RIVER PHYSICS LABORATORIES OF EUROPE AND AMERICA.

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Of recent years conviction has been gaining ground among hydraulic research workers that there is a physics of river flow and as such it is possible to study river movements and the changes in the course of a river from scale models in a laboratory. Though the science of River Physics has not attained to that stage of development as has been reached by the science of Nuclear Physics or any other branches of Physics, yet since the days of M. Fargue, Osborne Reynolds and Vernon-Hercourt the progress of this branch of Physics has been very rapid. The experiments of Prof. Gibson in England, of Engel, Winkel, Krey and Rehbock in Germany and of Freeman in America have proved conclusively that not only can scale models, properly conducted, give valuable indications for training of a river, quantitative information can also be obtained from such experiments. In his tidal model of the river Severn, Prof. Gibson has been able to reproduce the conditions of the river in 1927 starting with the river in 1848. Prof. Krey in his Elb model and Prof. Rehbock in the Rhine model have been able to get very good quantitative agreement between the model and the prototype. In the U.S. Waterways Experimental Station at Vicksberg, Vogel has been able to reproduce various conditions of the river Mississippi in a number of models.

It will be interesting to compare the various methods applied by different workers in developing their river models and also the amount of success they have attained in them.

Prof. Gibson's name is mainly associated with the tidal model of the river Severn. He has made this model a complete success. His method of working can be summarized as follows:—

The model was moulded in Portland cement supported by a wooden tank having the internal dimensions shewn in Fig. 1. For moulding the model a series of equidistant parallel cross-sections (138 in all) of the estuary and the surrounding district included within the boundaries of the tank were drawn on mill-board, data being obtained from the 1848 survey. These were cut and mounted vertically in the tank and were used as templets. Where rocks are marked in the charts these are moulded to the correct height. Where the soundings show gravel, clay or hard sand, this was reproduced by a cohesive mixture of Leighton Buzzard sand and a very fine silica sand containing a proportion of China clay. Where the charts showed a sandy bottom the cement bottom of the model is moulded at such a depth as to allow of the equivalent of at least 10 feet of sand in the upper reaches and from 30 feet to 40 feet in the lower reaches of the estuary and sand was afterwards filled in to the correct depth.

The tides were produced by the rise and fall of a plunger in a tank forming a continuation of the seaward end of the model. This plunger was operated

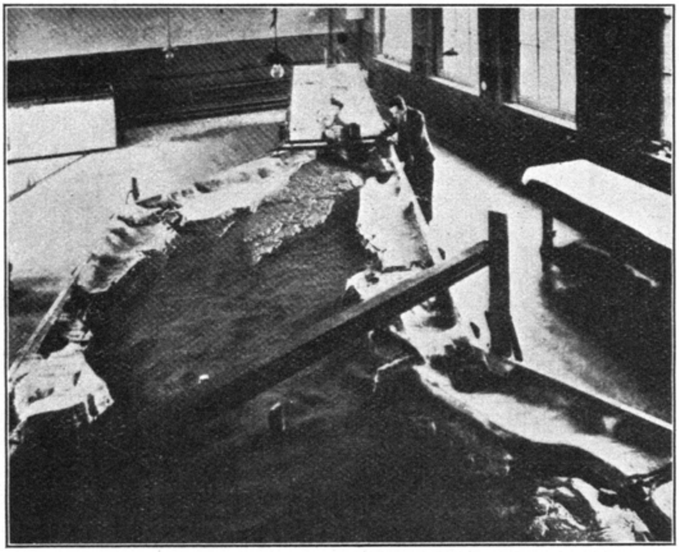

FIG. 1.

from a mechanism driven by a 2 h.p. induction motor. The correct tidal period in the model was calculated from the following relationship:—

$$t = T \frac{l}{L}\sqrt{\frac{H}{h}},$$

where capital letters refer to prototype. So that with a scale ratio 1/100 and 12 hr. 20 minutes as the tidal period in the prototype the tidal period in the model was kept at 52·23 sc.

One of the first requirements was to determine what size of sand would reproduce most accurately the conformation of the bed of the estuary and experiments to this end were carried out on both models after which the original programme was followed using this sand.

Owing to the fact that fine silt, such as is found in the Severn Estuary, becomes coagulated and settles much more rapidly in sea water than in fresh water it was necessary to reproduce this effect of the sea water in the model. For this it was decided to make use of the coagulating properties of a weak solution of alum. The alum was made up into a solution and fed into the model.

The results obtained by him are best expressed in his own words:—

'On the hydrodynamical side—the reproduction of currents, water-levels, tides and wave-motion—a suitable model is capable of giving results which may fairly be claimed to be accurate within the limits of experimental investigation.

The question as to how nearly quantitative agreement is to be expected regarding the movement of bed-materials, erosion and deposition is not so easy to answer. We know that training works, bridge piers and other structures affect the set and velocity of the currents to an extent and in a manner which is reproduced with close accuracy in a suitable model. Inasmuch as an increased velocity causes scour and a reduced velocity causes deposition, if the bed-material is moved the movement caused by the change will be in the same general direction and of the same kind as in nature, so that it is to be expected that the same kind of configuration will result.

Much depends on how far it is possible in a model to reproduce accurately all the factors involved. The final answer to the question can only be given when we have available the results of many model tests and corresponding results under similar conditions in nature, and until then caution must be used in predicting quantitative results.'

He concludes with the remarks:—

'I think it is not overstating the case to say that in expert hands such models are capable of giving results whose interpretation enables quantitative values to be pre-determined with sufficient accuracy for most practical engineering purposes.'

Prof. Krey of Berlin had carried out a long series of experiments on the river Elb. His method can be summarised as follows:—

The model was built on a platform 4 m: wide and 18 m: long. The platform rested on the adjustable support of the small flume, so that if found necessary afterwards the slope of the model could be varied by lowering one end of the platform. The outlines of the platform are shown by dotted line in Fig. 2. Projecting berms that in nature are kept in position by the growth of grass were formed in the model by sand and consolidated by milk of cement. Besides this the model river bed in the river channel and between the dikes consisted of fine moveable sand as in nature. This was laid to such a depth that every possible bed movement in nature could be reproduced in the model.

In order to reduce the error due to either of these two alternative methods in the experiments (distortion of the vertical scale or increasing the slope by tilting the platform) both the methods were combined. Thereby it was possible to deviate very slightly from geometrical similarity both in depth and slope. The error was rendered smaller by this method than what would have been the case if one had to obtain the tractive force necessary for the maintenance of silt movement in models either by increasing the depth or by steepening the slope.

The conclusions arrived at by him can be briefly indicated thus:—

Definite rules cannot be set up for the selection of the time scale as the time that is required for the formation of the bed in the model depends on the model scale ratio, the model sand and also on the particular problem. The time scale, therefore, should be determined beforehand according to the requirements of the experiments. It has, therefore, been the practice in the Institute

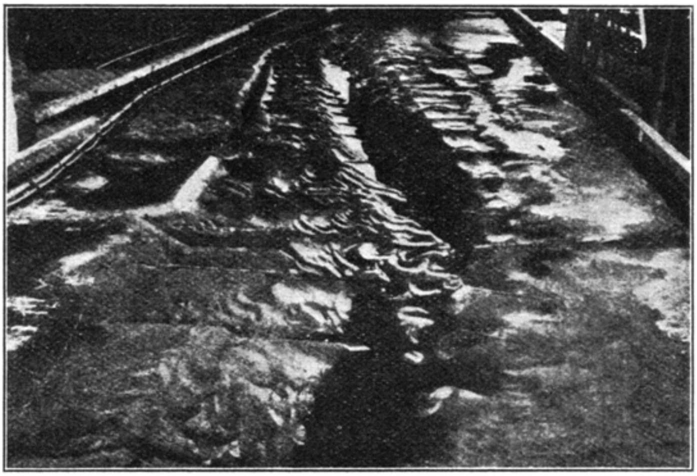

FIG. 2.

since 1928 to start the experiments on a bed with uniform slope and horizontal cross-section and to allow the model discharge to work out its own bed formation. The discharge was so selected as to give the required gauge readings of the prototype for a year or a number of years, at the end of this period a definite bed formation used to be attained. A comparison between the model bed formation and the prototype allowed an idea to be obtained about the correctness of the time scale selection. The model or one of the scale ratios must be altered if the reproduction of the bed formation is not complete within a reasonable model time scale.

The most important of the river models of Prof. Rehbock of Karlsruhe was that of the Rhine. This work he did for the Rhine River Commission. His general principles of river experiments are as follows: When it is decided to do model experiments on a stretch of a river a long stretch of the river is taken and 2 or 3 different models with different scale ratios are constructed, say 200 : 1, 160 : 1, 150 : 1, the length ratio and the depth are the same. Having thus fixed the scale ratio the discharge is consequently fixed. The river is then built with its levee that has remained stationary for a considerable length of time. The bed of the model which has a different slope steeper than that of the river is filled uniformly with brown coal—very light chips of coal about 1 to 1·5 mm. in size and density about 1·4—to a certain depth. A certain discharge is allowed to pass over the model for different lengths of time and the contours traced out by the water are photographed by a camera that travels on two rails at a height of about 2 or 3 m: above the model, the rail is kept parallel to the water surface so that photographs of the same size are obtained every time. These contours are then obtained for different discharges and then compared to the actual contours of the river bed: by this means a time factor for each experiment is obtained which is different for different rivers. This time factor depends on the slope and the quality of silt used. For a stretch of the Rhine, Prof. Rehbock has found that for the scale ratio 160 : 1 the time factor 61 is nearly correct and that a change that took 2 years in the Rhine to take place will require less than one day in the model.

Vogel's experiments on models of the river Mississippi are very interesting and show what can be attained in such experiments with proper care and judicious handling of the model.

A number of model results on the Mississippi carried out at the U.S. Waterways Experimental Station, Vicksburg, Miss., U.S.A., are quoted by Mr. H. D. Vogel in a paper entitled 'Hydraulic Laboratory Results and their Verification in Nature'. He gives instances of the following models:—

1. The Brooks Point Model.
2. The First Charters Model.
3. The Point Pleasant Model.
4. The Morrison Towhead Model.
5. The Walkers Bar Model.
6. The Stewarts Bar Model.
7. The Island No. 9 Model.

The agreement shown in the figures of the model and the prototype is almost complete. Only four figures of the Brooks Point Model are reproduced

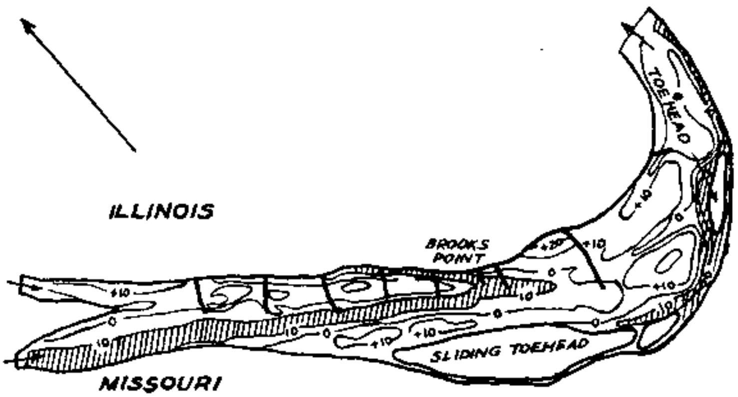

FIG. 3. CONDITION EXISTING IN NATURE, SEPTEMBER, 1932, IN THE MISSISSIPPI RIVER AT BROOKS POINT, ILL. (CONTOUR ELEVATIONS ARE REFERRED TO LOCAL LOW-WATER PLANE. HATCHED AREAS REPRESENT DEPTHS GREATER THAN 10 FEET).

here. I shall quote the following from his paper: 'The Model of Brooks Point, Ill (Fig. 3) was built in simulation of a 10 mile stretch of the Mississippi

River lying between mile 20 and mile 30 above Cairo, III. The purpose of the model study was to devise means for improving the depth of the navigation

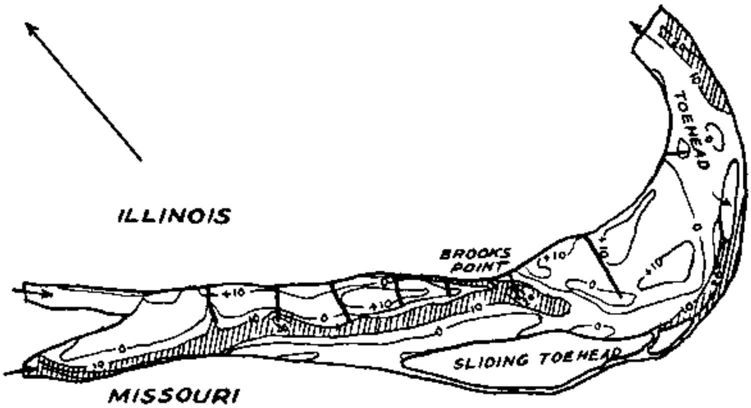

FIG. 4. FLAT BED VERIFICATION RUN, MODEL OF MISSISSIPPI RIVER AT BROOKS POINT, ILL. (CONTOUR ELEVATIONS ARE REFERRED TO LOCAL LOW-WATER PLANE. HATCHED AREAS REPRESENT DEPTHS GREATER THAN 10 FEET.

channel over the crossing at that point during low water stages. Only one general survey of the region was available to the laboratory. This was made in September 1932 and the model was constructed from the data thereof. Fig. 3 shows the condition in the prototype as revealed by the survey. Lacking any other survey data the model was subjected to flat-bed verification test. At the end of 100 hrs. operation (Fig. 4) it was found that the model was in close similarity with nature.'

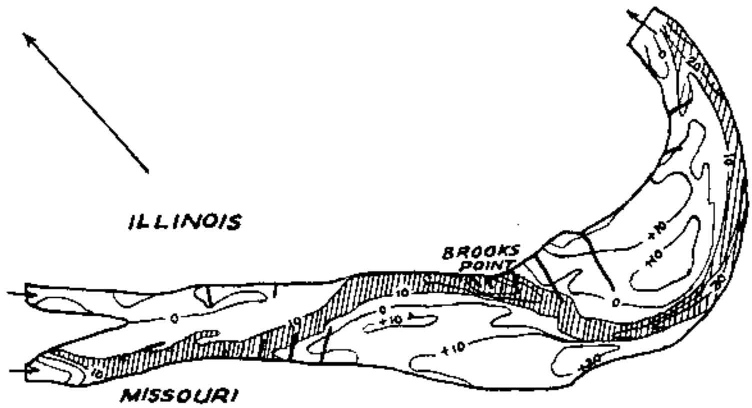

FIG. 5. INDICATED SOLUTION, BY LABORATORY TEST, OF CHANNEL IMPROVEMENTS AT BROOKS POINT, ILL. (CONTOUR ELEVATIONS ARE REFERRED TO LOCAL LOW-WATER PLANE. HATCHED AREA REPRESENT DEPTHS GREATER THAN 10 FEET)

'This model was successful in demonstrating several practical plans for the improvement of the channel at Brooks Point. The details of this plan are shown in Fig. 5. In order to preserve the best conditions for navigation, the removal of the dikes was conducted concurrently with the construction of the five new dikes.. The new dikes were completed in August 1933 but only sections of the old dikes had been removed at this time. A survey

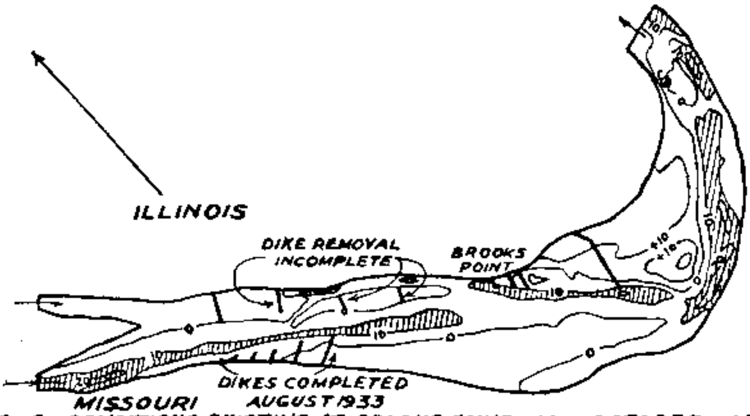

FIG. 6. CONDITIONS EXISTING AT BROOKS POINT, ILL., OCTOBER, 1933 (CONTOUR ELEVATIONS ARE REFERRED TO LOCAL LOW-WATER PLANE. HATCHED AREA REPRESENT DEPTHS GREATER THAN 10 FEET.

of this vicinity, made about two months later (October 1933), is shown in Fig. 6. It can be seen that in this short interval of time the river has shown unmistakable signs of adopting the new channel alignment.'

Having described the various river model experiments in Europe and America it may not be out of place here to mention a few experiments on models of rivers that have been recently carried out in India. The Hardinge Bridge experiments of Mr. Inglis are well known and have been described in detail by him. I shall here give a brief description of the experiments recently carried out by the author on a model of the river Chenab below its confluence with the river Jhelum. This was one of the series of experiments on models carried out by the author in connection with the Haveli Project of the Punjab Irrigation Department.

A stretch of the river Chenab about 1 mile upstream of the site where it is joined by the river Jhelum and about 5 miles downstream—the total length of the area included being 6 miles—has been modelled all in pure sand with a depth of sand equivalent to 50 feet in the prototype. The average diameter of the sand used is about the same as that of the prototype. The maximum breadth of the area modelled is about 3 miles. The horizontal scale of the model has been fixed at 1/300 and the vertical distortion has been calculated as 6·5 but it has been found from experiments that a distortion of 6·0 gives a better result. So that the vertical scale has been chosen as 1/50. The rivers were modelled to the survey of 1915 when a definite number of cross-sections were taken. Accurate discharge observations in these two rivers about 10 miles upstream of the point of confluence are available for the years 1922–37. For fixing the time scale the river was every time modelled to 1915 section and model discharges corresponding to the hydrographs in the rivers were run through the model, the interval of time that corresponded to a month in the prototype was varied from run to run. After each run, which covered the period from 1922–36, the river was surveyed and the cross-sections were compared with those of the prototype for 1936. The time interval that gave the best agreement has been selected as the time scale. This in this model was

$$10 \text{ min.} = 1 \text{ month.}$$

In the model only those months were reproduced in which there is any silt movement or bank formation in the river.

In the prototype there is a gauge site known as Trimmu Gauge Site where discharges and water surface levels have been observed daily since 1922. In the model also the water levels were observed at the corresponding site. The levels for different discharges in the model agreed within an inch or two with the prototype values.

Evidences about the reliability of model experiments for the purpose of anticipating changes in natural rivers are everyday accumulating. Experimenters all over the world are attacking from all points of view one of the most difficult problems of experimental physics, and theories of similitude and hydrodynamics are being constantly called upon to guide this infant science to its goal of success. The above comparisons between the characteristics of the model and the prototype show how completely successful has been this new science of River Physics. What Reynolds said about half a century ago is now applicable with greater force. 'This method of experimenting seems to afford a ready means of investigating beforehand the effects of any estuary or harbour work; a means which after what I have seen, I should feel it madness to neglect before entering upon any costly undertaking.'

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