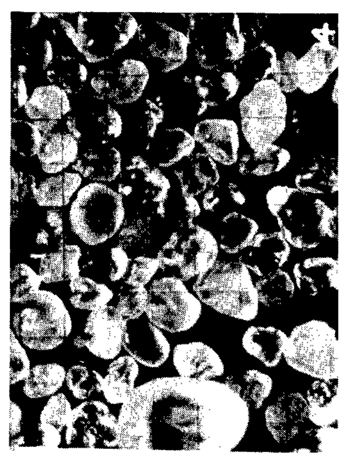


Figure 3. Size Distribution of Prototype and Model Bed Materials.



Walnut Shells

Missouri River Sand

Figure 4. Photomicrograph of Test Materials, Grid Size: 0.39 mm.

Verification of the model involved the determination of a set of model dimensions by which the model would respond to structure changes in much the same manner as the prototype's response to similar changes. First, the length of the reach to be modeled was selected and a sufficient flume length added to both the upper and lower segments of the reach to minimize the influences of undesirable entrance and exit conditions. The horizontal scale, or length radio, was then determined by fitting the largest possible model within the physical limits of the laboratory building. The vertical scale, or height dimension, and the velocity scale were determined by a series of verification tests.

Use of the Froude [1] relationship provides a basis for logical selection of a reasonable operating depth and computation of the velocity ratio. However, in a movable bed model, an additional variable is present that does not appear in the Froude Number; the sediment transport both in suspension and along the bed. Transport rates are a function of variables such as stream depth, velocity, individual grain characteristics, bed forms, intensity of turbulence, and the width-depth ratio of the stream. The horizontal scale ratio necessitated by the physical dimensions of the building dictated that a distorted model be employed[2]. The distortion in channel dimensions also results in distortions of such things as the bed forms and scour hole dimensions.

Preliminary verification tests revealed that the Froude Criteria could not be strictly adhered to. Results of prototype surveys indicated that a very confined channel existed throughout the Kansas River Bend and that a meandering channel was the principal problem in the Kansas City Reach. It was imperative that the model reproduce these conditions. A series of tests was conducted in which operating depths and velocities were varied. Changes in these parameters were made until the model satisfactorily reproduced the river as shown by the bed maps on Plate 2. Using the results of these tests as a guide, a complete set of model scales was then adopted. Because the average discharge during the navigation season is essentially the dominant bed forming discharge, nearly all of the subsequent tests utilized only this one flow. Exceptions to this are defined later under "Description of Tests." No attempt was made to reproduce a seasonal runoff, since a completely new set of scale relationships may have been necessary for each discharge involved. The scale relationships adopted for this model study are listed in Table 1.

TABLE 1
MODEL - PROTOTYPE RELATIONSHIPS

	Missouri River	Model Run No. 18	Scale Ratio Prototype/Model
Discharge, c.f.s.	40,000	0.486	82,300
Average Depth, ft.	10.7	0.198	54
Channel Width, ft.	875	5.8	150
Average Velocity, ft/sec	4.76	0.428	11.1
Slope, (ft/ft) x 10^4	1.9	7.2	0.26
Manning's "n"	0.021	0.032	0.66
Specific Gravity of Bed Material	2.65	1.33	1.99
D35, mm	0.26	0.23	1.13
D50, mm	0.30	0.26	1.15
D65, mm	0.38	0.30	1.27
Froude No.	0.257	0.169	1.52
Sediment Time Ratio*			28*

* Ratio based on measured prototype and model sediment transport rates.

TEST PROCEDURE

The basin used for this model study was a closed system in which both the water and transported sediments were recirculated. The water depth was controlled by regulating the stage at the midpoint of the model. No tailgate or depth control structure of any kind was used; therefore, the water surface and bed slopes were free to adjust. Laboratory testing procedures are further described in "MRD Hydraulic Laboratory Series Report No. 1"[2].

Table 2 is a summary of the measured data and the hydraulic computations made for each test. The basic parameters; discharge, average depth, energy slope, and transported sediment concentrations are average values of measurements taken during or after a test. The remaining items are functions of these basic quantities and can be used to compare one test with another. The ability of a given arrangement of structures to develop the desired navigation channel indicates the degree of control. Methods of relating these channel conditions to basic hydraulic calculations are very difficult. Because most of the tests were operated at basically the same depth and discharge, changes in the bed formations or hydraulic functions were assumed to be the result of changes in the structure layout. A description of each of the items shown in Table 2 is as follows:

Columns (1) & (2)	Model Test Number
Columns (3) & (4)	Prototype Discharge Represented
Columns (5) & (6)	Model Flows
Column (7)	The average flow area of the measured cross sections. Twenty-three Missouri River sections were used to establish this area.
Column (8)	Mean depth was determined for each section by dividing the flow area by top width. The mean depth for the model was determined by averaging the mean depths of all sections.
Column (9)	Average velocity - Discharge divided by flow area.
Column (10)	Energy slope observed in the model at the completion of each test.
Column (11)	Suspended sediment concentrations in parts per million by weight. Reference 1 explains methods used to collect samples. The values presented here are the results of measurements made after the model had reached equilibrium.
Column (12)	Manning's "n" = $\frac{1.486}{Q} \cdot A \cdot D^{2/3} \cdot S^{1/2}$

Column (12) - Cont'd

Where Q = Discharge in c.f.s.

A = Average flow area

D = Average depth

S = Energy slope

Column (13)

Froude Number $F = V/\sqrt{gD}$ represents the ratio of inertia forces to the gravitational force as they existed in the model.

DESCRIPTION OF KANSAS RIVER BEND TESTS

Many types of structures were tested in an attempt to increase the width of the navigation channel throughout the Kansas River Bend. These included spur dikes, low elevation sills, vane dikes, low elevation sills extended from the concave bank, and minor channel realignment. Studies were also made to determine the best location of each of the test structures. A description of the prototype problems and attempted model solutions follows.

The narrow navigation channel in the Missouri River near the mouth of the Kansas River has been a continuing problem. Nearly all hydrographic maps indicate a deep, narrow channel at the confluence. This condition is the result of the point bar that develops near the left bank and extends riverward. Occasionally, the degree of confinement develops to such an extent that a secondary channel develops along the left bank, with neither channel having suitable dimensions for navigation. Test structure 391.95 (see Plate 3) was placed in the model in an attempt to prevent the development of this secondary channel. The tendency for the development of the secondary channel can be seen on bed maps of the model verification runs shown on Plate 2.

A second problem in the Kansas River Bend occurs after higher than normal Kansas River flows. The Kansas River normally contributes only very low flows, but short-duration rises in the spring and summer are common. Because of the angle at which these two rivers merge, the higher Kansas River flows erode the left bank accretion below the confluence, and deposit the material throughout the downstream reaches. Figure 5 is an aerial photograph of the Kansas River Bend after the record flood of 1951. Although the left bank erosion depicted in this photograph is much more severe than that caused by the normal short duration increases in flow, it demonstrates the river's ability to erode the accretion material from this bank. Even though the erosion caused by these Kansas

TABLE 2

SUMMARY OF HYDRAULIC COMPUTATIONS

Run Number Series (1)	Run Number Test (2)	Discharge in C.F.S. Prototype Missouri R. (3)	Discharge in C.F.S. Prototype Kansas R. (4)	Discharge in C.F.S. Model Missouri R. (5)	Discharge in C.F.S. Model Kansas R. (6)	Average Flow Area (ft^2) (7)	Mean-Depth (ft) (8)	Average Velocity (ft/sec) (9)	Slope $x10^4$ (ft/ft) (10)	Transported Sediment Conc. (ppm) (11)	Mannings "n" (12)	Froude Number (13)
1		38,000	2,000	0.748	0.038	1.639	0.286	0.479	5.6		0.032	0.158
2		38,000	2,000	0.412	0.021	1.338	0.243	0.323	1.6	12	0.023	0.116
3		38,000	2,000	0.614	0.031	1.252	0.228	0.514	6.4	284	0.027	0.190
4		38,000	2,000	0.500	0.025	1.275	0.237	0.411	4.1	68	0.028	0.149
5		38,000	2,000	0.484	0.024	1.069	0.200	0.475	5.8	180	0.026	0.187
6		38,000	2,000	0.460	0.023	1.080	0.204	0.447	5.2	26	0.026	0.174
7		38,000	2,000	0.460	0.023	1.136	0.201	0.425	6.6	233	0.031	0.167
8		38,000	2,000	0.460	0.023	1.063	0.191	0.454	7.3	362	0.029	0.182
9		38,000	2,000	0.401	0.020	1.238	0.213	0.340	7.0	254	0.041	0.130
10		38,000	2,000	0.410	0.020	0.935	0.171	0.460	7.9	583	0.028	0.196
11		38,000	2,000	0.462	0.023	1.245	0.228	0.390	4.3	32	0.029	0.144
12		38,000	2,000	0.462	0.023	1.100	0.205	0.441	7.1	169	0.031	0.172
13		38,000	2,000	0.462	0.023				5.8	100		
14		38,000	2,000	0.530	0.030	1.085	0.186	0.516	10.1	1280	0.030	0.211
15		38,000	2,000	0.462	0.024	1.096	0.201	0.444	8.6	419	0.034	0.175
16		38,000	2,000	0.462	0.024	1.030	0.180	0.471	8.4	564	0.030	0.192
17		38,000	2,000	0.462	0.024	1.145	0.196	0.424	6.4	324	0.030	0.168
18		38,000	2,000	0.462	0.024	1.133	0.198	0.428	7.2	315	0.033	0.169
19	A	38,000	2,000	0.462	0.024	1.247	0.211	0.390	6.2	92	0.034	0.150
	B	38,000	2,000	0.462	0.024	1.115	0.192	0.436	6.5	147	0.029	0.174
	C	38,000	2,000	0.462	0.024	1.139	0.204	0.426	5.6	77	0.029	0.166
	D	38,000	2,000	0.462	0.024	1.165	0.203	0.417	6.5	314	0.031	0.163
	E	19,000	38,000	0.231	0.462				5.8	880		
	F	38,000	2,000	0.462	0.024	1.128	0.188	0.431	8.6	420	0.033	0.175
	G	38,000	2,000	0.462	0.024	1.162	0.197	0.417	7.5	230	0.033	0.166
	H	38,000	2,000	0.462	0.024	1.134	0.195	0.428	7.2	250	0.031	0.171
	I	38,000	2,000	0.462	0.024	1.067	0.184	0.456	7.4	420	0.029	0.187
20	A	38,000	2,000	0.462	0.024	1.115	0.192	0.436	7.2	310	0.030	0.175
	B	38,000	2,000	0.462	0.024	1.035	0.178	0.468	7.7	540	0.028	0.195
	C	38,000	2,000	0.462	0.024	1.044	0.178	0.465	7.8	330	0.028	0.194
	D	38,000	2,000	0.462	0.024				7.2	300		
21	A	38,000	2,000	0.462	0.024	1.152	0.202	0.421	5.9	150	0.030	0.165
	B	38,000	2,000	0.462	0.024	1.176	0.205	0.413	6.2	310	0.031	0.161
	C	38,000	2,000	0.462	0.024	1.128	0.199	0.431	6.0	140	0.029	0.170
22	A	71,000	2,000	0.868	0.024	1.572	0.251	0.567	5.5	440	0.025	0.194
	B	38,000	28,000	0.462	0.347	1.606	0.259	0.504	4.7	500	0.028	0.174
	C	38,000	14,000	0.462	0.173	1.348	0.224	0.472	6.2	460	0.029	0.175
	D	38,000	2,000	0.462	0.024	1.213	0.208	0.400	7.0	220	0.036	0.155
	E	38,000	2,000	0.462	0.024	1.242	0.205	0.391	5.8	110	0.032	0.152
23	A	38,000	2,000	0.462	0.024	1.158	0.199	0.419	6.7	200	0.031	0.166
	B	38,000	2,000	0.462	0.024	1.198	0.202	0.405	6.8	330	0.033	0.159
	C	38,000	2,000	0.462	0.024	1.221	0.208	0.397	6.5	400	0.033	0.153
	D	38,000	2,000	0.462	0.024	1.222	0.206	0.397	6.4	280	0.033	0.154
	E	38,000	2,000	0.462	0.024	1.208	0.207	0.402	7.9	350	0.036	0.156
	F	38,000	2,000	0.462	0.024	1.205	0.206	0.403	7.4	420	0.035	0.157
	G	38,000	2,000	0.462	0.024	1.126	0.199	0.431	8.3	450	0.034	0.170
24	A	38,000	2,000	0.462	0.024	1.280	0.215	0.379	6.3	210	0.035	0.142
	B	38,000	2,000	0.462	0.024	1.203	0.204	0.403	8.2	480	0.036	0.157
	C	38,000	2,000	0.462	0.024	1.219	0.206	0.398	7.2	460	0.035	0.155
25	A	38,000	2,000	0.462	0.024	1.143	0.195	0.424	8.4	530	0.034	0.171
	B	38,000	2,000	0.462	0.024	1.188	0.199	0.408	7.6	310	0.035	0.161
	C	38,000	2,000	0.462	0.024	1.225	0.202	0.396	7.4	190	0.035	0.155
26	A	38,000	2,000	0.462	0.024	1.201	0.198	0.404	7.6	390	0.035	0.160
	B	38,000	2,000	0.462	0.024	1.204	0.198	0.403	6.5	210	0.032	0.160
	C	38,000	2,000	0.462	0.024	1.244	0.204	0.390	6.7	150	0.034	0.152
	D	38,000	2,000	0.462	0.024	1.170	0.196	0.415	7.0	250	0.032	0.165
27	A1	38,000	2,000	0.462	0.024				7.4	110		
	A2	38,000	2,000	0.462	0.024				6.8	260		
	A6	38,000	2,000	0.462	0.024	1.265	0.215	0.384	6.1	210	0.034	0.146
	A7	38,000	2,000	0.462	0.024				7.2	130		
	B2	60,000	2,000	0.729	0.024				7.0	340		
	B4	60,000	2,000	0.729	0.024				7.9	490		
	C2	38,000	15,000	0.462	0.182				5.2	30		
	C4	38,000	15,000	0.462	0.182				6.4	370		
	D1	38,000	30,000	0.462	0.365				5.3	340		
	D2	38,000	30,000	0.462	0.365				5.5	340		
	D3	38,000	30,000	0.462	0.365				6.4	380		
	D4	38,000	30,000	0.462	0.365				5.8	410		
	E1	38,000	45,000	0.462	0.547				5.5	480		
	E2	38,000	45,000	0.462	0.547				5.3	570		
	E3	38,000	45,000	0.462	0.547				5.2	520		
	E4	38,000	45,000	0.462	0.547				5.4	450		
	E7	38,000	45,000	0.462	0.547				5.5	470		
	F1	38,000	60,000	0.462	0.729				5.0	800		
	F3	38,000	60,000	0.462	0.729				5.8	540		

TABLE 2 (Cont'd)

SUMMARY OF HYDRAULIC COMPUTATIONS

Run Number Series (1)	Test (2)	Discharge in C.F.S. Prototype Missouri R. (3)	Prototype Kansas R. (4)	Model Missouri R. (5)	Model Kansas R. (6)	Average Flow Area (ft^2) (7)	Mean-Depth (ft) (8)	Average Velocity (ft/sec) (9)	Slope $x10^4$ (ft/ft) (10)	Transported Sediment Conc. (ppm) (11)	Mannings "n" (12)	Froude Number (13)
27	F7	38,000	60,000	0.462	0.729				5.3	510		
	G1	38,000	75,000	0.462	0.912				4.6	470		
	G2	38,000	75,000	0.462	0.912				4.6	430		
	G3	38,000	75,000	0.462	0.912				4.5	640		
	G5	38,000	75,000	0.462	0.912				4.3	540		
	G6	38,000	75,000	0.462	0.912				4.5	410		
28	A	38,000	2,000	0.462	0.024	1.089	0.192	0.445	8.1	620	0.032	0.179
	B	38,000	2,000	0.462	0.024				8.1	600		
	C	38,000	2,000	0.462	0.024	1.157	0.204	0.419	8.3	640	0.035	0.164
	D	38,000	2,000	0.462	0.024				7.9	380		
	E	38,000	2,000	0.462	0.024				7.4	360		
	F	38,000	2,000	0.462	0.024				8.9	650		
	G	38,000	2,000	0.462	0.024				7.8	60		
29	A	38,000	2,000	0.462	0.024				8.6	500		
	B	38,000	2,000	0.462	0.024	1.090	0.184	0.445	8.8	540	0.032	0.182
	C	38,000	2,000	0.462	0.024				7.2	420		
	D	38,000	2,000	0.462	0.024	1.063	0.185	0.456	7.0	410	0.028	0.187
	E	38,000	2,000	0.462	0.024	1.120	0.201	0.433	8.5	320	0.034	0.170
	F	38,000	2,000	0.462	0.024				8.2	430		
	G	38,000	2,000	0.462	0.024				5.9	450		
	H	38,000	2,000	0.462	0.024				8.0	490		
	I	38,000	2,000	0.462	0.024	1.192	0.207	0.407	7.8	560	0.036	0.158
	J	38,000	2,000	0.462	0.024	1.167	0.211	0.416	7.9	480	0.035	0.160
	K	38,000	2,000	0.462	0.024	1.178	0.203	0.412	7.8	310	0.035	0.161
	L	38,000	2,000	0.462	0.024	1.177	0.206	0.412	7.6	240	0.035	0.160
	M	38,000	2,000	0.462	0.024				8.1	250		
	N	38,000	2,000	0.462	0.024				8.1	410		
	O	38,000	2,000	0.462	0.024				8.1	450		
	P	38,000	2,000	0.462	0.024				7.7	370		
	Q	38,000	2,000	0.462	0.024				7.8	460		
	R	38,000	2,000	0.462	0.024				8.5	350		
	S	38,000	2,000	0.462	0.024				7.8	330		
	T	38,000	2,000	0.462	0.024				8.8	460		
	U	38,000	2,000	0.462	0.024	1.162	0.204	0.418	7.7	450	0.034	0.163
	V	38,000	2,000	0.462	0.024				8.6	450		
30	A	38,000	2,000	0.462	0.024				7.6	460		
	B	38,000	2,000	0.462	0.024	1.136	0.194	0.427	8.0	420	0.033	0.171
	C	38,000	2,000	0.462	0.024				8.2	500		
	D	38,000	2,000	0.462	0.024				8.1	520		
	E	38,000	2,000	0.462	0.024				8.5	430		
	F	38,000	2,000	0.462	0.024				8.2	400		
	G	38,000	2,000	0.462	0.024	1.097	0.191	0.442	7.5	230	0.030	0.178
	H	38,000	2,000	0.462	0.024				6.8	240		
	I	38,000	2,000	0.462	0.024				8.0	360		
	J	38,000	2,000	0.462	0.024	1.070	0.186	0.453	7.9	320	0.030	0.185
	K	38,000	2,000	0.462	0.024				7.7	460		
	L	38,000	2,000	0.462	0.024				8.2	420		
	M	38,000	2,000	0.462	0.024				8.4	390		
31	A	38,000	2,000	0.462	0.024	1.127	0.190	0.431	8.7	560	0.034	0.174
	B	38,000	2,000	0.462	0.024				8.4	350		
	C	38,000	2,000	0.462	0.024	1.124	0.190	0.432	8.7	380	0.033	0.175
	D	38,000	2,000	0.462	0.024				8.2	540		
	E	38,000	2,000	0.462	0.024				8.0	540		
	F	38,000	2,000	0.462	0.024				8.4	370		
	G	38,000	2,000	0.462	0.024				8.6	450		
	H	38,000	2,000	0.462	0.024				8.5	330		
32	A	38,000	2,000	0.462	0.024	1.089	0.193	0.446	7.5	330	0.030	0.179
	B	38,000	2,000	0.462	0.024				8.3	490		
	C	38,000	2,000	0.462	0.024				8.6	380		
	D	40,000	0	0.486	0.000				8.1	380		
	E	40,000	0	0.486	0.000				8.6	420		
	F	40,000	0	0.486	0.000				8.8			
33	A1	73,000	2,000	0.983	0.024				7.2	640		
	A2	38,000	2,000	0.462	0.024				7.3	380		
34	A	38,000	2,000	0.462	0.024	1.100	0.202	0.442	7.7	270	0.032	0.173
	B	38,000	2,000	0.462	0.024				6.9	350		
	C	38,000	2,000	0.462	0.024				7.4	250		
	D	38,000	2,000	0.462	0.024				8.0	330		
	E	38,000	2,000	0.462	0.024	1.069	0.192	0.455	8.2	270	0.031	0.183
	F	38,000	2,000	0.462	0.024				7.9	310		
	G	38,000	2,000	0.462	0.024				8.4	390		

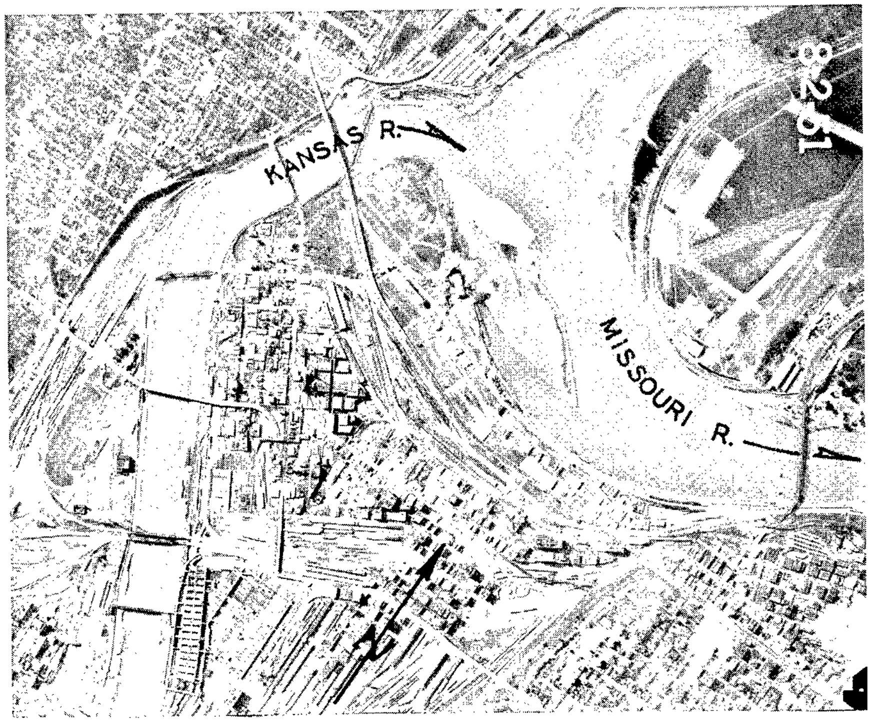


Figure 5. Photograph of the Kansas-Missouri confluence after the 1951 flood. Note large amount of deposition immediately downstream of junction in Missouri River channel.

River flows is not generally detrimental to the navigation channel in the Kansas River Bend, it is imperative that the scour be controlled because of the adverse effects of the corresponding sediment deposition in the river downstream. Initial attempts in the model to control this erosion involved the addition of dike and sill 391.3 as shown on Plate 3. The purpose of this structure was to cause the left bank flows developed during the higher Kansas River discharges to return to the right bank. Initial tests revealed that one dike and sill was not sufficient to control the left bank erosion. For this reason, another dike and sill were added. This structure (dike number 391.5) was placed in the model immediately below the confluence. The location and orientation of the dike and sill was altered as shown in Figure 6 in order to determine the most effective location. In addition to selecting the optimum location for the dikes, tests were conducted using various types of sills extending from the ends of the dikes. These included sills projecting directly into the flow, sills angled upstream and downstream, sills with "L" extensions, and curved sills. The greatest efforts centered on determining the best location and type of sill immediately below the confluence. In order to measure the effectiveness of the structure, tests were made using various combinations of flow from the Missouri and Kansas Rivers. The flows used in these tests are presented in Table 2, Series 22 and 27.

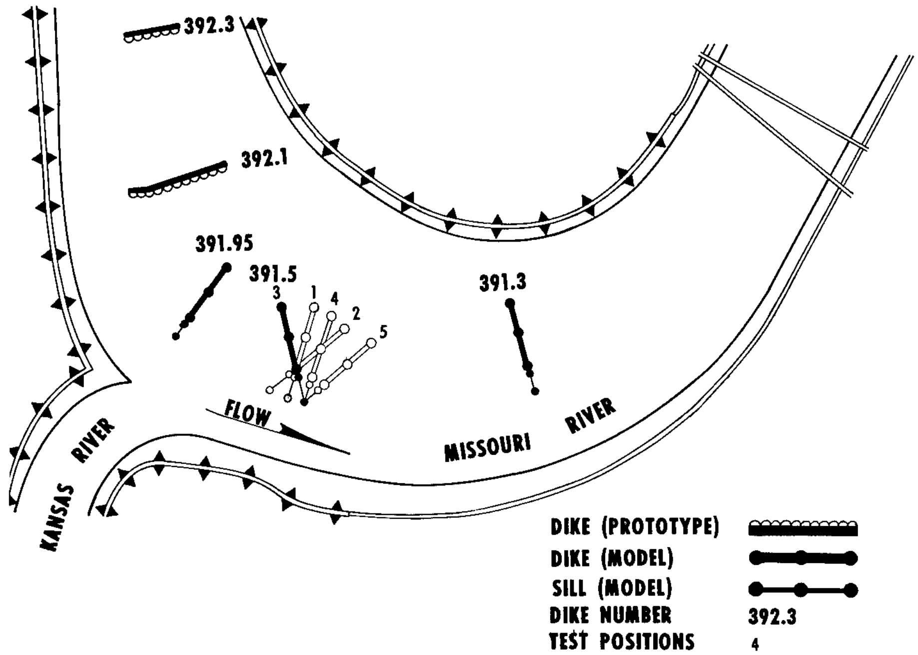


Figure 6. Test Locations for Dike and Sill 391.5.

The left bank dikes and sills discussed above were effective in controlling the erosion of the left bank and the split channel but were ineffective in improving the deep, narrow channel. The tendency for the point bar to develop directly across from the mouth of the Kansas River still existed. Attempts to widen the channel and reduce the thalweg depths were accomplished by constructing low elevation sills (representing depths greater than 12 feet) on the concave bank of the model. Structure layouts and resulting bed maps for two of the tests are shown on Plate 4. These structures were tested to determine if they would be an effective method of reducing the highly concentrated velocities in the region and thus widen the navigation channel. Additional right bank roughness would assist the velocities in becoming more uniform over a greater width. Only three tests were conducted using these low elevation sills. In addition to these low elevation sills, a left bank longitudinal dike that extended from dike 392.1 downstream to beyond dike 391.5 was included in order to limit left bank scour. This structure began at the nose of dike 392.1 and was constructed parallel to the right bank revetment.

The flow entering the Kansas River Bend is abruptly forced through this extremely short radius bend and a very deep and narrow right bank channel results. A series of tests concentrated on a realignment of the right bank revetment by slightly increasing the radius of curvature. Test 32c presented on Plate 5 shows the minor realignment in the lower portion of the curve. Further attempts to widen the deep narrow channel were accomplished by constructing a very slight realignment of the bend in the vicinity of the confluence. These results (test 34a) are also presented on Plate 5.

The realignment of the Kansas River Bend was limited by the presence of existing facilities and the extremely high costs associated with a major realignment. Studies were conducted using a minor extension of the Missouri River right bank revetment at the confluence. This structure is also shown on Plate 5 and was used to gain a more uniform flow distribution through the upper portion of the Kansas River Bend. The results of these tests were compared with previous realignment tests.

The model test results indicated that the dimensions of the channel through the Kansas River Bend was significantly influenced by the distribution of flow entering from the upstream reach. Consequently, tests were conducted using many structure arrangements in this upstream reach in order to develop a system that would stabilize this reach. After the upstream reaches had been stabilized in the model, changes in the Kansas River Bend channel geometry could be attributed to corresponding changes in the test structures in the Kansas River Bend. The extent of model construction works necessary to eliminate the meandering in this upstream reach was not used in the design prototype structures because the model results were influenced by model entrance conditions. They did, however, assist in the evaluations of the effectiveness of model test structures in the downstream reaches.

ANALYSIS OF MODEL RESULTS FOR KANSAS RIVER BEND TESTS

The model demonstrated that the split channel at the confluence can be controlled by constructing dike and sill 391.95. This is shown on Plate 3 by observing the bed maps of the Kansas River Bend for tests both with and without this dike and sill.

Effective control for maintaining the left bank accretion in the Kansas River Bend was much more difficult. The model results indicated that the construction of dike and sill 391.3 was not in itself effective in maintaining control during high Kansas River flows. Dike and sill 391.5 demonstrated its ability to maintain a desirable channel. Tests conducted in which the location of this dike and sill was altered revealed that the structure (see Figure 6) was quite ineffective when in position 2, because it intercepted too small a portion of the flow. Position 5 was found to be more effective.

The differences between positions 1 and 4 were insignificant. Model results revealed that greater amounts of scour occurred at the end of the sill when placed in these positions than when oriented either 30° upstream or downstream.

Some interesting observations were made when comparing the position 3 and 5 test results. During this study, as was noted during previous model studies in which submerged sills were tested, when flow passes over a sill it tends to pass over the sill perpendicular to it. This resulted in greater amounts of local scour below the sill when in position 3 than when in position 5. The difference, however, was quite local and only minor changes in the bed formation below the structure were noted. A slightly larger left bank scour hole existed below the number 3 position, although in nearly all cases it maintained a more suitable right bank channel for navigation. The differences in local scour between tests were too small to be depicted from the bed maps presented in Plates 2 and 3.

The results of the model tests in which attempts were made to widen the navigation channel through the use of low elevation right bank sills are presented on Plate 4. The tests demonstrated that the additional channel roughness caused by these sills resulted in greater turbulence in the vicinity of the structures, and severe scour adjacent to the structures. In addition, these structures encouraged the development of a center bar which resulted in a left bank channel similar to the split channel that dike 391.9 was designed to eliminate. The turbulence which developed near these structures would be detrimental to navigation traffic. A left bank longitudinal dike extending from dike 392.1 downstream to beyond dike 391.5 was used in conjunction with these low elevation sills. This structure was, in effect, a left bank revetment. Although adequate depths were maintained throughout the channel width using this dike, velocities were excessive and turbulence too great to permit safe passage of tows.

The results of the very minor realignment of the Kansas River Bend are shown on the bed maps on Plate 5. Test 32c demonstrated the effects of the very minor relocation of the lower half of the curve. A very minor realignment of the upper portion of the curve was also tried in subsequent tests. These changes resulted in virtually no improvements because the increase in the bend's radius of curvature was insignificant. A revetment extension of the confluence structure was found to be equally effective in streamlining the flow around the upper portion of the curve. This is demonstrated by the results of test 34E, which are presented on Plate 5.

The changes in bed forms and scour hole dimensions for the many types of sills and dike extensions were also documented. Similar tests of these sills were made in the straight Kansas City Reach. Test results for sills in both reaches were similar and are discussed under "Analysis of Model Results for Kansas City Reach Tests."

DESCRIPTION OF KANSAS CITY REACH MODEL TESTS

The model investigation of the Kansas City Reach involved the meandering characteristics of the channel throughout the long, straight reach. Prior to the initiation of the model study, the river channel was confined to an unobstructed width of about 800 feet, and the channel meandered within these limits. The objective of the investigation was to determine the degree of confinement and extent of construction necessary to maintain an adequate navigation channel throughout the reach. The requirement to maintain the navigation channel through the right bank swing span of the AS&B Bridge necessitated that the navigation channel be confined to the right bank throughout the entire reach. After the initial verification tests, changes were made in the model structures in an attempt to improve the navigation portion of the model channel. Plate 1 shows the structures present in the prototype at the time of the model study. The bed maps of Plate 2 indicate the location of the channel and major shoaling areas existing in the prototype at the time of the model study. This plate also shows the model reach at the completion of verification test number 18 and illustrates the model's ability to reproduce itself (model test 21a).

Initial attempts to produce the desired navigation channel centered on development of a series of dikes and sills that would contract the channel until the desired channel dimensions were achieved. This was accomplished by investigating many types of structures including: low elevation dikes called sills (both level and sloping crests) placed perpendicular to the flow; curved sills; and longitudinal structures called vane dikes. A description of each of the types of structures tested and the test results follow.

Because the flow is heavily concentrated on the right bank throughout the bend immediately upstream of the reach (the Kansas River Bend), strong secondary currents are developed. These currents cause the highly concentrated flows to leave the right bank and cross to the left bank in the upstream portion of the Kansas City Reach. Preventing the crossing was of utmost importance in developing an adequate navigation channel. Initial attempts to limit right bank shoaling in the model involved the combination of a left bank dike and a low elevation sill extending to within 500 prototype feet of the right bank at river mile 365.9. The dike crest, like other dikes in the reach, was constructed above the normal water surface elevation, while the sill was built to CRP which is about two or three feet below the normal water surface elevation. As testing progressed, additional sills were added to alternate existing dikes for each subsequent test, until sills extended from the end of every second dike throughout the entire length of the Kansas City Reach. For this series of tests, the channel was confined to a prototype width of 500 feet. Observations made during these tests revealed that after each sill was placed in the model, the right bank shoal would advance farther downstream into the reach. An exception to this was noted near the AS&B Bridge. A right bank shoal usually developed in the model when no sill was placed at dike 389.97, and an adequate navigation channel existed throughout the remainder of the straight reach. This condition was corrected by adding a sill to this dike. The degree of channel control and the resulting channel dimensions for this series of tests are shown on Plate 6.

After the determination was made of the number of sills necessary to control the reach, future efforts centered on the degree of confinement necessary to maintain an adequate navigation channel. In order to do this, sills were again extended from the same dikes, but all were shortened so that the remaining channel represented a prototype width of 650 feet. The sills were then altered so that the channel was confined to 575 feet. The results of these tests were then compared to the original tests in which the confinement had been 500 feet. Comparisons of these results are shown on Plate 6 and represent conditions for the indicated number of sills. A series of tests were run for various numbers of added sills. The number of structures was varied for each degree of channel confinement using the procedure discussed above for the 500-foot channel. The resulting bed maps for these tests are not included in this report.

Tests were also conducted in which the crest elevations of the structures were varied. The variation in crest height ranged from CRP to above the normal water surface elevation.

In still another series of tests, sloping sills were used in which the crest slopes of the test structures were varied. A total of nine model runs were completed in this series, using three different end elevations with each of three crest elevations at the root of the sills. The channel confinement remained constant at 500 prototype feet for this entire series. All structures were placed perpendicular to the flow.

The sills projecting directly into the flow caused substantial scour near the channel end of the test structures. For each basic structure type tested, greater degrees of channel confinement generally resulted in greater scour. Curved sills were tested in an attempt to decrease the turbulence near the ends of the structures. These curved sills extended from the end of the dikes perpendicular to the direction of the flow and then curved downstream through a 90° bend to parallel the flow at the channel end. All structures used for these tests were constructed to CRP and confined the channel to 500 prototype feet.

The final series of tests in the investigation utilized longitudinal structures called "Vane Dikes." These test structures were constructed to an elevation above the normal water surface, and were placed either parallel or slightly angled at 5° or 10° to the direction of flow. The dikes varied in length as did the spacing between structures. Plate 7 demonstrates the structure layout for three of the model tests. Structures were initially placed at the upstream limits of the reach and subsequent structures added in a downstream direction.

ANALYSIS OF MODEL RESULTS FOR KANSAS CITY REACH TESTS

Developing and maintaining an adequate navigation channel in the Kansas City Reach of the Missouri River can be accomplished by confining the channel to a width less than 800 feet. This can be achieved through the use of one of several types of control structures. Low elevation sills placed perpendicular to the flow were found to be the most effective method tested, and required the least amount of additional construction. These sills have a minimal effect on the flood control capacity of the channel, and also control meandering throughout the reach at normal navigation flows.

Model tests revealed that an additional dike and sill should be constructed at river mile 365.9 as shown on Plate 8. This structure would be instrumental in preventing the flow from crossing from the right to the left bank and, therefore, would limit the highly concentrated flow against dike 390.15. Tests were conducted in which two additional dikes and sills were placed between the AS&B Bridge (mile 365.5), and the Hannibal Bridge (mile 366.1). No measurable channel improvements were noted when the results of these tests were compared with the results of tests in which only one structure, shown on Plate 6, was used. Therefore, all subsequent studies utilized only the one test structure in this river segment.

No significant improvements were noted in the model channel when the crest elevations were raised from CRP to above the normal water surface elevation. Slightly larger volumes of accretion developed behind the higher sills; however, the lower elevation sills allowed only a negligible amount of flow in this portion of the channel, with little net influence on the resulting navigation channel. Reduced amounts of scour near the ends of the sills was noted when the sills were constructed to the lower crest elevations.

The amount of channel constriction was found to have significant influence on the ultimate shape of the navigation portion of the channel. This was clearly emphasized during the phase of the investigation in which sloping sills were tested. The channel width between the ends of the structures remained constant for this series of tests, but the amount of channel constriction varied according to the elevation at the root and the slope of the crest of the test sills. The results of these tests were similar to those in which level sills were tested. For comparable channel constrictions, the percent of the total flow behind both types of sills was comparable. Only slight differences were noted in their ultimate effect on the channel. During the study of level sills, a small secondary channel or chute often developed between and in line with the ends of the dikes, while higher deposits were noted toward the channel. This apparently was due to the large amount of accretion that developed between the sills from the channel side due to movement of material along the bed. The accretion in this region would continue to increase, severely limiting the influx of transported sediment necessary to deplete the small remaining channel. It was observed during the testing of sloping sills that accretion would often develop from the bank side and progress to the channel end of the test structures; thus, eliminating this small left bank chute. Slight differences in the velocity distribution were apparently responsible for this change. This small channel was not particularly objectionable; therefore, there appeared to be no significant advantage in using the sloping sill.

The degree of channel confinement (distance between the end of the left bank dike or sill, and the right bank revetments) was a prime consideration of this model study, as was the number of structures required to control channel meandering. The model study revealed that sills constructed from the end of a proposed new model dike at mile 365.9 and from the ends of alternate dikes presently existing throughout the reach would adequately control channel meander and shoaling. Generally, additional sills did not result in further improvements in the navigation channel. One major exception to this is at Dike No. 389.97 just below the AS&B Bridge. A sill was required at this structure to prevent a major right bank shoal from developing immediately downstream of this location. The recommended structure layout for the entire reach is shown on Plate 8. The selected structures do not necessarily represent the optimum development of the reach, but represent a system of structures which will insure a suitable navigation channel completely incorporating the existing channel control structures. The economic necessity of utilizing existing structures limited the position and number of possible sills.

The degree of channel confinement significantly influenced the dimensions of the channel along the right bank throughout the length of the Kansas City Reach. Verification tests (see Plate 2) indicate the presence of a large right bank shoal at mile 365.6 and a meandering channel downstream of this location. Tests in which the channel was confined to 650 prototype feet (Plate 6) indicated only minor improvements over existing conditions. Further confinement to 575 prototype feet indicates a greatly improved channel, although a slight tendency to meander was still evident. Further confinement to 500 prototype feet resulted in additional improvements, although they were not considered significant. Based on the results of these model tests, it is recommended that the channel be confined through the use of level sills to a width of 600 feet.

The use of curved sills (an example of these is shown on Plate 5) resulted in less turbulence and scour at the channel end than what was observed when the sills projected perpendicular to the flow. However, the ultimate improvement in the channel due to the reduction of this scour was not considered sufficient to justify the additional construction and maintenance costs associated with a structure of this nature.

Plate 7 shows the channel geometry that existed at the completion of three of the model tests in which longitudinal structures or vane dikes were tested. Many tests were conducted in which dike length, distance between dikes, and the angle between the dike and flow direction were varied. Model tests revealed that the dikes should be slightly angled to the flow to prevent a large portion of the flow from passing along the backside of the structures. No reduction of flow was noted, however, when the angle between the dike and flow direction was increased from 5 to 10 degrees.

The investigation revealed that there is an optimum length for the longitudinal structures. It was noted that model structures two feet long were much less effective than those three feet long. To achieve the same degree of control using two-foot dikes rather than three-foot structures, it was necessary to reduce the spacing between structures by more than one-third. This resulted in a greater total length of structures required to achieve the same degree of control. The model results also indicated that when dike lengths were increased beyond three feet, the spacing between dikes could not be comparably increased.

Although the tests showed that an adequate channel could be developed in the reach through the use of vane dikes, this means of control was not recommended for this reach because of the high costs involved. This type of construction appears to be more adequately suited to river reaches where previously constructed control structures do not exist. Further model tests of an uncontrolled river segment are necessary to adequately define general design criteria for this type of structure.

CONCLUSIONS

The model study of the Kansas River Bend and Kansas City Reach indicated the following:

a. The Kansas River Bend split channel at the confluence can be controlled through the use of dike and sill 391.9.

b. Removal of portions of the left bank accretion in the Kansas River Bend can be controlled by construction of dikes and sills 391.3 and 391.5. The most effective structure location for dike and sill 391.5 is shown on Plate 8.

c. Additional right bank roughness in the bend through use of low elevation sills is not an effective method for developing a wider, more uniform navigation channel around the bend. Tests using these structures resulted in severe turbulence and scour near the test structures and in some cases, caused the development of a left bank secondary channel.

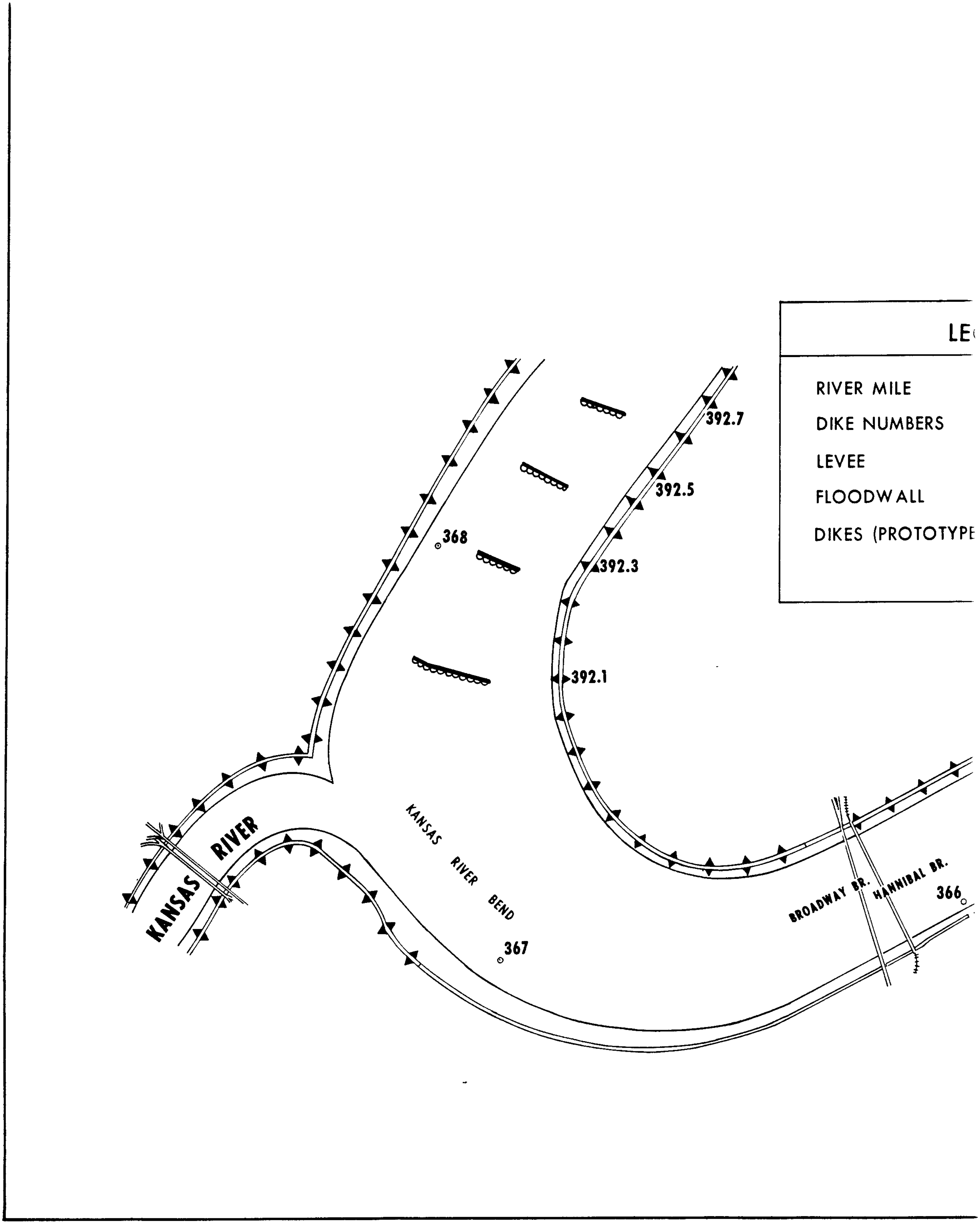
d. Minor realignments of both the upper and lower segments of the Kansas River Bend resulted in no significant improvement in the dimensions of the navigation channel. An equally effective improvement was demonstrated by a revetment extension of existing revetment 378.91 at the confluence. This extension is shown by run 34E on Plate 5 and again on Plate 8.

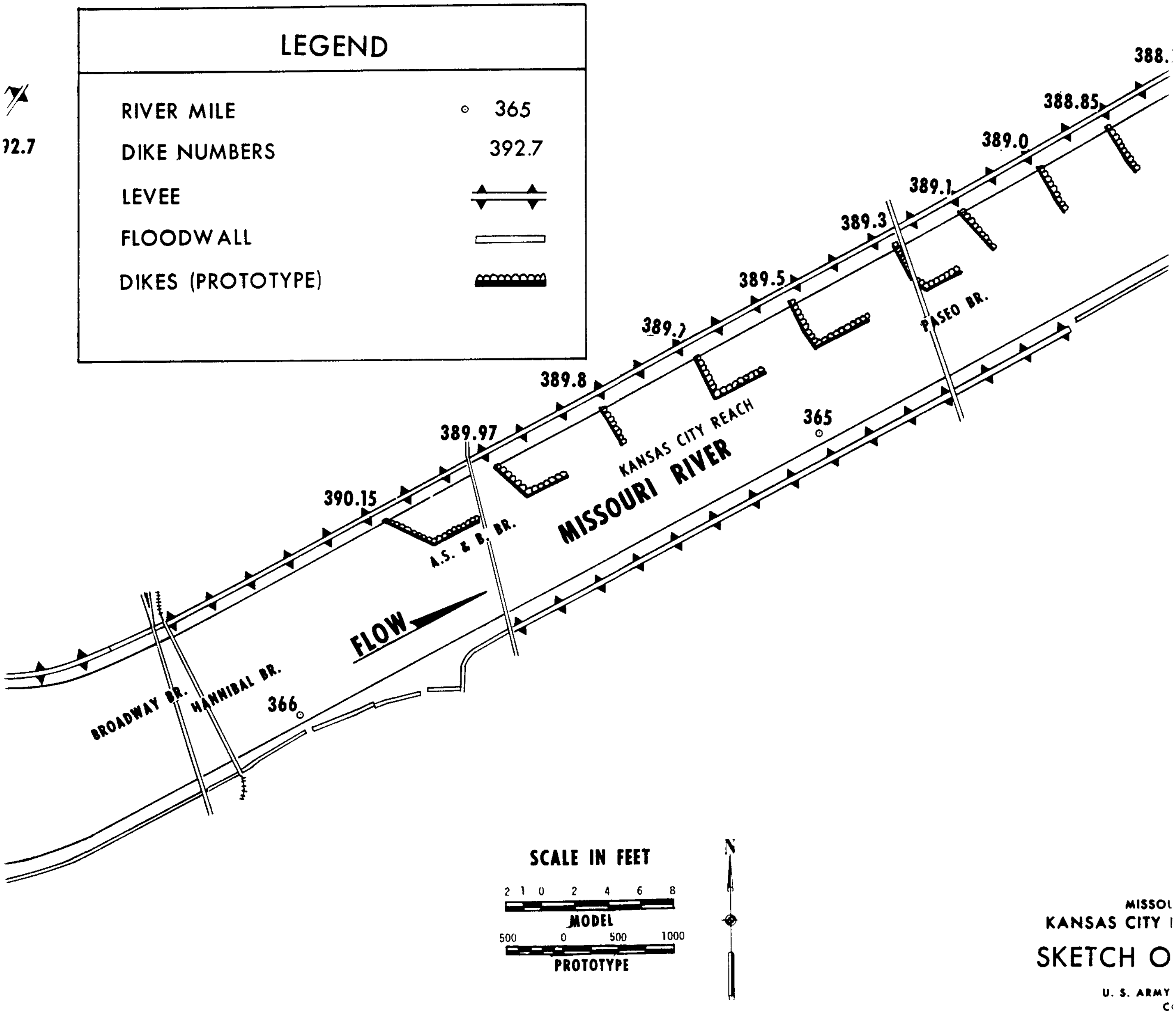
e. Tests of the Kansas City Reach indicated that dike and sill 390.35 would limit the flows crossing in the upper segment of the reach. Further tests revealed that sills constructed on alternate existing dikes throughout the reach would limit channel meander within the reach except that an additional sill was necessary below the AS&B Bridge. The channel confinement must be reduced from the existing 800 feet to 600 feet in order for this system to be effective. Level sills constructed to the Construction Reference Plane are as effective as those built to above-normal water surface.

f. Sloping sills demonstrated comparable improvements in navigation channel dimensions when compared with level sills where similar channel constrictions were used. The very slight difference in the accretion development was considered to be insignificant.

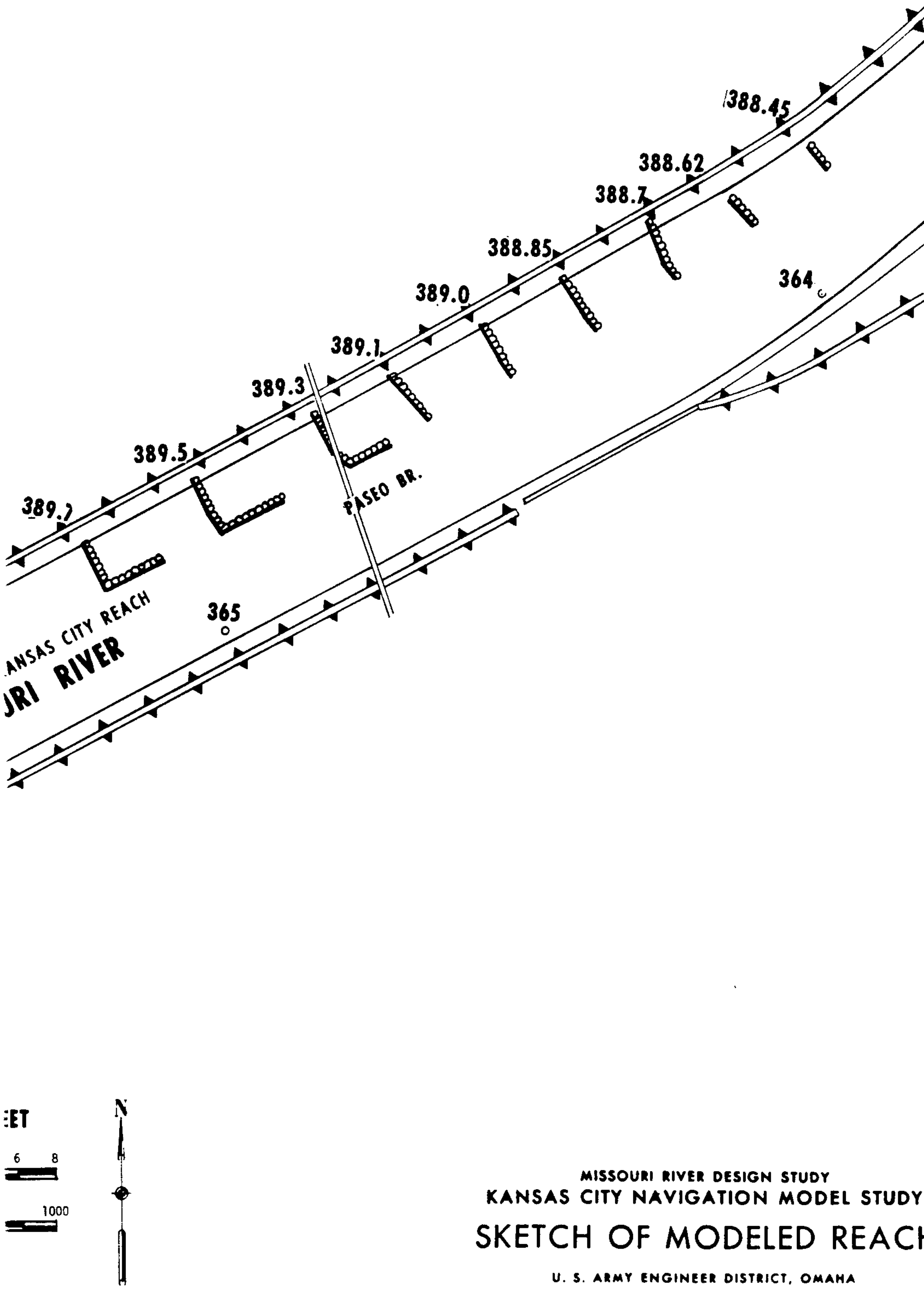
g. Vane dikes have a definite place in river development, particularly in the original stabilization attempts. Because of the existing construction in the modeled reach, this type of control was not feasible for the Kansas City Reach. Use of these structures warrants additional study.

h. All of the structures that were demonstrated by the model to be the most effective and feasible are shown on Plate 8.


LE
RIVER MILE
DIKE NUMBERS
LEVEE
FLOODWALL
DIKES (PROTOTYPE
392.7
392.5
392.3
392.1
368
367
366
KANSAS RIVER
KANSAS RIVER BEND
BROADWAY BR.
HANNIBAL BR.



LEGEND
RIVER MILE 365
DIKE NUMBERS 392.7
LEVEE
FLOODWALL
DIKES (PROTOTYPE)
388.85
389.0
389.1
389.3
389.5
389.8
389.97
390.15
PASEO BR.
KANSAS CITY REACH
MISSOURI RIVER
365
A.S. & B. BR.
FLOW
BROADWAY BR.
HANNIBAL BR.
366
SCALE IN FEET
2 1 0 2 4 6 8
MODEL
500 0 500 1000
PROTOTYPE
N
MISSOU
KANSAS CITY
SKETCH O
U. S. ARMY



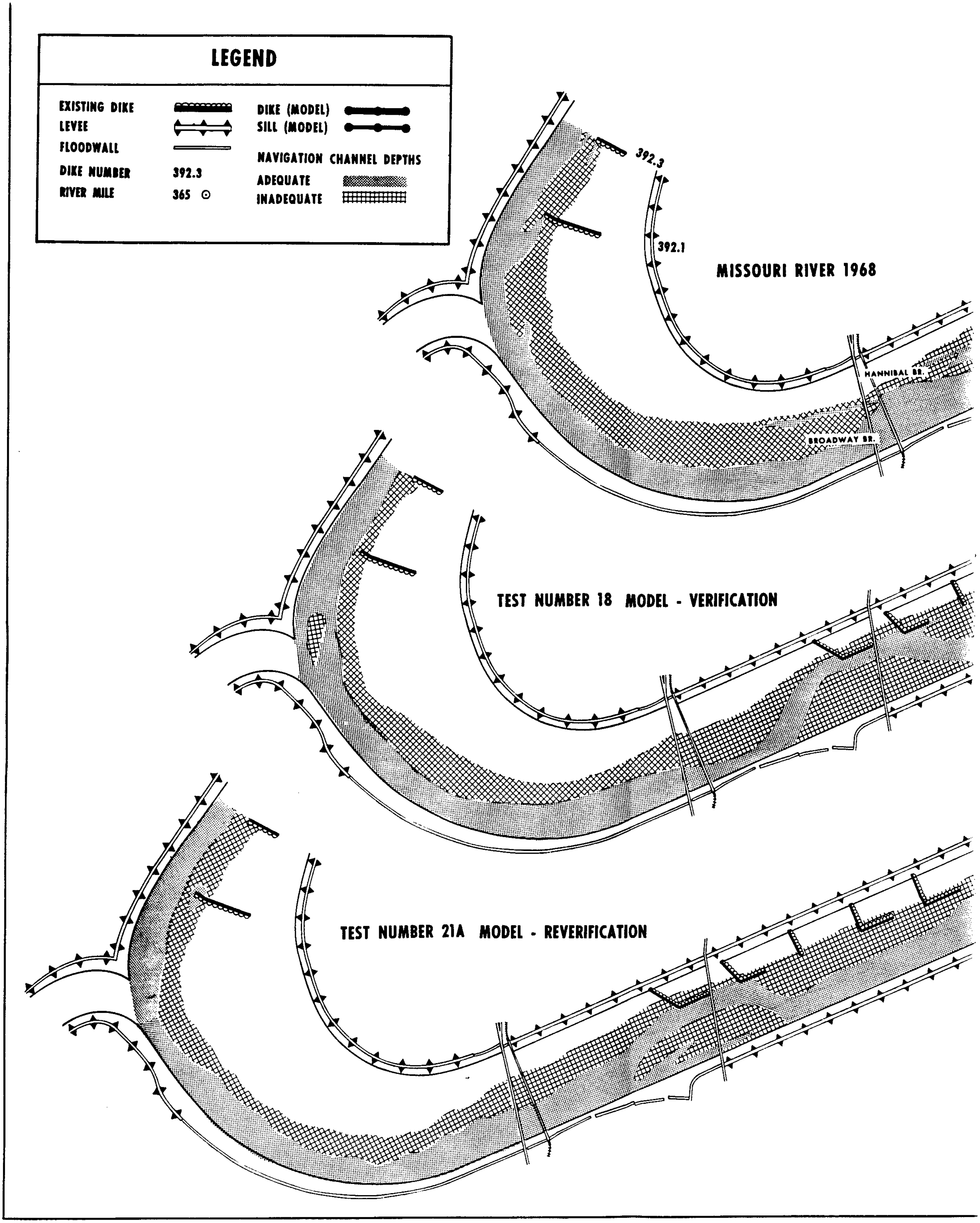
MISSOURI RIVER DESIGN STUDY
KANSAS CITY NAVIGATION MODEL STUDY

SKETCH OF MODELED REACH

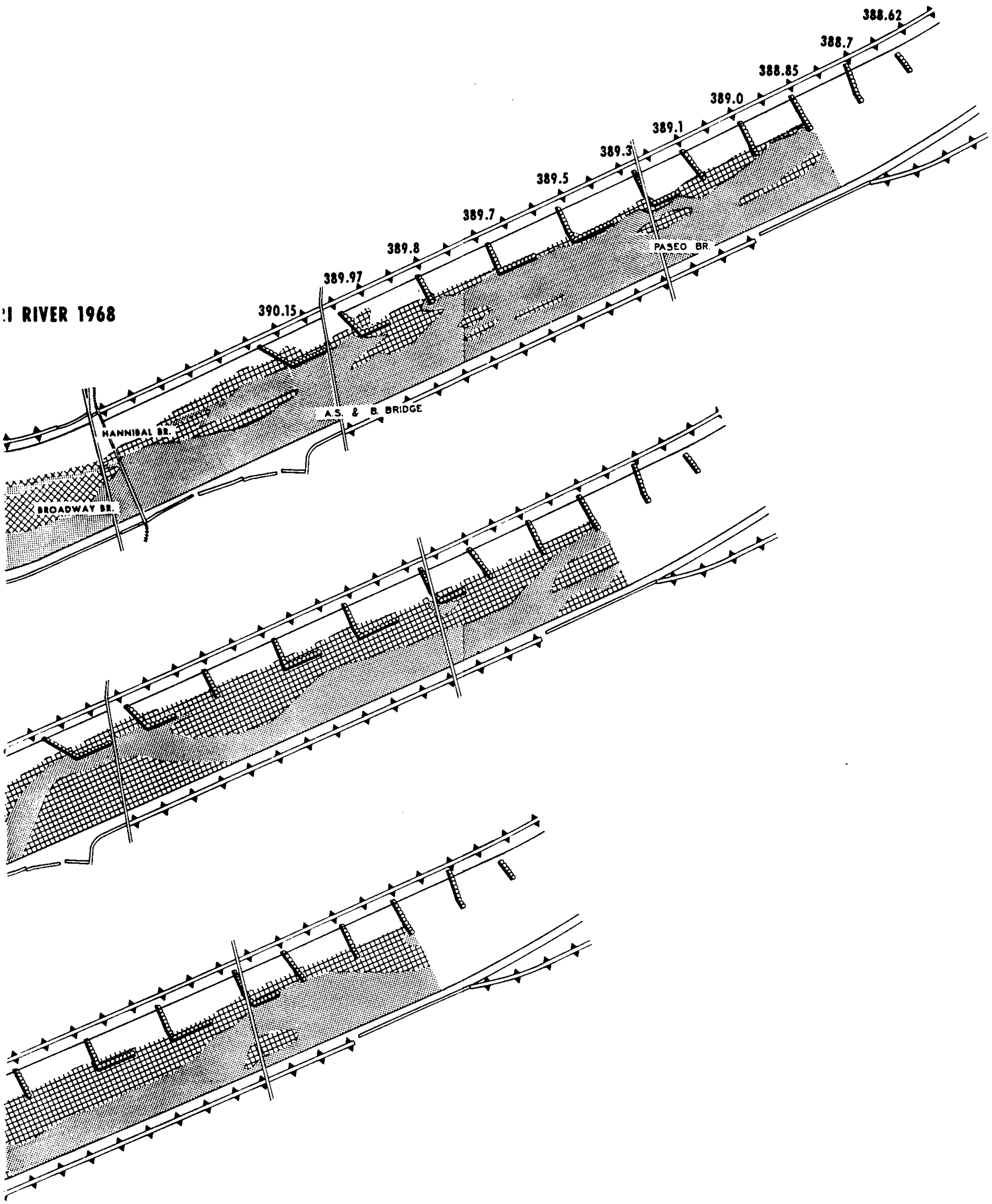
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DECEMBER 1971

PLATE 1



LEGEND
EXISTING DIKE
LEVEE
FLOODWALL
DIKE NUMBER 392.3
RIVER MILE 365
DIKE (MODEL)
SILL (MODEL)
NAVIGATION CHANNEL DEPTHS
ADEQUATE
INADEQUATE
392.3
392.1
MISSOURI RIVER 1968
HANNIBAL BR.
BROADWAY BR.
TEST NUMBER 18 MODEL - VERIFICATION
TEST NUMBER 21A MODEL - REVERIFICATION



MISSOURI RIVER DESIGN STUDY
KANSAS CITY NAVIGATION MODEL STUDY

BED MAPS-MODEL VERIFICATION

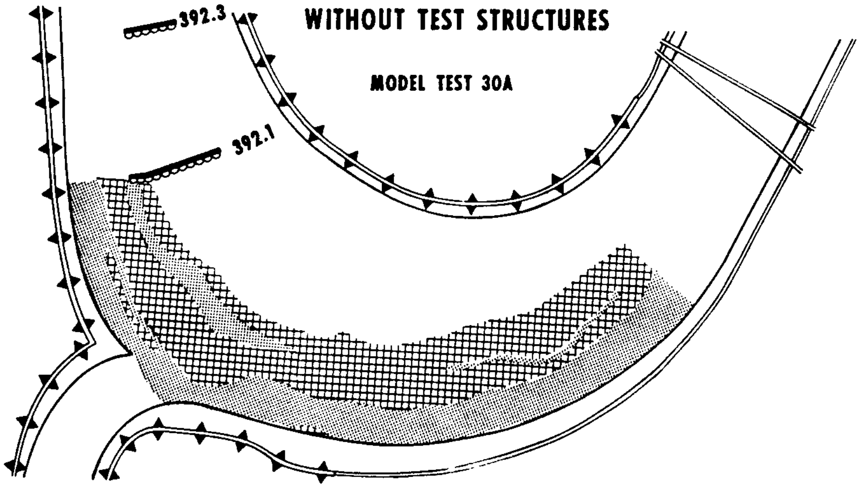
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

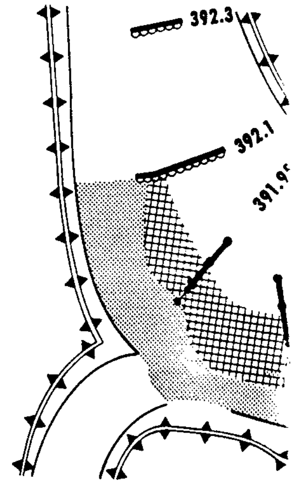
DECEMBER 1971

PLATE 2

WITHOUT TEST STRUCTURES

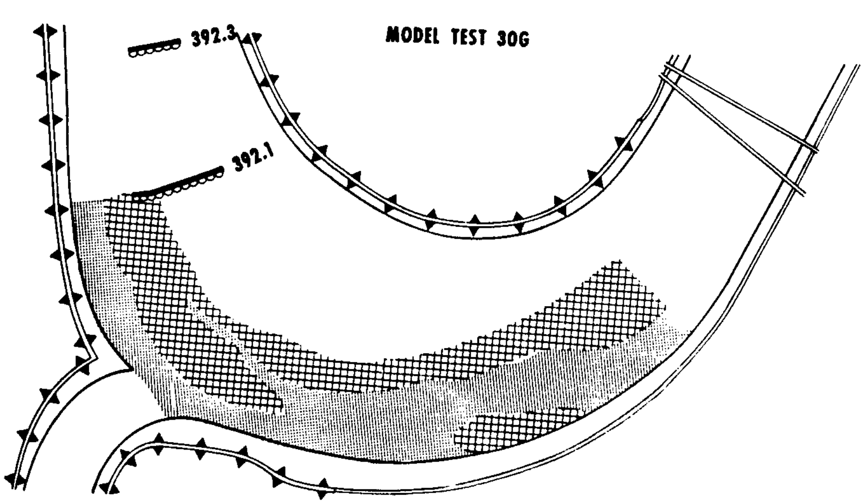
MODEL TEST 30A

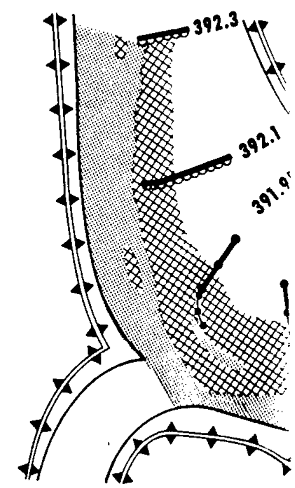




WITHOUT TEST STRUCTURES

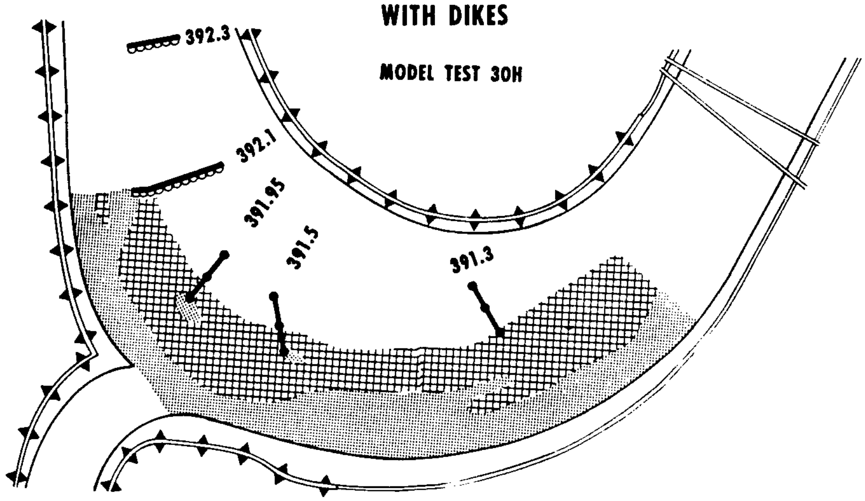
MODEL TEST 30G

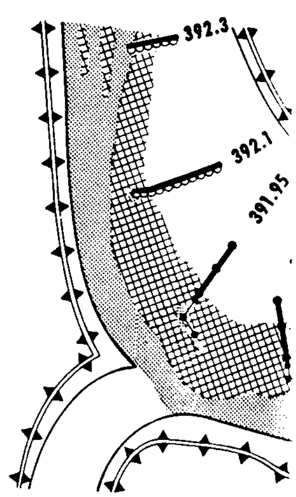


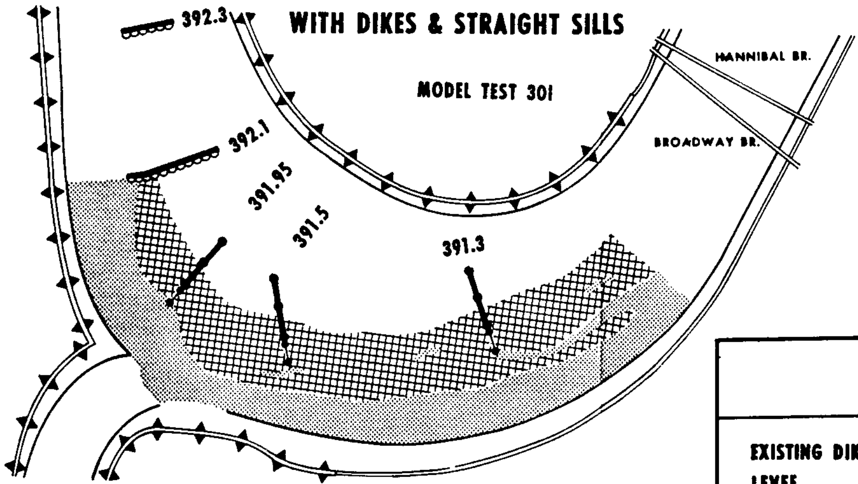


WITH DIKES

MODEL TEST 30H

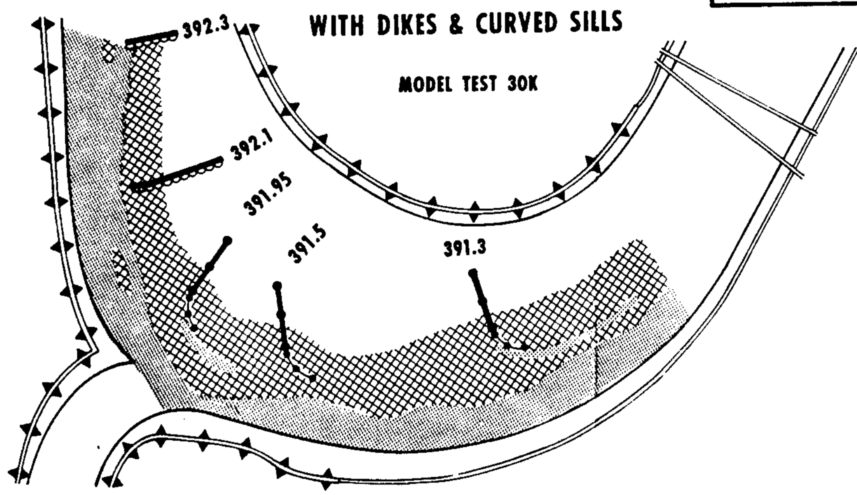


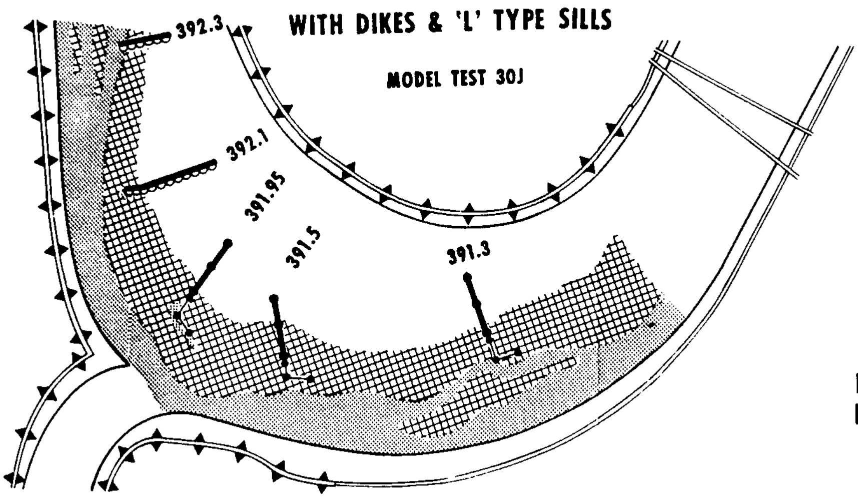




LEGEND

EXISTING DIKE		DIKE (MODEL)	
LEVEE		SILL (MODEL)	
FLOODWALL		NAVIGATION CHANNEL DEPTHS	
DIKE NUMBER	392.3	ADEQUATE	
RIVER MILE	365 ⊙	INADEQUATE	



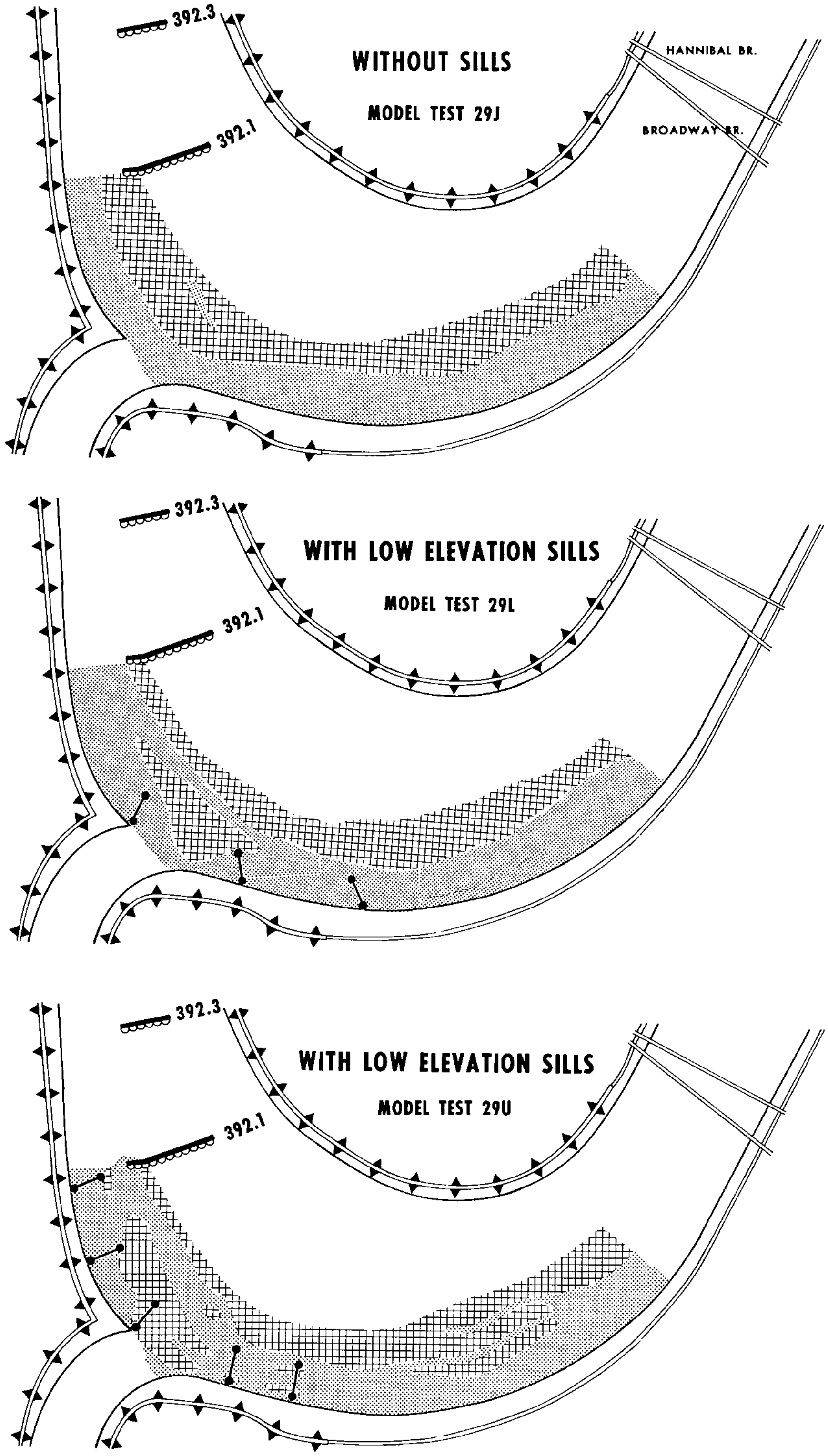


MISSOURI RIVER DESIGN STUDY
KANSAS CITY NAVIGATION MODEL STUDY

KANSAS RIVER BEND BED MAPS
LEFT BANK DIKE AND SILL TESTS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DECEMBER 1971



LEGEND

EXISTING DIKE		DIKE (MODEL)	
LEVEE		SILL (MODEL)	
FLOODWALL			
		NAVIGATION CHANNEL DEPTHS	
DIKE NUMBER	392.3	ADEQUATE	
RIVER MILE	365 ⊙	INADEQUATE	

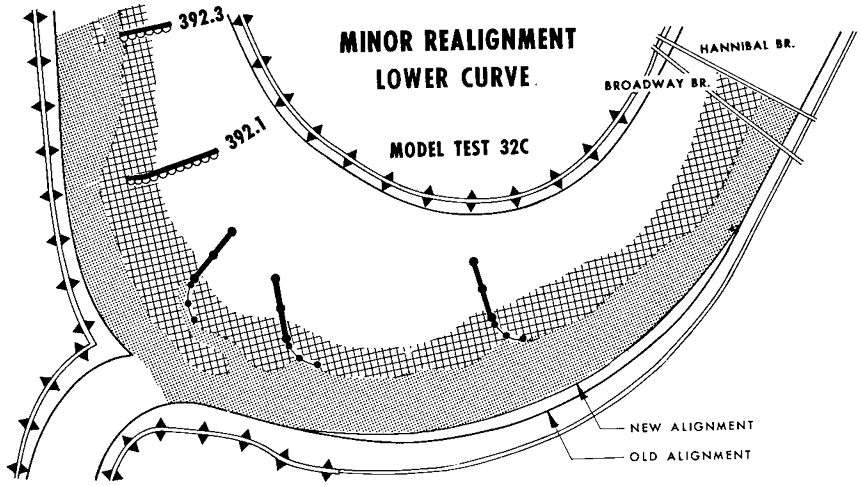
NOTE: The concave bank sills shown on this plate were constructed below navigation depths.

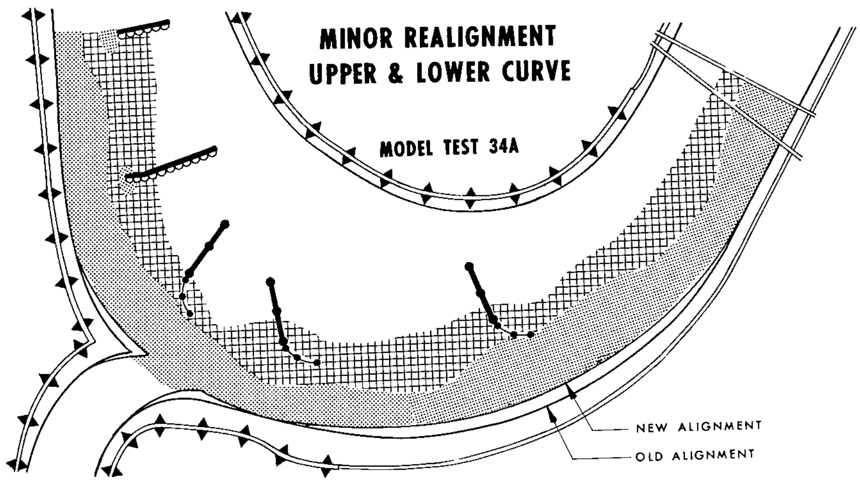
MISSOURI RIVER DESIGN STUDY
KANSAS CITY NAVIGATION MODEL STUDY

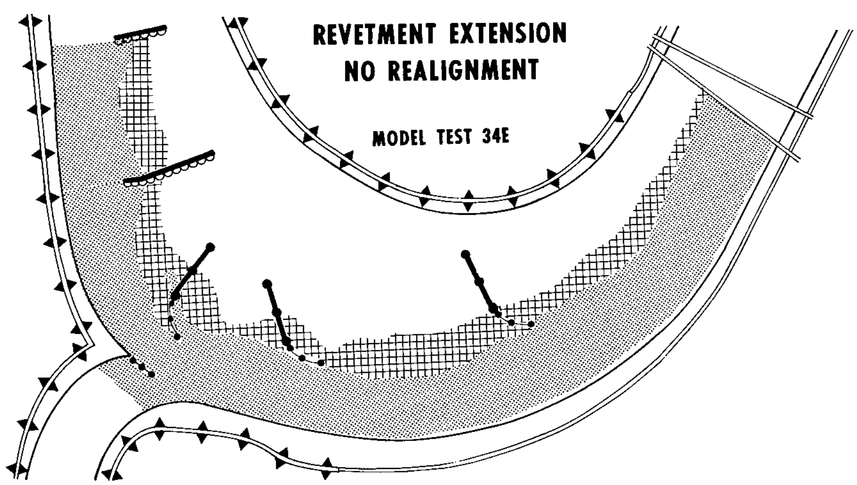
KANSAS RIVER BEND BED MAPS
LOW ELEVATION SILL TESTS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DECEMBER 1971







LEGEND

EXISTING DIKE
LEVEE
FLOODWALL
DIKE NUMBER 392.3
RIVER MILE 365 ⊙

DIKE (MODEL)
SILL (MODEL)

NAVIGATION CHANNEL DEPTHS
ADEQUATE
INADEQUATE

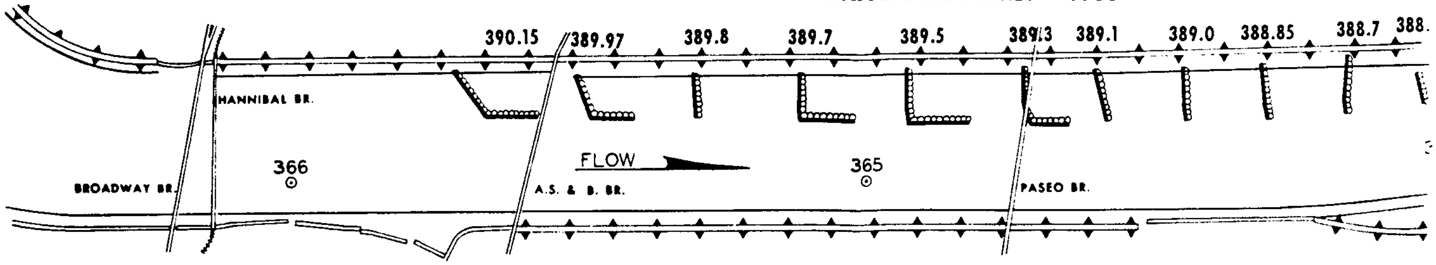
MISSOURI RIVER DESIGN STUDY
KANSAS CITY NAVIGATION MODEL STUDY

KANSAS RIVER BEND BED MAPS MINOR REALIGNMENT TESTS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

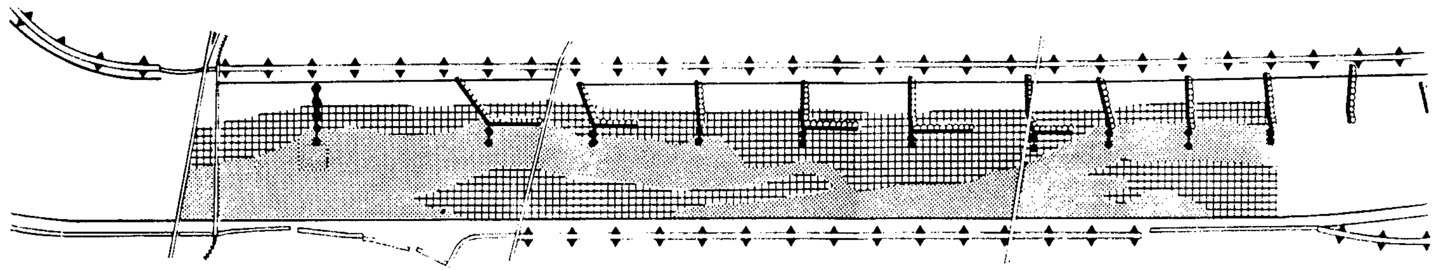
DECEMBER 1971

KANSAS CITY REACH CHANNEL CONTROL STRUCTURES - 1968



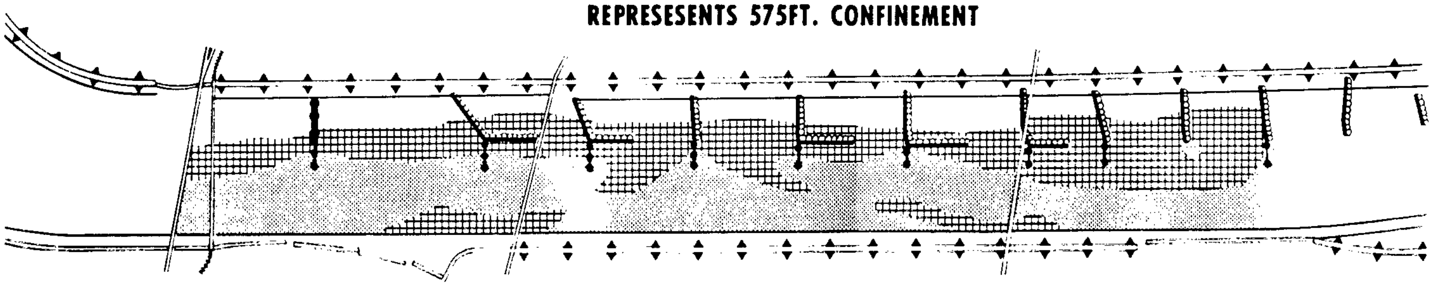
MODEL TEST 26A

REPRESENTS 650FT. CONFINEMENT



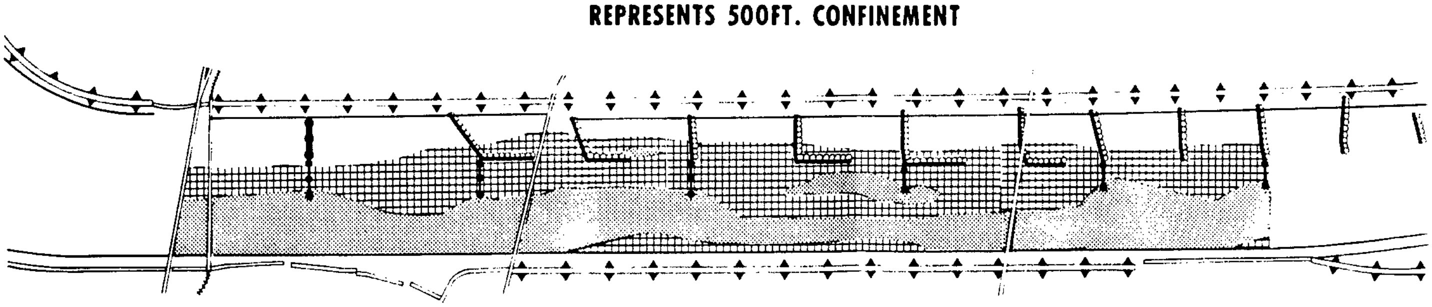
MODEL TEST 26D

REPRESESENTS 575FT. CONFINEMENT



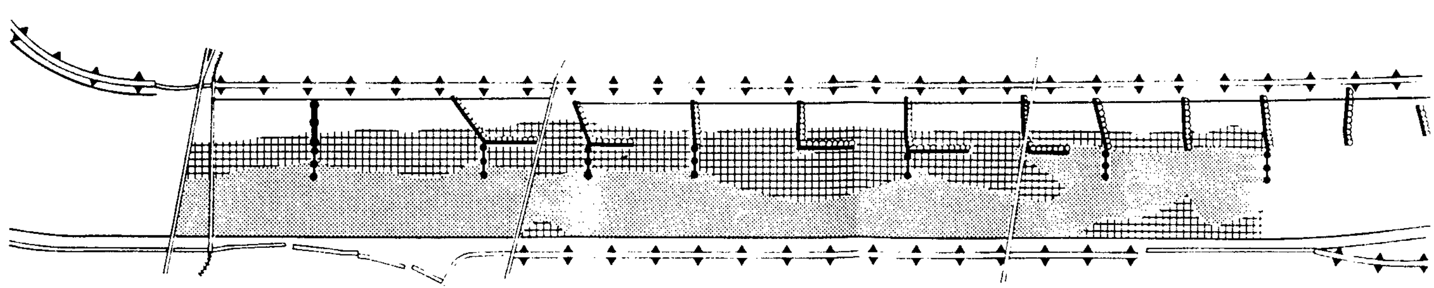
MODEL TEST 23G

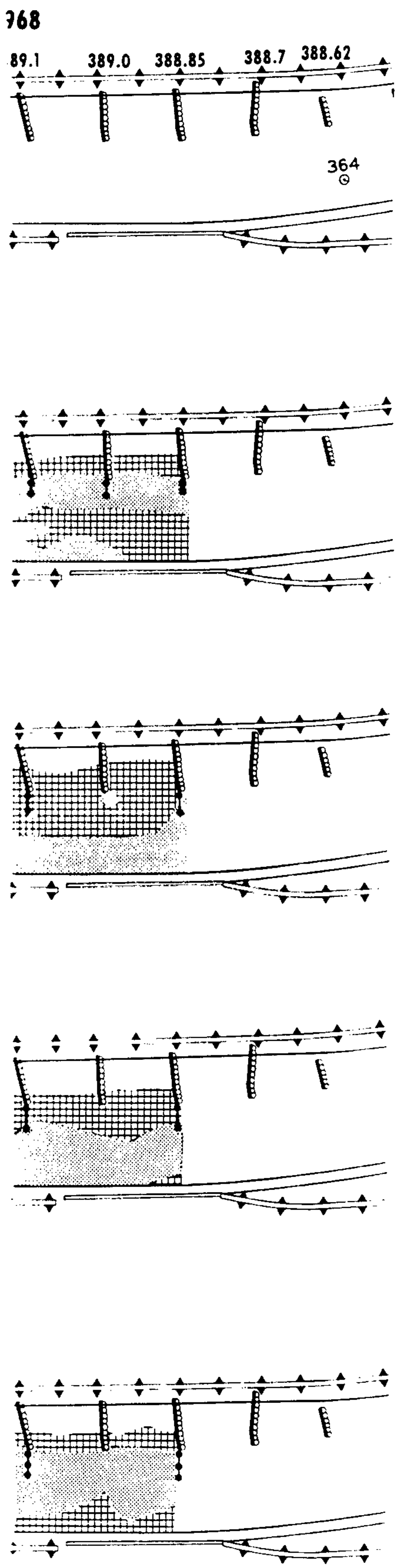
REPRESENTS 500FT. CONFINEMENT



MODEL TEST 25B

REPRESENTS 500 FT. CONFINEMENT





LEGEND

EXISTING DIKE
LEVEE
FLOODWALL
DIKE NUMBER 392.3
RIVER MILE 365
DIKE (MODEL)
SILL (MODEL)
NAVIGATION CHANNEL DEPTHS
ADEQUATE
INADEQUATE

MISSOURI RIVER DESIGN STUDY
KANSAS CITY NAVIGATION MODEL STUDY

KANSAS CITY REACH BED MAPS VARYING DEGREES OF CHANNEL CONFINEMENT

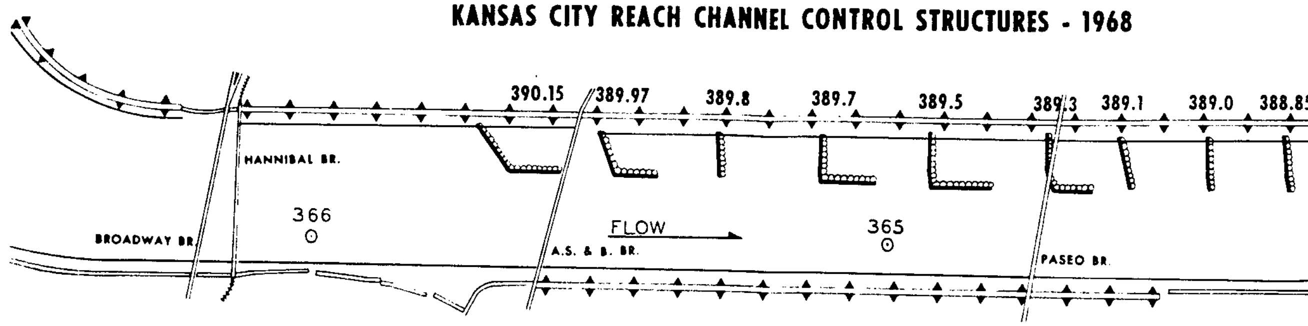
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DECEMBER 1971

PLATE 6

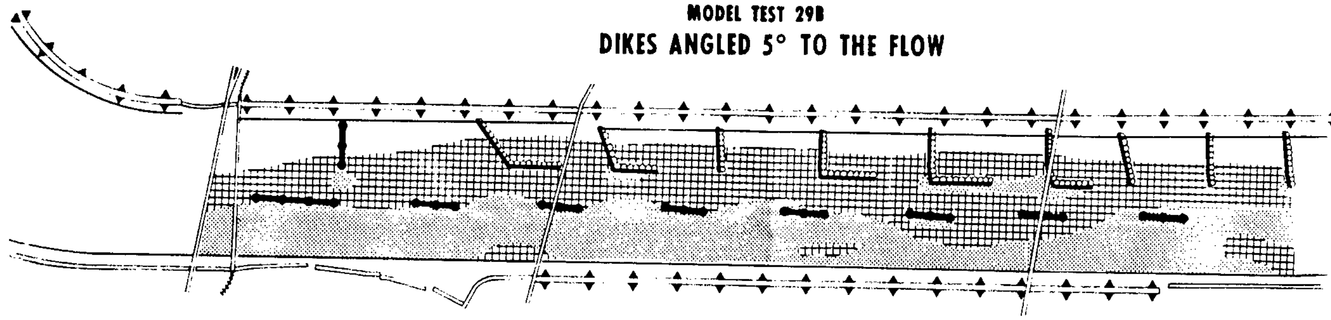
2

KANSAS CITY REACH CHANNEL CONTROL STRUCTURES - 1968



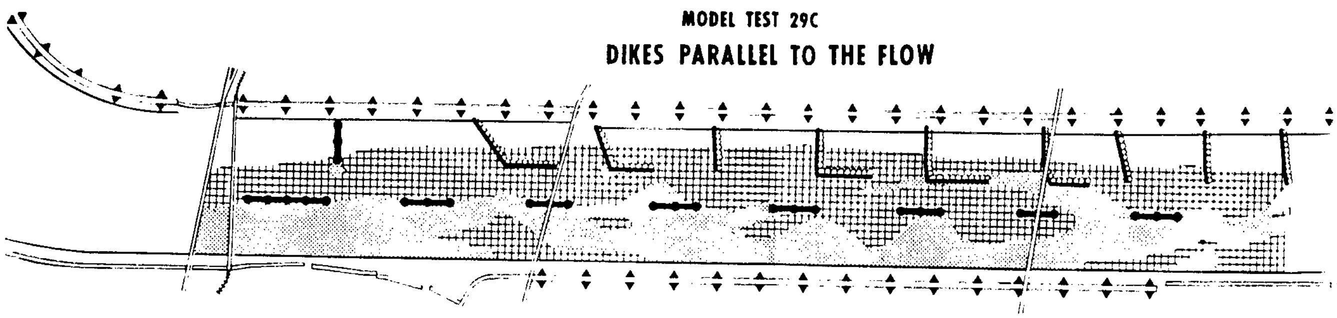
MODEL TEST 29B

DIKES ANGLED 5° TO THE FLOW



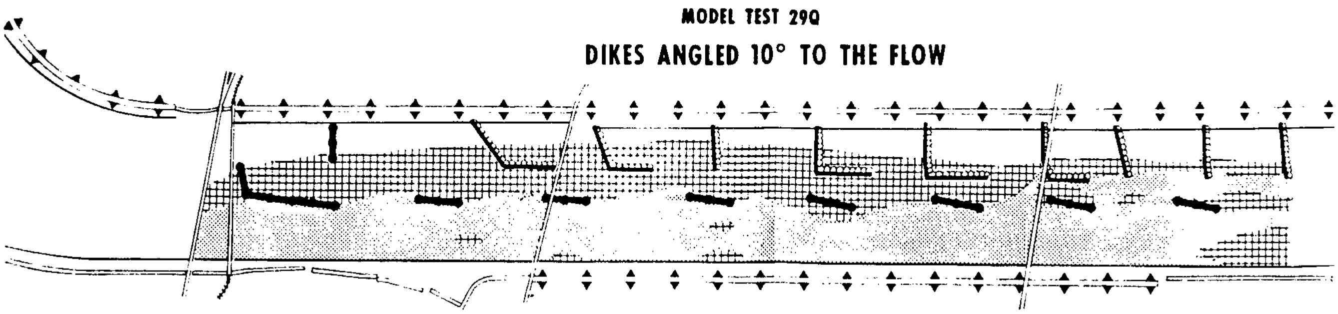
MODEL TEST 29C

DIKES PARALLEL TO THE FLOW

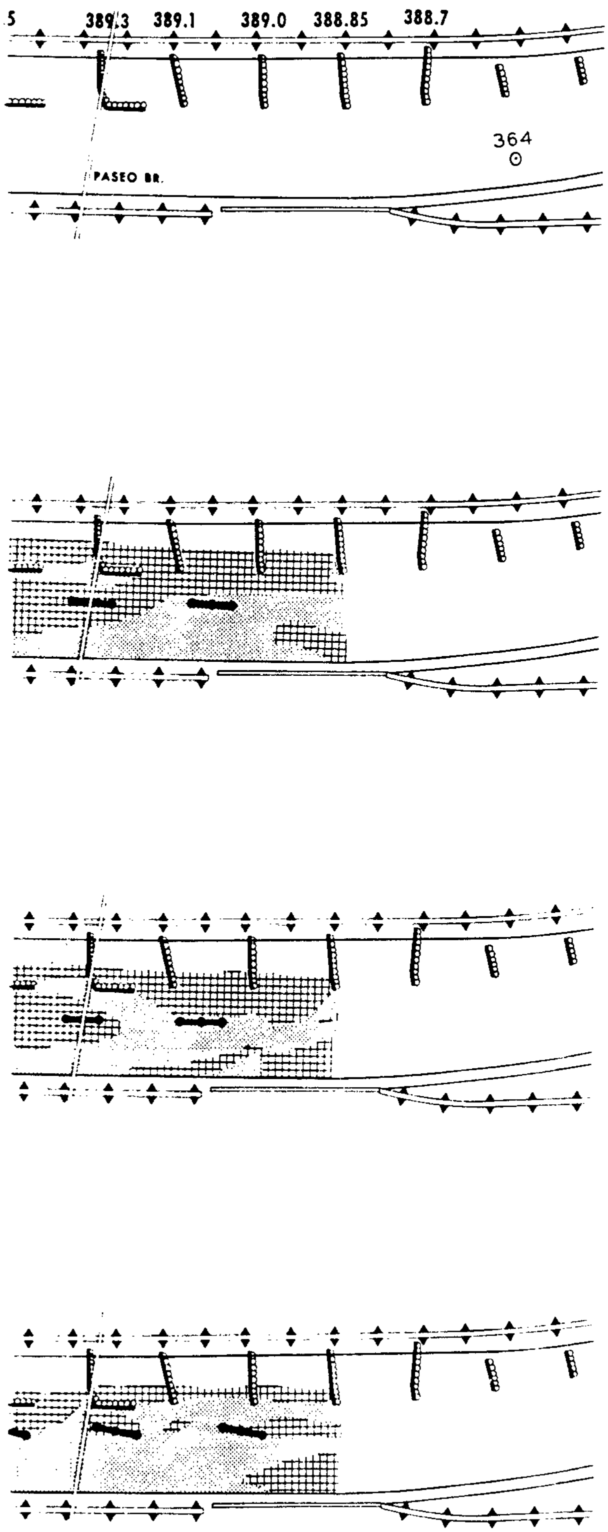


MODEL TEST 29Q

DIKES ANGLED 10° TO THE FLOW



ɩUCTURES - 1968



LEGEND

EXISTING DIKE		DIKE (MODEL)	
LEVEE		SILL (MODEL)	
FLOODWALL		NAVIGATION CHANNEL DEPTHS	
DIKE NUMBER	392.3	ADEQUATE	
RIVER MILE	365 ⊙	INADEQUATE	

MISSOURI RIVER DESIGN STUDY
KANSAS CITY NAVIGATION MODEL STUDY

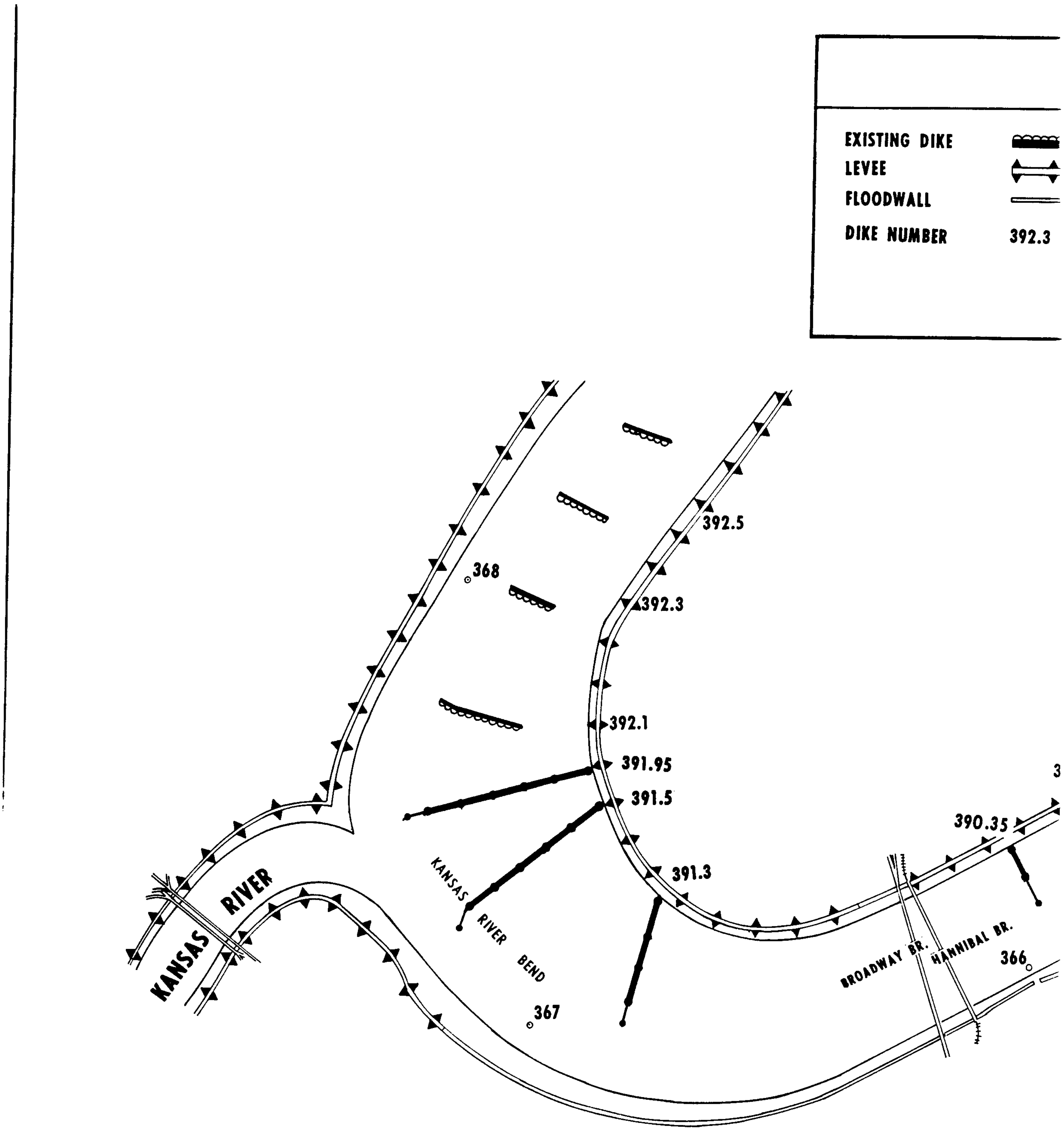
KANSAS CITY REACH BED MAPS
VANE DIKE MODEL TESTS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DECEMBER 1971

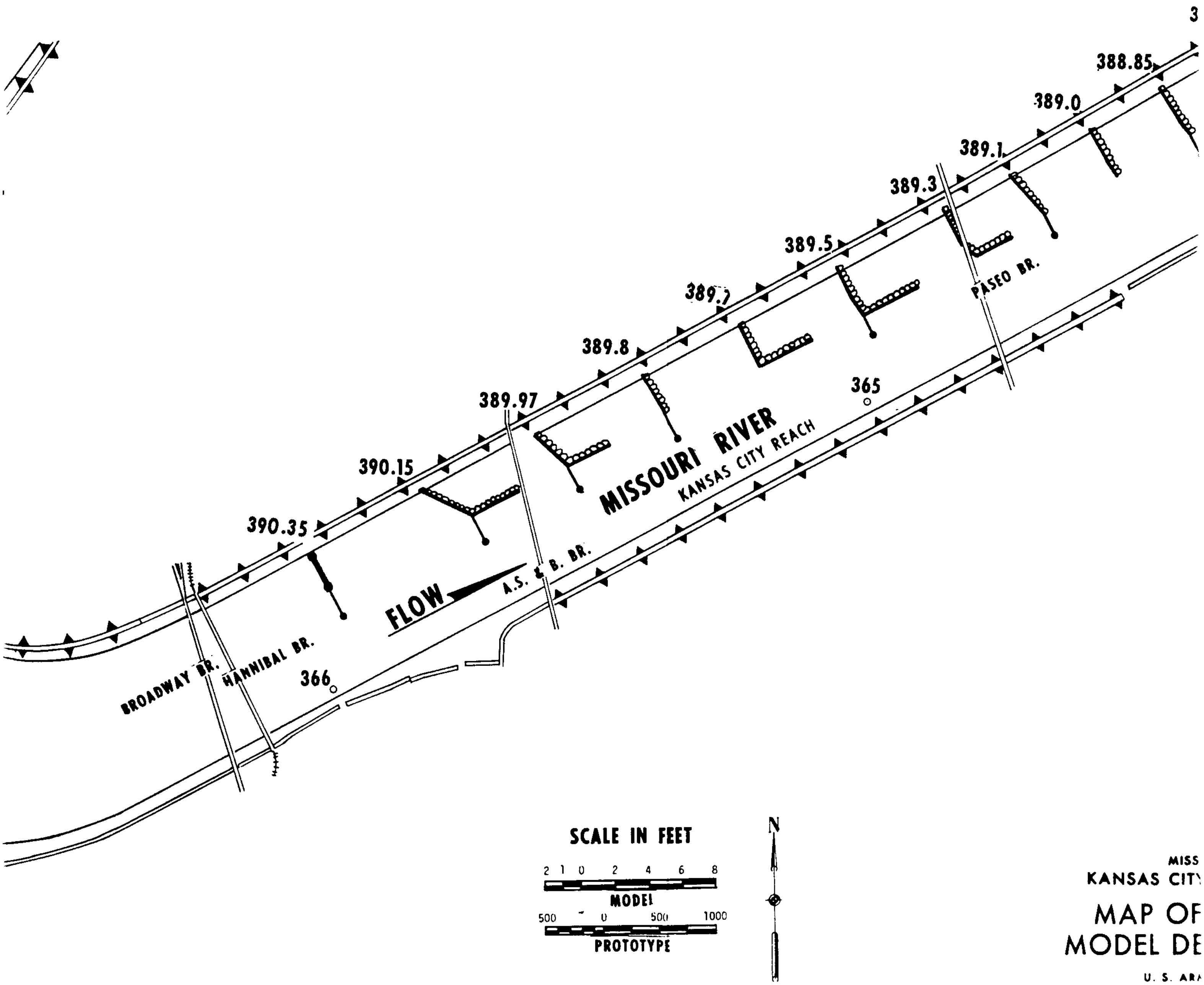
PLATE 7

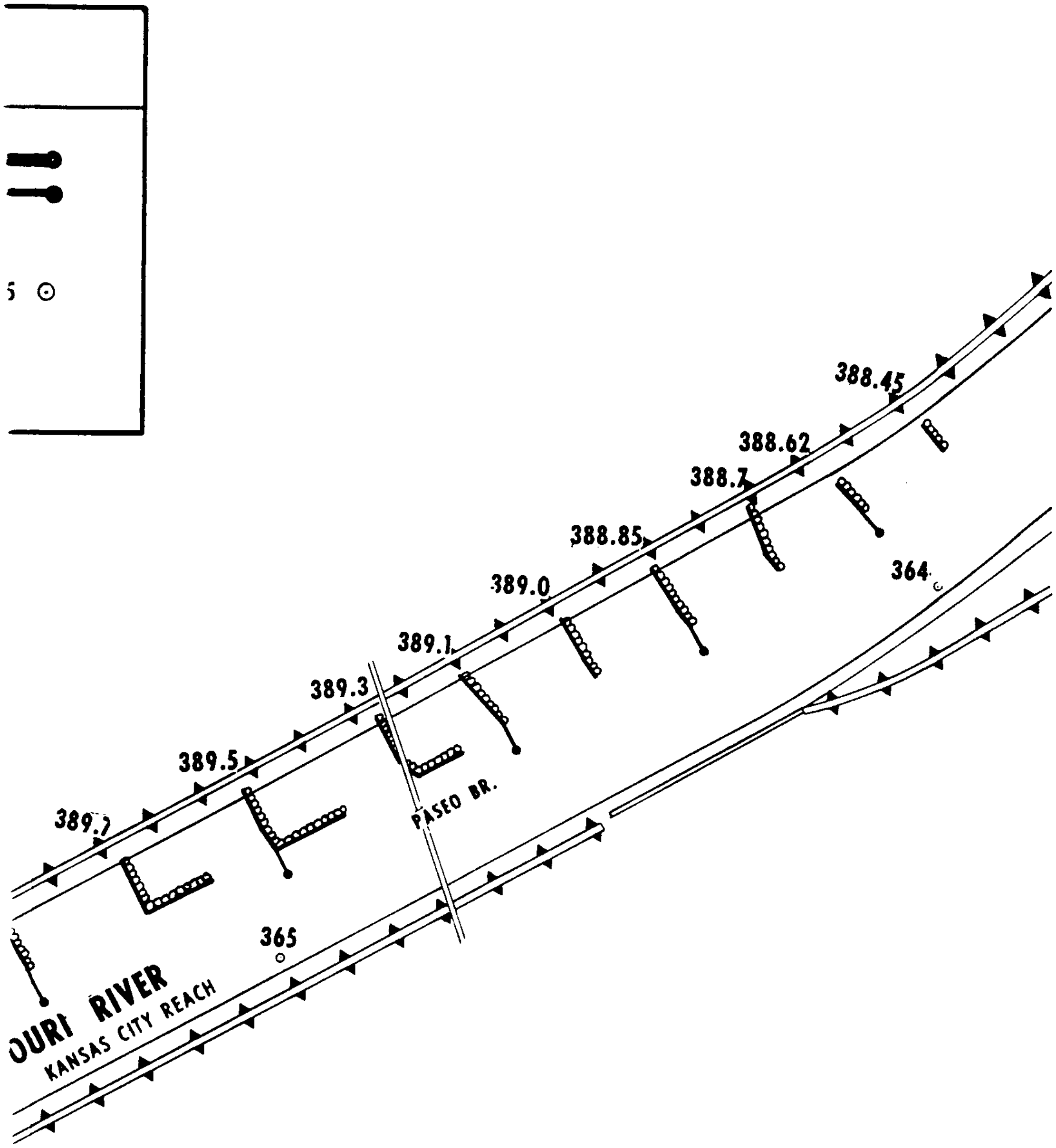
②

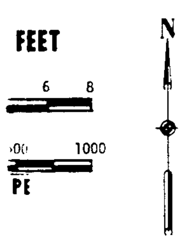

EXISTING DIKE
LEVEE
FLOODWALL
DIKE NUMBER
392.3
392.5
368
392.3
392.1
391.95
391.5
390.35
391.3
KANSAS RIVER
KANSAS RIVER BEND
367
366
BROADWAY BR.
HANNIBAL BR.

LEGEND

EXISTING DIKE		DIKE (MODEL)	
LEVEE		SILL (MODEL)	
FLOODWALL			
DIKE NUMBER	392.3	RIVER MILE	365







MISSOURI RIVER DESIGN STUDY

KANSAS CITY NAVIGATION MODEL STUDY

MAP OF REACH SHOWING MODEL DESIGNED STRUCTURES

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DECEMBER 1971

PLATE 8