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Investigations of diversion on the lower Mississippi River

Elmer John Sperling

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INVESTIGATIONS OF DIVERSION ON THE LOWER MISSISSIPPI RIVER

BY

ELMER JOHN SPERLING.

A

THESIS

submitted to the faculty of the SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI in partial fulfillment of the work required for the Degree of MASTER OF SCIENCE IN CIVIL ENGINEERING

Rolla, Mo.

1932.

Approved by. C. E. Bardole Professor of Hydraulic Engineering.
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INVESTIGATIONS OF DIVERSION ON THE LOWER MISSISSIPPI RIVER.
Elmer J. Sperling.

INTRODUCTION.

Early in the spring of 1931 Dr. C. E. Bardsley, Professor of Hydraulic Engineering at the Missouri School of Mines and Metallurgy, Rolla, Missouri, gained knowledge of the fact that he was to do research work at the United States Waterways Experiment Station at Vicksburg, Mississippi. It occurred to him that if he could make arrangements to have Mr. Elmer J. Sperling, a graduate student in Hydraulic Engineering in the Civil Engineering Department, appointed to a position in the Government Laboratory, it would be a splendid opportunity for him to work out a real research problem for his masters degree dissertation.

This plan was confided to the Head of the Civil Engineering Department and then to the Chairman of the Graduate Committee and mutually agreed upon, provided the research were directly supervised by Dr. Bardsley, a member of the Missouri School of Mines and Metallurgy teaching staff.
The above arrangements were successfully culminated with Mississippi River Commission and with the Director of the United States Waterways Experiment Station and the writer was made the Assistant of Dr. Bardsley who personally supervised his investigations.

The Director of the United States Waterways Experiment Station was gratified that the University of Missouri considered the River Laboratory on a par with the Research Laboratories of the United States Bureau of Standards where members of its personnel attain Doctor's Degrees through cooperative agreements with the Colleges and Universities.

The Director kindly permitted the writer to use as a thesis the investigations made in the Government Laboratory.

In the summer of 1931 the writer was called to Vicksburg, Mississippi to assist Dr. C. E. Bardsley in performing very important experiments for needed investigations of means of controlling the lower Mississippi Valley.

These investigations were carried out in conformity with the Mississippi Flood Control Plan to safeguard this region against disastrous floods. The proposed plan is to construct pilot channels in the Boeuf and
Atchelalaya Basins that would take care of the excess waters from the Mississippi River during the time of high stages. In the attempt to determine the effect of such channels a model of the Boeuf Basin and proposed channel was constructed, also a model for erosion of the soils encountered, and this thesis records the findings. Unfortunately, the time was so limited that only the Boeuf Basin could be investigated.

The three principle methods of flood control are; (1) the "Keep-in Method" accomplished by means of levees; (2) the "Keep-out Method" by use of reservoirs; (3) and the "Take-out Method" by utilizing diversion channels. The investigations that follow fall under the last mentioned method of flood control.
ACKNOWLEDGMENTS

To Dr.-Ing., 1st Lieut. W. D. Vogel, Director of the United States Waterways Experiment Station of the Mississippi River Commission, Vicksburg, Mississippi, the writer wishes to express his appreciation for the advice and help that made possible the accomplishment of this piece of work. Not only did Dr. Vogel contribute valuable suggestions, but through the cooperation of the entire staff members, made it possible to obtain the necessary equipment with which to carry on the extensive investigations and tests for this research.

Further thanks are due to Dr. C. E. Bardale, Professor of Hydraulic Engineering of the Missouri School of Mines and Metallurgy at Rolla, Missouri who was chief of the Technical Staff of the above mentioned Experiment Station at the time this work was performed and under whose guidance and supervision this work was carried out.

The writer also wishes to thank Professor J. B. Butler, head of the Civil Engineering Department and the graduate committee for their approval of this thesis and permitting the work to be done at the Experiment Station.
PURPOSES OF THE INVESTIGATION.

The purposes of this investigation were severally as follows:

(a) To determine the feasibility of digging pilot channels to scour out channels through the Boeuf and Atchafalaya basins of sufficient size to handle the project flows contemplated for these basins in time of superflood.

(b) To determine the best forms of these pilot channels and the best approximate dimensions.

(c) To determine velocities conducive to erosion, transportation, and deposition; the manner and rate of enlargement under below-bank, bankful, and overbank flows; and the character of trace to be expected after enlargement of the proposed channels.

(d) To investigate any suggested modifications of the proposed plan.
ANALYSIS OF THE PROBLEM.

The enlargement of dredged channels by the flow of water through them involves three hydraulic phenomena, namely, soil erosion, sediment transportation and sediment deposition. Transportation and deposition are actuated by identical laws of friction, gravitation and complexities of current, but erosion is only distantly related to the other two. Much confusion results from failure to recognize this fact and formulae for nonsilting and noneroding velocities have often been applied indiscriminately. The principles involved are those controlling some of the least understood natural phenomena, namely, those arising from the flow of water and from the mechanics of soils. Definite prediction as to channel enlargement under the action of flowing water would require proven theories for both erosion and transportation and without tenable theories for both, a tenable solution is impossible.

If a ditch be dug similar, parallel, and very close to an older ditch it might be expected to erode or silt nearly the same as the other, assuming that it be subjected to the same conditions. If subjected to different conditions, i.e., dissimilar flow characteristics, water of a different sediment content, locally varying geology,
or even extreme climatic variances, a different development is possible. It follows that comparisons will always be difficult where the phenomena of erosion are encountered. Thus we are forced to draw joint conclusions from imperfect parallels in nature and from theories of erosion, transportation and deposition as confirmed, established or modified by laboratory experiments designed for the specific problem at hand.

In the formulation of hypotheses, past observations, must be carefully considered, for material evidence is irrefutable. Old theories may be used, but cautiously, for the true significance of facts may be easily misconstrued. At the same time it should be realized that nearly every theory, though apparently incorrect, is, in the final analysis, underlain by a foundation of facts. The procedure adopted for the solution of this particular problem has been to formulate hypotheses from past experience, establish theories by experimentation and verify predictions by application to existing examples.

Research was made into literature of the subject, consulting authoritative treatises of three languages. The object was to assemble the known facts and to find out what experiments has been conducted along these lines, in order to prevent a series of needless
Publications of the Bureau of Soils, U. S. Department of Agriculture, were first reviewed, and from them a preliminary bibliography was arranged. Publications not available locally were borrowed from university libraries, and references when not available in English were translated by members of the laboratory staff. As expected, the results of this preliminary research were largely negative, for practically all foreign experience has been in connection with stream transportation of sands and gravels, and it is only recently that the American engineer has felt the need for greater knowledge of the phenomenon of erosion. Tenable theories of transportation and deposition have been formulated, but the controlling factors of erosion remain generally undetermined and unmeasured.

LABORATORY INVESTIGATIONS.

The investigations conducted at the U. S. Waterways Experiment Station were designed to utilize the facts of past experiences and to determine specific data relative to the soils encountered along the lines of the proposed pilot channels. The experiments fell naturally into two general classes, as follows:

(a) Tests with a geographical model of the entire Boeuf Basin to determine general aspects of
the problem.

(b) Experiments with a large, especially designed, tilting flume to obtain true erosional velocities.

(a) GEOGRAPHICAL MODEL OF BOEUF BASIN.

Purpose of the experiment. The purpose of this model was to assist in the determination of the qualitative results that might follow the construction of the proposed pilot channel in the Boeuf Basin; to aid in ascertaining the feasibility of the adopted location of this channel; and to indicate possible tendencies of the water to follow other more natural paths. Further, it was hoped that the model would indicate:

(1) Those areas in which the bulk of the silt resulting from the erosion of the channel would be deposited.

(2) The direction assumed by overbank flow, and

(3) The tendencies of these waters to seek new channels. Any other and unexpected pertinent information brought out by test runs through this model were to receive careful consideration and to be subjected to further and more detailed investigation.

Model. With distorted scales of 1/10,000 horizontal and 1/100 vertical, the completed model attained
a length of 65 feet and a width of from 8 to 10 feet, depending upon the actual limits of the basin. Located in the approximate center and at presumably the lowest elevation was placed the pilot channel, 300 feet in width and 30 feet in depth. At the head of this pilot channel a spillway was constructed. From the spillway the pilot channel extended approximately 124 miles to its confluence with the Ouachita River near Columbia, La.

The first attempt in construction was to use sheet-metal templates set vertical and perpendicular to the pilot channel at two foot intervals, but this plan was subsequently abandoned. Instead, the 1/48,000 map of the entire Boeuf Basin was pantographed to the model scale of 1/10,000, showing only the 5-foot contours, streams, principal highways, railroads, levees and towns. With the aid of these enlarged maps the relief was carved directly into the natural loess of the laboratory grounds at the site selected for the model. Upon completion of this work, which had required 20 working days, gage wells were placed at 10-foot intervals throughout the length of the pilot channel and connected by 1/2-inch iron pipes to a battery of manometer tubes that registered the depths by gravity. Finally, to prevent the disfiguration of the model surfacing, it was coated
with a thin layer of cement mortar. To correctly simulate actual conditions of overbank roughness, Spanish Moss was gathered from nearby woods and placed on the model to cover those areas that remain uncleared in nature. For determining the exact location of these areas a mosaic was made of aerial photographs of the entire Boeuf Basin. Previous tests conducted by this laboratory had shown this moss to be the ideal material for use in simulating wooded areas on models of this type, resulting, as it does, in an almost exact duplication of the overbank conditions effecting rate, quantity and characteristics of actual flow. The flow of water through the model was controlled and measured by a 90° Thompson V-notch weir, and minor gage adjustments were accomplished by variations in the density of the moss at controlling points. The discharge from the lower end of the model was controlled by a tail gate capable of delicate adjustment, by means of which backwater conditions could be properly simulated as required. Major tributaries, especially the Ouachita River, supplied their equivalent quantity of water from a source independent of that passing over the control weir. The model as a whole was constructed so as to easily permit any desired modification of the proposed plan with a view of assisting
in the determination of the best solution of the problem involved.

Contemporaneously with the construction and study of this model a smaller model was built, to the same scales and carved out of the same material, but incorporating only the upper 15 miles of the basin.* One of the uses to which this model was put was the testing of various forms of coating to be applied to the earth-relief in the large model for protection against the deteriorating action of rain, wind, surface cracking, etc. A mixture of three parts of finely sifted sand to one part of cement with least necessary water to attain plasticity was adopted.

Procedure. The test runs made on the completed large model were designed to ascertain:

(a) Ability of pilot channel to carry sediment. (Bankfull stages throughout.)

(b) Results from bankfull stage encountering back-water. (Slightly overbank from just above Monroe.)

(1) Location and relative amounts of sediment deposits.

(2) Apparent tendencies to erode.

(3) Direction assumed by overbank flow, and

* See Plate No. 1, Page 12.
Plate No.1. The Auxiliary Model.

Looking north upstream along the Boeuf channel of the auxiliary model near its upper end, showing the effects of erosion of different surface coatings. Water is flowing down the Boeuf Basin at a little more than overbank stage. This model was subsequently abandoned when three to one cement mortar was decided upon as the most suitable coating for the model of the entire Boeuf basin. The scales of this model are: l = 1:10,000, and d = 1:100.
tendencies of these waters to seek new channels.

(4) Indications pointing to the advisability of changing the location of portions of the pilot channel.

(c) Results from superflood discharge with channel at its present dimensions (itemized as in b).

(d) Results from superflood, (conditions as in b and c.)

Methods. Tests to determine the most suitable material with which to simulate the movement and deposition of eroded materials included the use of creosoted sawdust, fine sand, powdered silt and solutions of slacked lime. Due to the comparatively steep slopes of the model it was found that solutions of lime gave the best results, although the other media produced identical results in a less obvious manner. The insoluble particles of the lime settled nicely in clearly definable areas and their whiteness made them equally discernible in the wooded and the cleared section. For the purpose of determining the general direction assumed by the overbank flow, generous quantities of a solution of potassium permanganate were introduced periodically into the pilot channel at its origin,* and the clouds of

* See Plate No. 2, page 15.
Plate No. 2. The Geographical Model

View looking north showing overbank flow in the backwater area at and below Monroe, as well as minor overflow conditions further upstream along the pilot channel. In the background an operator is inducing a solution of potassium Permanganate into the pilot channel.
color thus projected into the flow could easily be
traced throughout their entire course. This proved so
completely satisfactory that no other method was tried.
Upon completion of the test runs the silted areas were
sprinkled with neat cement to preserve them for further
inspection.

Results. The pilot channel as constructed on this
model with the distorted scales of $l = 1/10,000$ and $d = 
1/100$ showed little difficulty in carrying all but un-
reasonably heavy introductions of sediment. Continuing
this experiment over lengthy periods of time showed, how-
ever, a gradually increasing deposit in the narrow bottom
of the pilot channel throughout its length, resulting
finally in its overflow at the points of lowest banks.
Upon introduction of backwater effect limit to just above
Monroe, and continuing bankfull flow within the pilot
channel, sediment introduced into the pilot channel at
its upper end, was carried as before up to its entrance
into the backwater pool and then continued at a de-
celerating rate within the banks of the channel, settling
in its entirety within it and eventually filling it with
only negligible quantities depositing overbank.

Upon imposing the conditions and continuing the
constant introduction of a solution of slacked limed,
*See Plate No. 8, page 17.
Plate No.3. The Geographical Model.

General view of the Boeuf Basin model looking downstream. A portion of the Greenville Bends system as well as the beginning of the pilot channel in the immediate foreground.
minor silt deposits became immediately apparent at all low places within the backwater area, and as the test continued the deposits began to accumulate along the valley of the Boeuf River proper. The greatest deposit at this stage of slightly overbank flow in the lower reaches occurred due east of Monroe where the pilot channel approached Bayou La Fourche to within 1000 feet. The extent of this deposit may best be understood by a glance at the accompanying photographs. All marked deposits in the vicinity of the pilot channel were accompanied by pronounced shoaling within the channel, although this never reached the point of obliteration of the channel. Tendencies to erode were clearly discernible where banks were of sufficient height to include the total flow. The waters were turbulent, with pronounced ripples and eddies occurring within these reaches. No tendencies to erode were noted on the overbank flow. As far downstream as Monroe the overbank current merely filled up the low places and continued downstream more or less parallel to the pilot channel but at much lesser velocities. Passing Monroe, however, some of the waters entered the Boeuf River and continued permanently down that stream. The greatest tendency toward following a new course occurred at the point of near
contact between the pilot channel and the Bayou La Fourche just east and southeast of Monroe. Here it appeared that a greater amount changed its course to the La Fourche than continued down the pilot channel. It was at this place that the greatest silt deposit occurred.

At flood stage the picture changed somewhat.* Whereas during the former stage no great silt deposit occurred above Monroe, at this stage the bulk of all deposit passes over the cleared lands in and around Lake Village, into and over Lake Chicot, leaving considerable deposit within the lake and on the land encircled by the lake, with the bulk of the silt carried through the southern outlet of the lake and covering the entire area north of Otter Lake. From here to below Monroe the conditions are similar to those observed under previous stages, except for the slight additional deposits occurring in areas not previously flooded. Below Monroe the pilot channel loses its integrity completely, having filled the Ouachita, passing in a broad stream beyond the limits of the model.

At a superflood stage the pilot channel served no function whatever, quickly silted, and ceased even to guide the stream. The two great deposit areas at Lake

* See Plate No. 4, page 20.
Plate No. 4. The Geographical Model.

View looking downstream from the upper end of the Boeuf Basin model, showing river at flood stages, full overbank conditions, and pilot channel obliterated.
Village and east of Monroe still carried the burden of the deposit, all other areas showing decreased accumulations. Below Monroe the La Fourche, the pilot channel and the Boeuf lost their integrity and combined into one broad stream from the remainder of the model.

**Summary and indications.** The test runs made through this model indicated (a) the areas recipient of the bulk of deposit resulting from channel erosion at bankful and higher stages, (b) the courses pursued by overbank waters below Monroe, (c) the inability of the pilot channel to carry off all of the eroded materials at any stage, (d) the necessity of making provisions for maintenance dredging and snagging subsequent to the operation of the pilot channel, and, (e) the failure of the pilot channel to function in even a guiding capacity to flood discharges.

(a) At those stages at which the pilot channel would be bankful to the vicinity of Monroe, and slightly overbank from that point through the remainder of the backwater area, the greatest silt deposit would occur in the lowlands south-east of Monroe and south of Millhaven and tending downstream in the La Fourche. Minor sedimentation is observed over all flooded areas, with the pilot channel completely silting up at the points
opposite the Monroe area.

(b) The course pursued by overbank waters below Monroe follows the natural configuration of the relief of the ground, the bulk of the excess following the La Fourche and the remainder entering the Boeuf. At the highest flood stages tested these two streams together with the pilot channel between them form one broad stream.

(c) During the lowest stage tested, that is, that stage at which no overbank occurs at any point throughout the entire course of the pilot channel, sediment slowly accumulated in the bottom of the channel until it had raised the water surface to overbank stage. The pilot channel had its greatest efficiency when sufficient water was introduced to produce bankful stage to a point just above Monroe, but slightly overbank conditions from thence throughout its remaining course through the backwater area. Here the pilot channel maintained its depths nicely except at those points of egress into the adjoining low lands, when the channel silted up nearly completely.

(d) These conditions suggest the necessity of providing for maintenance operation, to be employed at those points having suffered excessive silting, as well as
snagging operations throughout the entire length of the channel to remove obstructions lodged by these floods.

(e) During general overbank stages the pilot channel fails to function as such in the reaches below Monroe, and loses its integrity entirely throughout its entire length upon being subjected to super floods.

(b) EROSION EXPERIMENTS WITH TILTING FLUME.

Purpose. The purposes of the following described series of tests were to determine the velocities required to erode typical soils when placed under different conditions in a laboratory testing flume; and to obtain corresponding indices of erosion, and consequent tendencies toward dredged channel enlargements.

The Flume. A large erosion flume was constructed to contain actual soil samples obtained from the field and to employ velocities of flow equivalent to those anticipated in the proposed pilot channel. Its area of cross section was sufficient to accommodate almost any conceivable soil placement in addition to those employed and hereafter described. The section for erosion was recessed and provided with a calibrated track in the longitudinal or Z direction upon which the hook gage and pitot tube carriage ran. The carriage was calibrated to measure the X and Y dimensions of cross-sections be-
fore and after erosion. A template carriage also ran on this track for bringing the initial section to true grade. Although non-erodible sections were provided upstream and downstream from the erosion section it was found that the best results could be obtained with the entire length of flume (13.6 feet) filled to the desired cross-section with the material to be eroded.

Water was delivered to the flume from the outdoor reservoir of the Experiment Station through a twelve inch pipe, discharging under water-sealed head into a large stilling chamber (4.5' wide x 4.0' long x 3.0' deep) provided with baffles. Water delivered to the entrance flume was devoid of boils and eddies and started on its course through the erosion flume under perfect entrance conditions. At the lower end of the flume a stilling weir box with baffles was provided, and below this was placed a sharp-created suppressed rectangular Francis weir, used to check the Pitot Tube measurements. Prior to the experiment this weir was calibrated for the entire range of discharge expected (0.05 ft. to 0.6 ft. head) by using the laboratory's standardized measuring tank.*

In conducting a run the following measurements were taken at six stations, one foot apart in the erodible section of the flume: Initial cross-sections at 0.1

* See Figs. on 25, 26 and 27.
Figure No. 1. The Tilting Flume.

An isometric perspective of the soil erosion tilting flume.
Figure No. 2. The Tilting Flume.

Detail drawings of the soil erosion tilting flume.
Figure No. 3. The Tilting Flume.

Detail drawings of the soil erosion tilting flume. (Original set-up)
foot intervals transversely on sides and bed, head of water on erodible bed, head on measuring weir, pitot velocity traverse of mid-cross-section, final cross-sections after run, time of run, slope tilt of erosion flume, volume of eroded pits, and depth of over bank when so run. Samples of the eroded material were gathered and inspected after each run. While erosion was taking place in the flume, close watch was kept to ascertain all the physical phenomena of the erosion, which were noted in the observation records. Some of the erosion flume set-ups are indicated in the accompanying sketches.

Tests. The following tables show in condensed form the number of tests conducted, the kind of materials investigated, and a summary of results as obtained for each case:
## CHARACTER OF MATERIALS Investigated AND METHODS OF PLACEMENT

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Kind of Material</th>
<th>Source of Material</th>
<th>Condition of Material</th>
<th>Depth of Sample in Flume</th>
<th>Smoothness</th>
<th>Smoothness of Sample</th>
<th>Condition of Material on and dryness</th>
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<tr>
<td>1</td>
<td>Sand</td>
<td>Miss. R.</td>
<td>Near Surface</td>
<td>Compacted</td>
<td>Smooth</td>
<td>Smooth</td>
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<tr>
<td></td>
<td></td>
<td>Vicksburg bar</td>
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<td>then inundated</td>
<td></td>
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<td></td>
<td></td>
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<td>12 hours</td>
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<tr>
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<td>Loess</td>
<td>U. S. Waterways Ex-</td>
<td>Near Surface</td>
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<td>do</td>
<td>do</td>
<td>do</td>
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<td></td>
<td></td>
<td>per. Sta.</td>
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<td>do</td>
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<tr>
<td>3</td>
<td>Loess</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td>do</td>
</tr>
<tr>
<td>4</td>
<td>Loess</td>
<td>do</td>
<td>do</td>
<td>Compacted</td>
<td>do</td>
<td>do</td>
<td>but left very dry</td>
</tr>
<tr>
<td>5</td>
<td>Loess</td>
<td>do</td>
<td>do</td>
<td>Natural slabs of loess</td>
<td>do</td>
<td>do</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Loess</td>
<td>do</td>
<td>do</td>
<td>Compacted</td>
<td>Made to template</td>
<td>Made to template</td>
<td>then inundated, but pitted and seasoned for three days ed</td>
</tr>
<tr>
<td>7</td>
<td>Loess</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td>Made to template</td>
<td>Made to template</td>
<td>channel sinuous</td>
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<tr>
<td>8</td>
<td>Clay</td>
<td>Boeuf Basin</td>
<td>3705</td>
<td>Compacted</td>
<td>Smooth</td>
<td>Smooth</td>
<td>to template</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>lft. to 3 ft.</td>
<td>then inundated,</td>
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<td></td>
<td></td>
<td></td>
<td>deep</td>
<td>seasoned</td>
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<td>three days</td>
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</table>
CHARACTER OF MATERIALS INVESTIGATED AND METHODS OF PLACEMENT (Continued)

<p>| Test No. | Kind of Material | Source of Material | Depth of Number of Sample | Condition of Material in Flume | Condition of Smoothness of | Smoothness of | Condition of | Compact- | Surface | Dryness |
|----------|------------------|--------------------|--------------------------|-------------------------------|----------------------------|-------------------|--------------| Surface | of | Surface | Dryness |
| 9        | Clay over sand   | Boeuf Basin        | 3705 do do do           | do                            | do                         | do                | do           |
| 10       | Red Sandy Loam   | Boeuf Basin Center Line | 4200 do do do   | do                            | do                         | do                | do           |
| 11       | Red Sandy Loam   | Boeuf Center Line | 4200 do do do   | do                            | do                         | do                | do           |</p>
<table>
<thead>
<tr>
<th>Test No.</th>
<th>Slope of Flume</th>
<th>Mean Velocity ft./sec.</th>
<th>Bottom Velocity ft./sec.</th>
<th>Feasibility of Pilot channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Level</td>
<td>1.3</td>
<td>1.2</td>
<td>Feasible in short reaches</td>
</tr>
<tr>
<td>2</td>
<td>do</td>
<td>Insufficient velocity for erosion</td>
<td>No erosion</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Inclined</td>
<td>4.1</td>
<td>3.6</td>
<td>Not feasible</td>
</tr>
<tr>
<td>4</td>
<td>Level</td>
<td>1.5</td>
<td>1.4</td>
<td>Feasible</td>
</tr>
<tr>
<td>5</td>
<td>do</td>
<td>4.0</td>
<td>3.6</td>
<td>Not feasible for good development</td>
</tr>
<tr>
<td>6</td>
<td>do</td>
<td>4.1</td>
<td>3.6</td>
<td>Not feasible for good development</td>
</tr>
<tr>
<td>7</td>
<td>do</td>
<td>4.0</td>
<td>3.6</td>
<td>Not feasible for good development</td>
</tr>
<tr>
<td>8</td>
<td>Inclined</td>
<td>9.7</td>
<td>6.0</td>
<td>Not feasible</td>
</tr>
<tr>
<td>9</td>
<td>Level</td>
<td>2.2 (sand)</td>
<td>1.5 (sand)</td>
<td>Not feasible</td>
</tr>
<tr>
<td>10</td>
<td>Inclined</td>
<td>6.2</td>
<td>4.9</td>
<td>Not feasible</td>
</tr>
<tr>
<td>11</td>
<td>Level</td>
<td>2.2 (sand)</td>
<td>1.5 (sand)</td>
<td>Feasible in local reaches</td>
</tr>
</tbody>
</table>
At the inception of these experiments two objectives were sought: first, to attempt to create a standard accelerated erosion test; second, to select a standard erosive material, uniform in texture and locally abundant. These objectives were practically fulfilled in adopting the tilting erosion flume previously described, and in selecting loess as the standard material for erosion. In the following discussion, an attempt will be made to compare the erosion of Boeuf Basin Soils with the erodibility of loess. Of course, other conditions equally important arise in the erosion of soils in the Boeuf Basin, in that for great distances the clays are underlain with sand which accelerates bank caving. Experiments were also run to investigate the latter condition.

First, sand was selected as the material to be eroded to check up the characteristics of the erosion flume. This showed reasonable agreement with tests of other engineers.

Next, compacted inundated loess was eroded; and questions arose as to whether the test had duplicated what might occur in nature. Subsequently, variations were tried with the loess, using it as a dry, compacted material, and noting the eroding velocities. Then slabs
of natural loess undisturbed and unbroken when taken from the embankments in the near vicinity of the laboratory were cut, placed in the flume and eroded.

To artificially hasten the processes of erosion, the inundated loess was scratched and pitted, but this apparently brought about no acceleration of the action. Next it was thought that a sinuosity of channel through the compacted, inundated loess might accelerate the test. This did prove to accelerate the erosion, as the convex banks were in all cases literally shaved off by the swift current, but the phenomenon appeared to be an unnatural one and was not considered further. In all of the tests, however, where velocities were less than those required to produce shooting flow, tendencies toward natural meanders were observed.

After the preliminary tests, attempting to standardize the procedure and conserve the samples shipped to the laboratory from great distances and procured in the field with certain difficulties, runs were made on clay, sand, clay over sand, red sandy loam, and red sandy loam over sand.

The eroding velocities for each case will be found in Table 1, and the substantiating data appears throughout the report.
THE ELEVEN EROSION EXPERIMENTS:

Test Number One.

Erosion of Mississippi River Sand.

The erosion flume was first filled with Mississippi River sand to determine whether erosion and transportation would occur at velocities already known to engineers. It was found that the bottom scoured out at 1.4 ft./sec. mean velocity (1.3 ft./sec. bottom velocity), and upon consultation of tables on erosion, it was found that fine non-colloidal sands should erode at 1.5 ft./sec. This indicated that thus far the principles of the erosion flume were correct. The test cannot be taken to indicate that uniform evacuation of sand will occur in long channel reaches, but only that the velocities stated are sufficient to produce local bottom movements. Depositions will occur below the eroded section and when covered by clay particles will refuse to permit development in these regions of deterioration.

Tests Numbers Two and Three.

Observed Phenomena of Erosion of Wet Compacted Loess.

Velocities were built up in a channel lined with wet compacted loess until measurable erosion occurred. The velocities were mean velocity : .32'/sec. \(\approx .86\), bottom velocity \(\approx .28'/sec. \approx .80\)

* See Plate No. 5, page 35.
Plate No. 5. The Tilting Flume.

Original set-up of erosion flume filled with loess ready for a run. It was subsequently found that velocities could only be attained sufficient to erode sand. So the next step after this was to make a tilting flume by raising the flume up bodily and setting it on a fulcrum. Sacks of samples can be seen to the left from the Boeuf Basin. Hook gage pot and lamp can be seen on weir box in foreground.
2.1, 2.9 and 3.4 for the level flume; and 4.33, 3.67, and 4.9 for the inclined flume. At the eroding velocity, the first noticeable erosive effect was a roughening or slight pitting of the sides and bottom in contact with the water. No pits appeared on the center line of the channel, but developed about halfway between the center line and the toe of the nearest side slope. The pit in the bed would first deepen about one-half inch and enlarge in horizontal diameter to about the size of a quarter of a dollar, after which intense eddy currents would appear. The interval between pits in the channel was approximately ten inches, with bottom velocities ranging from 3.6 ft./sec. to 4.1 ft./sec.

In a typical pit the eddy currents enlarged the excavation both in depth and in plan, following which enlargement proceeded downstream and toward the nearest side slope, at an angle of about 30° with the center line of the channel. Upon reaching the mean velocity, the side slope, undercutting developed rapidly with intense lateral currents directed toward the foot of the slope along the bed of the channel, ever digging at the side slope and boring below bed level. Upon reaching and digging into the side slope the current assumed a
forward and upward movement, and, when digging, the return current was muddy. The return current boiled up and laterally out at about 45° with the center line of the stream and high up in the main channel. As the turbulent eddy current undermined the bank, bank caving occurred vertically above and downstream from the hole eroded in the bank.

The work of an eddy, assisted by gravity, may be as follows: (1) dispersion of colloidal particles, (2) the lifting out of the particles and larger pieces of the bank, and (3) transportation of both particles and great masses of the lifted and caving banks. As the bank is undercut, just before a great cave or slide of bank material occurs, the stream will increase in mud-diness; then huge chunks of the bank will cave, part of which will fall into the pot hole excavated and part of which will be caught in the swift current and bodily transported. Disintegration and transportation occur quickly in the case of sloughed material trapped in pot holes, and the issuing stream remains muddy until the holes have been cleaned out. Following this the pot holes enlarge downstream and the currents continue to attack and undermine the bank.

The process just described continues until the
influence of another similar center of erosion is reached or until the effect from the opposite bank joins at the center line of the channel. In a wide channel, of course, the influence from the other bank would not be so directly effective in the erosive process. It was noticed also that bank caving occurred alternately along the channel, resulting eventually in a sinuous channel. The following tabulations, photographs and charts show quantitatively the space displacement of the bed and side slopes. The flume was first run for two hours and five minutes in 25 minute periods with bottom velocities from 1.28 ft./sec. to 2.8 ft./sec. with no measurable erosion. The flume was level throughout this entire test.

Subsequently the flume was run for one hour and fifteen minutes in 25-minute periods on a slope of 0.063: first, at 0.1 ft. depth with 3.6 ft./sec. bottom velocity; second, at 0.166 ft. depth with 3.1 ft./sec. bottom velocity; and finally, at 0.26 ft. depth with 4.1 ft./sec. bottom velocity. At the conclusion of this last run, it was decided that further runs would be of little avail as the channel was being eroded nearly to the wooden flume in places.

Average eroding bottom velocity for the compacted

* See Plate No. 6, page 39.
Plate No.6. The Tilting Flume.

Main Flume horizontal, but section molded in flume on a slope of 0.063. Photograph shows condition of compacted, unundated loess lining after 10,15 run in periods of 25 run each with bottom velocities of 3.6 ft/sec., 3.1 ft/sec, and 4.1 ft/sec. Note the sinuosity of channel and the bank caving near the upper end on the right hand side.
Loess was 3.6 ft./sec. and the effective time required to erode 1.3025 cu. ft. below the water line was found to be seventy five minutes. Reducing this to unit bases of time and area, we find the material eroded at the rate of 0.000175 cu. ft./sec. In a channel such as that proposed for the Boeuf Basin development should then occur at the rate of 0.000175 X 384 or .0675 cu. ft./sec. in each foot of length, assuming the bed and side to be entirely of this material. *

* See Plate No. 7, page 41.
Final set-up of erosion flume as a tilting flume. The length of the flume was 13.6 ft, bottom width 1.0 ft, side slopes 1:1, recessed erosion section 5.0 ft long. The limits of tilt were from -3.7% grade to +13.4% grade. The attainable velocities ranged from 0.5 ft/sec. to 10.0 ft/sec. Lake spillway level was at horizontal pipe near top of window in background. Water was led into flume by inverted 12 inch pipe near window. The fulcrum under flume can be seen. Flume was nicely balanced at all times and easily tilted with chain-falls shown near lower end. Flume was provided with calibrated track, self plumbing manometer columns for pitot tube, observation platforms, operator's car, and measuring weir with hook gage. Flume can be tilted while running without shutting down. The wye-level was used to ascertain slope of flume for each run. Both the entrance and weir measuring boxes were provided with stilling devices. All types of flow are attainable in the flume: streamline flow, Reynolds's critical range, turbulent flow, and shooting flow above the Unwin range.
FLUME EROSION TEST OBSERVATION SHEET

COMPACTED LOESS—BED INCLINED. S = .063

TESTS NOS. 2 AND 3.

Section of soil 5 feet long, and 0.5 ft. thick on bed and 1 to 1 side slopes, packed in recessed section flume.

Surface of soil smooth and true to standard flume section.

<table>
<thead>
<tr>
<th>No.</th>
<th>Time of run (Mins)</th>
<th>Total Time of model subject to scouring action (Hrs.)</th>
<th>Depth of water over bed</th>
<th>Mean velocity (ft./sec.)</th>
<th>Bottom velocity (ft./sec.)</th>
<th>Weir Measurement Length (ft.)</th>
<th>Condition of bed and banks after each run is shown by the accompanying profile charts.</th>
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<tr>
<td>6</td>
<td>25</td>
<td>0\textsuperscript{h}25\textsuperscript{m}</td>
<td>0.100</td>
<td>4.33</td>
<td>3.6</td>
<td>0.12</td>
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<tr>
<td>7</td>
<td>25</td>
<td>0\textsuperscript{h}50\textsuperscript{m}</td>
<td>0.166</td>
<td>3.67</td>
<td>3.1</td>
<td>0.199</td>
<td>1.10</td>
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<tr>
<td>8</td>
<td>25</td>
<td>1\textsuperscript{h}15\textsuperscript{m}</td>
<td>0.26</td>
<td>4.90</td>
<td>4.1</td>
<td>0.25</td>
<td>1.72</td>
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EROSION AND BANK CAVERNING OF WET COMPACTED LOESS

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<tr>
<th>Station</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<td>0.0944</td>
<td>0.0970</td>
<td>0.1014</td>
<td>0.1066</td>
<td>0.1114</td>
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<tr>
<td>Area. sq. ft.</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 after Run No. 6</td>
<td>0.0938</td>
<td>0.0944</td>
<td>0.0970</td>
<td>0.1014</td>
<td>0.1066</td>
<td>0.1114</td>
</tr>
<tr>
<td>Scoured Area</td>
<td>0.0938</td>
<td>0.0944</td>
<td>0.0970</td>
<td>0.1014</td>
<td>0.1066</td>
<td>0.1114</td>
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<tr>
<td>4 Volume after Run No. 6</td>
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<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
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<tr>
<td>Scoured cu. ft.</td>
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<tr>
<td>5 Area after Run No. 6</td>
<td>0.1806</td>
<td>0.1744</td>
<td>0.1951</td>
<td>0.2248</td>
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<tr>
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<tr>
<td>6 Area after Run No. 7</td>
<td>0.0868</td>
<td>0.0800</td>
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<tr>
<td>Scoured sq. ft.</td>
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<td>7 Volume after Run No. 7</td>
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<td>0.0891</td>
<td>0.1107</td>
<td>0.0672</td>
<td>0.0202</td>
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<tr>
<td>Scoured cu. ft.</td>
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<tr>
<td>8 Area after Run No. 8</td>
<td>0.3058</td>
<td>0.3230</td>
<td>0.4813</td>
<td>0.3489</td>
<td>0.3192</td>
<td>0.3588</td>
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<tr>
<td>Scoured sq. ft.</td>
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<td></td>
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EROSION AND BANK CAVING OF WET COMPACTED LOESS

CONTINUED

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<tr>
<th>Station</th>
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<th>2</th>
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<td>Scoured</td>
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<td></td>
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<tr>
<td>Area</td>
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<td>0.2015</td>
<td>0.2180</td>
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<td>Run No. 8</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>sq. ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scoured</td>
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<tr>
<td>Volume</td>
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<td>0.2051</td>
<td>0.1628</td>
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<td>Run No. 8</td>
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<tr>
<td>cu. ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Total scoured</td>
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<td>0.2286</td>
<td>0.3843</td>
<td>0.2475</td>
<td>0.2126</td>
<td>0.2474</td>
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<tr>
<td>Area. sq. ft.</td>
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<tr>
<td>Total Scoured</td>
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<td>0.3065</td>
<td>0.3158</td>
<td>0.2300</td>
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<tr>
<td>Volume cu. ft.</td>
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<td></td>
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<tr>
<td>Area. caving</td>
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<td>0.1380</td>
<td>0.1530</td>
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<tr>
<td>bank above water line. sq. ft.</td>
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<td></td>
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<tr>
<td>Total</td>
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<td>0.1455</td>
<td>0.1312</td>
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<td>Volume caving bank above water line cu. ft.</td>
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<td>Center. line depth</td>
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<td>0.92</td>
<td>0.78</td>
<td>0.84</td>
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<tr>
<td>Av. G. Depth</td>
<td>0.52</td>
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<td></td>
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</tbody>
</table>
EROSION AND BANK CAVING OF WET COMPACTED LOESS

(Continued)

Only slight pitting.

Runs 1, 2, 3, 4, 5, No erosion, flume level.

Run 6, depth on flume 0.10 ft. \( S = 0.063 \) Above Data

* 7, * * * 0.166 ft. \( S = 0.063 \) Planimetered

* 8, * * * 0.26 ft. \( S = 0.063 \) from Measured

Cross-sections.*

Total time runs 6, 7, 8, = 75 minutes.

All measurable erosion occurred during runs 7 and 8

in the last 50 minutes but no doubt there was

some influence from Run No. 6. Total volume of

evacuated material was 1.0599 cu. ft.

* See Cross-sections on pages 46, 47, 48, 49, 50 and 51.
Cross-section (Loess) Sta. 0.
The Tilting Flume.

Cross-sections taken at one foot intervals transversely with the soil erosion tilting flume after the desired material has been placed in the flume. The successive cross-sections after the initial sections indicate the contour of the material eroded after its respective run.
Cross-section (Loess) Sta.1.
The Tilting Flume.

Cross-sections taken at one foot intervals transversely with the soil erosion tilting flume after the desired material has been placed in the flume. The successive cross-sections after the initial sections indicate the contour of the material eroded after its respective run.
Cross-section (Loess) Sta. 2.
The Tilting Flume.

Cross-sections taken at one foot intervals transversely with the soil erosion tilting flume after the desired material has been placed in the flume. The successive cross-sections after the initial sections indicate the contour of the material eroded after its respective run.
Cross-section (Loess) Sta. 3.
The Tilting Flume.

Cross-sections taken at one foot intervals transversely with the soil erosion tilting flume after the desired material has been placed in the flume. The successive cross-sections after the initial sections indicate the contour of the material eroded after its respective run.
Cross-section (Loess) Sta. 4.
The Tilting Flume.

Cross-sections taken at one foot intervals transversely with the soil erosion tilting flume after the desired material has been placed in the flume. The successive cross-sections after the initial sections indicate the contour of the material eroded after its respective run.
Cross-section (Loess) Sta.5.  
The Tilting Flume.

Cross-sections taken at one foot intervals transversely with the soil erosion tilting flume after the desired material has been placed in the flume. The successive cross-sections after the initial sections indicate the contour of the material eroded after its respective run.
Test Number Four.

**Dry Compacted Loess (Memphis Silt Loam)**

Dry loess from near the surface of a hill on the U. S. Waterways Experiment Station grounds was placed in the erosion flume and compacted to true template form. This loess was not in its natural bed state as taken from the hill, but completely broken up in the handling.

The loess in this condition eroded out at 1.5 ft./sec. to a depth of 0.15 foot throughout the erosion section of the flume in four minutes. Water depth over the bottom was 0.3 foot. The total volume of material eroded was 0.637 cu. ft. and the volume eroded per foot of flume was 0.1274 cu. ft. Reducing to unit bases of time and area, we find that the material was removed at the rate of 0.000288 cu. ft./sec., and from this it follows that in a pilot channel 30 feet deep by 300 feet wide, development should occur at a rate of .1107 cu. ft./sec. for each foot of length.

This particular test has little value beyond showing the eroding velocity of the material in the described condition, and it is possible that the material might assume this state if eroded from its natural bed. However, we cannot accept this as standard because the
eroding velocity is not sufficient to erode the same material in its natural state or the wet state that it might have in a natural channel.

Test Number Five.

Slabs of Loess in its Natural State.

Slabs of loess in natural state about one foot square and four inches thick were carefully cut and the erosion flume paved with same. The flume was run at 0.3 ft. depth for 20 minutes with a mean velocity of 2.5 ft./sec. and no erosion occurred. The flume was then tilted until erosion began; the mean erosive velocity as measured with the Gregory Pitot tube was 4.0 ft./sec., and the bottom velocity was 3.6 ft./sec.
Test Number Six.

Compacted Inundated Loess with Scratched and Pitted Section.

For this test loess was inundated and allowed to season by exposure to the air for three days. Erosion was assisted by artificial roughening of the surface and by the formation of holes in the sides and bed. A mean velocity of 4.1 ft./sec. was found sufficient to produce scour.

Test Number Seven.

Compacted Inundated Loess with Sinuous Channel.

In a further attempt to accelerate the erosion test, the channel was made sinuous in the erosion flume, as indicated in an accompanying sketch; and a velocity of 2.8 ft./sec. was run for 30 minutes. There was no erosion of the sides, but a hole was scoured in the bed near station No. 5 to a depth of 0.35 ft. as a result of impact. The mean velocity was finally stepped up to 4.0 ft./sec. (bottom velocity 3.6 ft./sec) and the noses of the mounds shown in the sketch were shaved off. The bed became pitted with many holes at this last velocity.

Test Number Eight.

Clay (Sand 20%, Silt 19%, Clay 61%) Abs. spec. gr. 2.40

From Station 3705

Boeuf Channel

(1 to 3 ft. deep)
Compacted, Inundated and Seasoned.

Having completed basic tests to determine flume constants from station 3705 (depth 1 ft. to 3 ft.) of the proposed Boeuf channel was placed in the three sections of the tilting erosion flume, inundated 12 hours and seasoned for three days. The total length of eroding surfaces was 13.6 feet.

Upon seasoning, the material showed hair contraction cracks after 24 hours, and these cracks multiplied and widened to as much as an inch in seven days. The clay in the flume never got so dry during the tests as to crumble in water.

A series of tests was run on the clay in the tilting erosion flume, keeping the water 0.3 foot deep over the bed, and increasing the slope until appreciable erosion had been observed. The channel section was made with a bottom 0.915 feet wide and with 1:1 side slopes.

An accompanying table gives additional facts pertinent to the erosion of the clay. During the first four runs of 30 minutes each, no appreciable or measurable erosion occurred; only a slight roughening of the surface was observed. After run five when the mean velocity was 7.2 ft./sec. (bottom velocity 5.75
CLAY FROM STATION 3705 - BOEUF BASIN PILOT CHANNEL

DEPTH OF SOIL BELOW SURFACE 1' to 3'

EXPERIMENT NO. 8

Section of soil 5 feet long, and 0.5 feet thick on bed and on 1 to 1 side slopes, packed in recessed section of flume. Surface of soil smooth and true to standard flume section. Approach and discharge sections also filled with Buckshot.*

<table>
<thead>
<tr>
<th>No.</th>
<th>Time of Run</th>
<th>Total Depth of Model Submerged Top Bed</th>
<th>Top Bed Condition or of Time of Velocity of Soil after Run</th>
<th>Measured Erosion, if possible.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean Velocity of Water over Sides</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hrs.</td>
<td>Ft.</td>
<td>Ft. per sec.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ft.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>30</td>
<td>0.5</td>
<td>1.92</td>
<td>1.8</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>1.0</td>
<td>4.6</td>
<td>4.5</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>1.5</td>
<td>6.1</td>
<td>5.9</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>2.0</td>
<td>6.6</td>
<td>6.1</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>2.5</td>
<td>7.2</td>
<td>5.75</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>3.0</td>
<td>7.85</td>
<td>6.2</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>3.5</td>
<td>8.4</td>
<td>5.9</td>
</tr>
<tr>
<td>8</td>
<td>30</td>
<td>4.0</td>
<td>8.8</td>
<td>6.2</td>
</tr>
<tr>
<td>9</td>
<td>30</td>
<td>4.5</td>
<td>9.2</td>
<td>5.9</td>
</tr>
<tr>
<td>10</td>
<td>1010</td>
<td>21.3</td>
<td>6.6</td>
<td>5.2</td>
</tr>
</tbody>
</table>

* See Plate No. 8, page 58.
CLAY FROM STATION 3705 - BOEUF BASIN PILOT CHANNEL

DEPTH OF SOIL BELOW SURFACE 1' to 3'

EXPERIMENT NO. 8

(Continued)

<table>
<thead>
<tr>
<th>No.</th>
<th>Time of Run (Mins.)</th>
<th>Total Time of Run (Sec.)</th>
<th>Depth of Water Over Bed (Ft.)</th>
<th>Mean Bottom Velocity (Ft./Sec.)</th>
<th>Condition of soil after run. Measured erosion, if possible.</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>60</td>
<td>22.3</td>
<td>0.3</td>
<td>5.45</td>
<td>considerable erosion. See Sketch.</td>
</tr>
<tr>
<td>12</td>
<td>60</td>
<td>23.3</td>
<td>0.45</td>
<td>9.75</td>
<td>No new changes. Slightly more erosion than previous run.</td>
</tr>
</tbody>
</table>

considerable erosion. See Sketch.
Plate No. 8. The Tilting Flume.

Erosion of Blue Clay (Buckshot) from Station 3705 (1' - 3' deep) of the proposed Bœuf Pilot Channel. This photograph was taken after run No. 5 of Experiment No. 8. Up to this time the clay had been exposed to erosion for two and one-half hours with bottom velocities up to 6.1'/sec. A hook gage and Pitot tube is shown in the picture. Note at this time shrinkage cracks are appearing on the side slopes of the model. It will be also noted that the bed has roughened considerably. The rubber tube in the rear was used to siphon off the water so as not to cause highlights on the photograph.
a measurable erosion was noted.

Four more runs of 30 minutes each at 0.3 ft.

...measured erosions were noted. It was then decided that possibly more time was required for the erosion of clay; so for run number ten the flume was allowed to run for 16 hours and 50 minutes. The depth of water in the flume during this run was 0.3 foot and the mean velocity was 6.6 ft./sec. (bottom velocity, 5.2 ft./sec.). Observations made at the conclusion of this run revealed that the area of surface erosion had been nearly doubled. After each run cross-sections of the flume were taken and plotted to ascertain the quantitative erosion. The flume was also leveled at the conclusion of run number ten, the erosion pits filled with water, and the water siphoned off through a measuring graduate. The weighted mean of erosive mean velocities was 9.7 ft./sec. (Bottom velocity 6.0 ft./sec.). The measured erosion was 0.328 cu. ft. for the five foot erosion section; the effective eroding time was 20 hours. This is equivalent to \[
\frac{0.328}{5 \times 20 \times 60 \times 60}
\]

= 0.000000911 cu. ft./sec. per foot of flume, which is further equivalent to 0.00000493 cu. ft./sec. per unit area. And the erosion per second per foot of pilot
channel on this basis will be 0.000190 cu. ft., assuming bottom velocities of about 6 ft./sec. (5.9-6.2). These velocities, are, of course, higher than can be rightfully anticipated in the proposed pilot channel. With erosion occurring at the rate of .00019 cu. ft./sec. per unit length of channel in nature, full development of the pilot channel may be obtained in 177 years with the stipulated velocities. Indications are that no erosion of consequence will occur at less than six feet per second bottom velocity, and it follows that if velocities are kept within limits anticipated for the pilot channel (5.2 f/s mean; 3.8 f/s bottom) 800 - 1000 years will be required for the necessary development to super- flood capacity. Six hundred years will probably be required for development sufficient to accommodate a 15 year flood.

From the irregular increase in size of the erosion pits with respect to the center line of the channel, it is apparent that a sinuous channel would eventually be produced.

Two additional runs of sixty minutes each (runs 11 and 12) were made at 0.3 ft. depth and 0.45 ft. depth respectively, attempting to get flow conditions in the middle turbulent region above the Reynolds's Critical
stage and below the Unwine critical stage. These runs produced only slight effects.

**Test Number Nine.**

Clay (Sand 20%, Silt 19%, Clay 61%)  
(From the Boeuf Basin)

Underlain with sand, compacted, inundated, and seasoned for three days before tested.

Borings were made by the Vicksburg District in the Boeuf Basin, commencing near Arkansas City, at intervals of about two miles. The average depth of these holes was 50 feet. The borings follow along the entire length of the basin for a distance of about 124 miles. For most of this distance the logs of the holes indicate a surface layer of clay from 12 feet to 20 feet in thickness. Below this clay stratum is a bed of saturated sand grading somewhat coarser with depth. In some cases gravel was encountered in bottoms of holes, but in most cases the holes bottomed in sand.

The next experiment in the erosion flume was designed to reproduce this latter condition. Sand was packed in below a layer of clay and inundated all night. Following this, the flume was allowed to season for three days, when it was evidenced by the formation of cracks that the clay had assumed its natural granular structure. Water 0.5 ft. deep was run so as to impinge on both
strata, and the flume was given a slope of 0.00184 to produce a mean bottom velocity of about 1.5 ft./sec. The mean velocity was 2.2 ft./sec. Observations were made with depth-bed-scope (Geschieberohr), and in five minutes the approach and discharge sections of flume were practically cleared of all bed sand. The flume was immediately shut down for further observation.*

The immediate observation showed that all of the sand strata down to the recess in flume had gone out, leaving over-hanging banks on both sides. It was noted as the stage in the flume was lowered, that bank caving started on one side and continued for nearly five minutes. The caving was more intense on the left hand bank of flume, indicating that there had been a longer test range, a sinuosity of channel would have developed. The more plastic the material became on wetting, the less bank caving was noted. This was also true with respect to transportability. Next the bottom velocity was stepped up to 2.5 ft./sec. by increasing the depth to 0.8 ft. The flume was run at this depth for 15 minutes. The caved material remained where it fell from the bank for the most part. These caved pieces were of irregular shape ranging from chunks 6" x 3" x 1.5"

* See Plate No. 9, page 63.
Plate No. 9. The Tilting Flume.

Sand strata was placed below strata of blue Buckshot from Station 3705, the contact plane being horizontal. The tilting flume was nearly horizontal, the slope being 0.00184, water 0.5 ft deep was run, the bottom velocity being 1.5 ft/sec, mean velocity 2.2 ft/sec. In five minutes sand in approach and discharge sections had eroded out and sand in erosion section was down to the level of the fixed approach and discharge sections, leaving overhanging banks. When the water level was let down, some bank caving occurred as will be noticed on the right bank.
to smaller pieces less than 1" in diameter. After 15 minutes most of the finer material had washed out but all of the larger pieces still remained. The depth was then reduced to 0.3 ft. and velocities stepped up gradually until a bottom velocity of 5 ft./sec was attained. At this velocity the larger pieces were washed loose. Five feet per second was found to be also the critical depositing velocity as some of the largest pieces remained in the lower end of the flume. Thus, for this condition the transporting velocity is much higher than bank caving velocity. This process consumed 20 minutes. Figure 4 shows the condition of the erosion section after caving bank material had been evacuated. Assuming a water stage of 0.5 ft. in the model initially, and an ultimate depth of 0.8 ft., the channel modifications took place in five minutes eroding time at bank caving velocity, plus possibly another five minutes transporting time at transporting velocity. Although development of the channel was apparently assisted by the undermining of the clay strata and the subsequent caving of banks, it was noted that the time required to disintegrate the caved lump was an important consideration. Practically the same time will be required for development of a channel with an underlying
sand layer as will be necessary in the first case considered. Sand movements being of local importance only, in a long channel shoal reaches are created below the regions of transportation and in these places the clay will tend to deposit and seal the sand. The general model of the basin indicated that depositions will occur in back-water areas opposite and below Monroe and that the channel will completely fill up in this locality.

**Test Number Ten.**

(Sand 39%, Silt 40%, clay 21%)
(From the Boeuf Basin Station 4200)

Compacted, then Inundated. Seasoned Three Days.

The approach section, erosion section, and discharge section of the erosion flume were filled, and compacted to template with red sandy loam from station 4200 C of the Boeuf Basin pilot channel. The flume was then inundated for 12 hours and afterwards seasoned for three days, cracks appearing in the material in the interim to indicate the return of the material to its natural state.

The flume was run for two hours and five minutes in 25 minute intervals with a constant depth of 0.3 feet and bottom velocities ranging from 2.3 ft./sec. to 4.9 ft./sec. At the minimum velocity of 2.3 ft./sec. very
slight pitting occurred at two places in the bed of the channel. These pits started from shrinkage cracks and this erosion was upstream from where started, and near the center of the channel. At a bottom velocity of 2.6 ft./sec., additional small pits appeared, mainly in the bed but several on side slopes near the water surface. In all cases these pits started from shrinkage cracks and worked upstream. At a bottom velocity of 3.8 ft./sec., no new pits appeared but old ones were slightly augmented. The average measured pit size was now about 1 inch long by 3 inches wide by 1/2 inch deep. At a mean velocity of 6.2 ft./sec. (bottom velocity 4.8 ft./sec.) no further change appeared, but at a mean velocity of 6.7 ft./sec. (bottom velocity 4.9 ft./sec.) the pits were greatly enlarged, and shrinkage cracks along the toe of the side slopes enlarged as if they were on the verge of eroding out long holes. The enlargement of holes now appeared to be working downstream instead of upstream, and the average size of pit was 2-1/2" wide by 8" long by 1" deep. Surface pitting appeared generally over the entire bed. The holes started on the side slopes did not enlarge to any considerable extent.

In a five foot length of flume the measured erosion was 64.4 cu. in. (0.0373 cu. ft.) on the bed and 23.8 cu.
in. (0.01376 cu. ft.) on the side slopes below the water line. There was no bank caving. It is to be noted here that the bank erosion was 37-1/2 per cent, or 3/8 of the bed erosion. The effective eroding time was 100 minutes. The eroding velocity was 4.9 ft./sec. (bottom), the mean velocity being 6.5 ft./sec.

Reducing the total amount of material eroded from the flume to bases of unit time and area, it is found that .000000918 cu. ft./sec. was removed per unit area. The corresponding volume that might be removed from a channel 300 feet wide at bottom, and 30 feet deep with 1:1 side slopes, is 0.000354 cu. ft./sec. per unit length. It is obvious that, with all material of the red sandy loam type and with velocities somewhat in excess of those possible, erosion would progress nearly twice as fast as in the case of the clay previously investigated. Assuming best possible conditions, however, 102 years will be required for full development of the channel and under normal conditions, with backwater effective to reduce velocities, 500-600 years will be necessary.
FLUME EROSION TEST OBSERVATION SHEET

TEST ON SANDY LOAM -- STATION 4200 & BOEUF BASIN

TEST NO. 10.

Section of soil 5 feet long, and 0.5 feet thick on bed and on 1 to 1 side slopes, packed in recessed section of flume. Surface of soil smooth and true to standard flume section. Also approach and discharge section filled with material to be eroded.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>25</td>
<td>25</td>
<td>0.3</td>
<td>2.6</td>
<td>2.3</td>
<td>Very slight pitting at 2 places in bottom.</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>50</td>
<td>0.3</td>
<td>3.3</td>
<td>2.6</td>
<td>Additional small pits appear</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>1h15</td>
<td>0.3</td>
<td>5.1</td>
<td>3.8</td>
<td>Pits slightly augmented</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>1h40</td>
<td>0.3</td>
<td>6.2</td>
<td>4.8</td>
<td>No further change</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>2h05</td>
<td>0.3</td>
<td>6.7</td>
<td>4.9</td>
<td>Pits greatly enlarged.</td>
</tr>
</tbody>
</table>


Test Number Eleven.
Red Sandy Loam Over Sand
(From the Boeuf Basin)
Station 4200

Materials compacted, then inundated, seasoned for three days.

The material, red sandy loam from station 4200 of the proposed Boeuf Pilot Channel, used in run ten, was smoothed to template grade (b = 0.916 ft., side slopes 1:1) in the approach and discharge sections.* In the five foot erosion section, the lower 0.3 ft. of the red sandy loam composing the sides and bed was removed, leaving the upper portions of the soil suspended on the flume cleats. Sand was then packed tightly in place to act as a support at the bottom after wetting. In this was, as before, the underlying sand stratum was represented. Water was run 0.5 ft. deep for seven minutes, during which time the sand washed out to a depth of 0.10 feet. Practically all of the sand moved was carried out by the current during the first three minutes of the run.

The mean velocity was 2.5 ft./sec. and the bottom velocity was 2.0 ft./sec., which of course was in excess of the eroding velocity of sand. This, same sand eroded

* See Plate No. 10, page 70.
Plate No.10. The Tilting Flume.

Red Sandy Loam after sand strata below had washed out. Note the additional bank material caved by comparing with previous photograph. Also note the caved material strown along the bed of the channel. The hammer in the background indicated the scale of the picture and the relative size of the debris and caved portions of the side slopes. When this view was taken, the flume had been run 32 minutes, the maximum bottom velocity being 2.0' sec. The caved material in general slaked rapidly, in which condition, it evacuated readily.
at a mean velocity of 2.2 ft./sec. (1.5 ft./sec bottom velocity) under a layer of buckshot in run nine, which can in this case be taken as the eroding velocity. The volume of sand evacuated in approximately four minutes by observation was 2.4 cu. ft. in the five foot flume section. The sand below a depth of 0.10 feet from the bottom of the original channel remained in the flume after the run.

When the flume was shut down after the seven minute run, large slabs of the loam caved from the bank. The flume was now run at the same depth for 25 minutes, with the mean velocity at 2.2 ft./sec. (bottom velocity 1.9 ft./sec.).

The large slabs of sandy loam rapidly disintegrated into small particles which would all be carried out eventually at the mean velocity of 2.2 ft./sec. by being rolled along the remaining bed of sand. The disintegrated particles referred to were from 1/2" to 3/4" in diameter.

In concluding this test the flume was given its maximum tilt of $S = 0.1335$ to produce a mean velocity of 10.5 ft./sec. (bottom velocity of 6.7 ft./sec), with a depth of water of 0.5 ft. The time given the final run was 25 minutes. All of the sand and material caved from the bank was evacuated as is shown in the last photograph under experiment number eleven.
RECAPITULATION AND DISCUSSION OF RESULTS.

In the Boeuf pilot channel enlargement in the upper section may occur through both widening and deepening if sufficient time be allowed for this to occur. The clay banks of the ditch may be expected to erode under the most favorable conditions of operation—assuming annual clearing and the removal of obstructions—to such an extent that a bankful capacity sufficient to accommodate a 15-year flood, may be obtained in 600 years. Another 400 years will be required for the channel to enlarge to superfluvial capacity. If this is the case, it ceases to be to be river engineering and should be relegated to the field of geology. The movement of caved material will be largely by suspension and only small amounts will be carried as bottom load. It is believed that in overbank and backwater areas, the movement of sand will be only local and almost entirely in the form of sand waves. In the regions of underlying sand deposits the tendency to meander will be more manifest than in other sections of the floodway due to the fact that any slight obstruction or lowering of velocities will cause immediate deposition with the consequent impingement of the current against the opposite bank. It appears that as soon as the channel reaches the backwater area at about the
latitude of Monroe, heavy deposition of sands and silts will occur in the channel and in the overbank area. There is extreme unlikelihood that this material can be flushed out during low-water stages, since it is only possible to obtain sufficient flowage for this from overbank water of the Mississippi River. This will be during flood stages when the backwater effects will prohibit flushing, and as a consequence there will be an accumulative piling up of detritus accompanied by a consequent raising of the backwater curve. Following this there will be observed a general reduction of capacity and an eventual deterioration of the channel.

The effect on the Ouachita River will probably be a widening and shoaling of the stream accompanied by more deposition of silts carried from above.

The assumed channel section (30 ft. deep and 300 ft. wide at bottom, with 1:1 side slopes) was indicated to be as satisfactory as any for the Boeuf basin. The ratio for side slopes (1:1) has been shown by tests to be most reasonably advantageous to proper development of the channel through either bank erosion or bank caving and in addition, certain construction advantages may be attached to this slope of cut.

Although certain rates of channel enlargement are
Given under results of the tilting flume experiment, it must be realized that these results apply only to the materials investigated in each case and to the same materials as they were placed in the erosion flume. Notwithstanding these facts, the rates, as given, furnish a good index to what may be expected in nature, and it is probable that similar soils encountered in the Boeuf Basin will give nearly similar results. In any case it has been found possible to predict where erosion may or may not occur and to predict likewise the locations of probable depositions. As brought out in earlier paragraphs of this report, each particular soil must be tested on its own merits; it is obviously a mistake to attempt the application of generalities to any special case or even to the solution of the general problem.

A summation of all facts brought out by the many tests conducted serves to indicate that little or no uniform development of the pilot channel in the Boeuf Basin may be reasonably expected. The Boeuf basin presents a problem in that here a considerably greater uniformity of soil types is to be found, and that the surface layer of soil is underlain throughout by a sand stratum that may succumb locally to the action of flowing water. Here the main
difficulty is that of moving the eroded sand out to a final resting place beyond the mouth of the channel, and of, likewise, moving out the particles of overlying clay caved in by an undermining of the banks, and disintegrated by the force of the water. All the investigations showed that a widening of channel may reasonably be expected in limited reaches of the proposed channel, but that on the other hand there will be many reaches in which little or no bank failure will occur. The experiments also bring out that where erosion may occur, it will be followed by a meandering of the original alignment and a consequent lowering of velocities, which, although destructive to concave banks, will be less and less effective in producing uniform development of the channel as a whole. The observations made on the geographical model of the Boeuf basin bear out this reasoning and show further that several extended regions of deposit will be produced.

The net result of all the investigations is to show the impracticability of the proposed plan and warn against the expectation of satisfactory pilot channel development.
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