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CONGRESSES OF NAVIGATION

# INLAND NAVIGATION

# Improvement of Rivers

for navigation, production of power, rafting, drainage and irrigation ; results of tests made with models, use of models for the solution of hydrotechnic questions.

## REPORT

BY

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### I. — IMPROVEMENT OF RIVERS FOR NAVIGATION.

In the matter of the improvement of rivers for navigation, the Reporter can only refer to the report which he had the honor to offer, on the same subject, at the XIIth Congress which was held at Philadelphia and of which the conclusions, adopted in principle, were the following :

« 1. The method generally preferred for improving rivers for purposes of navigation is regulation by the construction of permanent works, submersible dykes or spur-dykes, together with heavy dredging and, if needs be, when the conditions are favorable for this action, by reservoirs.

Canalization by means of movable dams is another method of improvement but it has against it the disadvantage of high cost and heavy expenses for operation and maintenance.

Whereas the expenditures made for canalization have varied in Europe between 140,000 and 375,000 francs per kilometre, those for regulation have reached only 105,000 to 200,000 francs per kilometre.

Hence it is better to resort to regulation when this method is applicable, by making the dredging as extensive as possible and by beginning even exclusively by dredging, reserving the right to complete this action, if experience demands it, by means of contraction works.

When the surface slope increases and the discharge diminishes, regulation becomes more difficult and finally impossible, so that it must be abandoned in favor of canalization or of a lateral canal. »

» 2. The degree of the slope and the amount of the discharge are, in fact, the most important hydrometric elements which characterize the nature of rivers and which, in connection with the ultimate object of the improvement carried on and the degree of navigability sought, help to set the limits beyond which the regulation of a river is no longer possible and at which canalization becomes a necessity.

The slope must not only not exceed the limit beyond which the force required for towing boats up stream becomes greater than that required for hauling a railway train of the same carrying capacity — for then navigation could not compete with the railways — but it must also not exceed the limit beyond which the banks and bed of the stream may be eroded.

Then again, the discharge must always be sufficient, even during low water, to enable the wetted portion of the right section to let two trains of the largest boats pass each other when loaded to their full carrying capacity. »

» 3. The canalization of a river becomes necessary whenever the unit slope exceeds the limit mentioned above, and whenever the discharge falls below the limit set. In either case, these limits which depend partly on the natural conditions of the stream and partly on the degree of navigability sought must be stated exactly in figures.

It must be borne in mind also that, except for extraordinary circumstances in the before mentioned cases, the canalization of the river is always to be preferred to a lateral canal, because such a canal for equality of navigable capacity is ever the more expensive. »

» 4. The exceptional cases in which it is well or even necessary to resort to the lateral canal are especially the following :

*a)* When it is a question of parts of rivers where rapids or curves make navigation too difficult; where navigation is already so very intense that the improvement of the stream is out of the question, or where impetuous torrents come together.

*b)* On parts of rivers where not only is the low-water discharge too small but the banks are also far too low for either regulation or canalization, as the movable dams would cause the overflow of the land alongside of the stream. »

» 5. Wherever work for the improvement of a river is going on, too much insistance cannot be laid on this point, that the greatest care should be taken of the interest of agriculture, so that the level of the subterranean waters shall not be so changed as to work harm; and that whenever such works may cause an increase in the height of floods to be anticipated, protection must be provided for the banks, while the other work is going on, by raising and strengthening the existing levees so far as may be necessary, or by building new ones in the future. »

Before passing on to other points of the question, it will be well to call attention to the system of improving the navigability of rivers by means of retaining gates *(Stautore)*, recently proposed by Messrs Sympher and Helmershausen for making the Werra navigable from Münden to Wernshausen, which seem as though they should give good results in certain cases.

## II. — PRODUCTION OF ENERGY

It is not always easy to find in the upper part of the basin of a stream great tracts of ground which, considering what they will cost, are suitable for the construction of artificial reservoirs. The cost of building high dams is very large and the greatest precautions should always be taken to guarantee the strength of the work both in its construction and in the absolute tightness of the ground on which it stands. Very great attention must be paid at all times to the service of the water supply in order to avoid an excess of discharge in the stream.

These circumstances have led to the conclusion that reservoirs are too uncertain, too dangerous and too expensive for use exclusively in the improvement of the navigability of rivers.

But when water is stored up for other purposes, for example : for manufacturing, for irrigation, for reducing the discharge of floods and dangers of overflows along a stream, to supply drinking water to a city, for lighting purposes or for operating locks and dams along a river, then the construction of a reservoir dam may be proper as well as remunerative.

This is the solution which has been adopted recently in Germany, for example, to improve the navigability of the Weser, along with supplementary works for regulating the river, by building a dam across the valley of the Eder at Hemfurt (a reservoir containing 202,000,000 m3) and one across the valley of the Diemel at Helminghausen (reservoir holding 20,000,000 m3). And as the report laid by Dr. Leo Sympher before the Congress of Philadelphia shows, these two high dams (the depth of water at the Eder dam being 41 metres and at the Diemel dam 31.40 m.) were built because they can be used, in addition to the principal service which has been mentioned :

1. For supplying the canal from the Rhine to the Weser;

2. For reducing the flood discharge and dangers of inundation all the way from the reservoirs to the City of Bremen;

3. For utilizing the hydraulic power given right at the dams.

In order to conciliate the opposing interests of navigation and industry, seeing that, at certain moments, it might be necessary to deprive the latter of any water supply in order to satisfy the demands of navigation on the Weser while the demands for motive power are unceasing, it has been possible to reach a happy compensation by transforming two old mills, at Münden on the Werra, belonging to the Administration of the Works, in such a way as to obtain a better utilization of the hydraulic forces. The simultaneous working of the new power station at Münden and of the reservoir dams at Hemfurt and Helminghausen gives the means for serving properly all the interests at stake.

The project for utilizing the hydraulic power produced by the falls at dams along canalized rivers is by us means of recent date. But, up to now, this idea has been but rarely applied; it was put into use at the Mühlendamm on the canalized Spree at Berlin and at he newly built lock at Horin, where the energy produced by the fall (8.90 m.) is used for the operations of this work; and also at Brahemünde on the canalized Brahe where the energy produced does all the work required at a dam, a lock and a movable bridge and also furnishes all the light needed.

The facility with which energy can be transported to a great distance by means of electricity has brought up again the question of utilizing the power produced at the dams.

This question was discussed at the International Congress of Navigation held at Brussels in 1898 and its Reporter expressed the opinion that the industrial utilization of hydraudic power might be advantageous whenever it could cover the amortization and the interest on the great cost which it would involve, whereas the Congress considered that it would be well « to recommend » the study of the applications of the strength of the falls of » canalized rivers to operating the machinery of the dams and » of the locks, as well as to hauling boats while passing through » the locks and their approaches », that is to say : « that it would » be well, as a matter of principle, to reserve the power of the » falls to the service of navigation and only to allow it to be » used with great circumspection for public interests first and » afterwards for private interests. »

It is well also to recall the proposition made by Mr. Prüsmann at the same Congress of Brussels and developed by him at the Congress of Düsseldorf in 1902, by applying it to the canalization of the Weser (dam at Rinteln) and at the dams existing or projected on the Main near Frankfort, on the Oder near Krappitz and on the Moselle near Valwig. Mr. Prüsmann's idea was to build movable dams in two parts separated by a central pier, sufficiently long up- and down-stream for the reception of turbines capable of developing the necessary energy and acting also as a waste weir.

In the case of the dam at Rinteln on the Weser, Mr. Prüsmann proposed to make the central pier 8 metres wide and 90 metres long up- and down-stream so as to place 10 reaction turbines which, having the top of the wheel at the level of low water, should be in condition to receive the largest discharges.

Mr. Prüsmann has set forth the advantages of his system which may be summed up as follows :

1° Possibility of construction even in narrow sections inside of cities and at points where the shore is made of rock;

2° No necessity for opening large industrial channels on the banks;

3° There is a great saving of ground along the shore and this can be used for installations for the use of navigation ;

4° It becomes possible to bring the hydraulic energy gradually into use by increasing the number of turbines;

5° The place for the turbines is such that it will not reduce the cross-section required for the passage of floods nor will it offer any obstacle for the movement of ice;

6° Possibility of utilizing the central pier and the supply canal for the turbines as a waste weir and so preventing too great a height of the back-water.

Mr. Prüsmann also observes that, for estimating the energy produced, the latter should not be referred to low water, but to mean water on account of their greater regularity, frequency and facility for use. Besides, it is necessary in practice for the utilizable hydraulic energy to maintain its maximum of regularity during the longest time possible in the year. Under these conditions, the mean useful energy is much less than the maximum utilizable energy which is only available during a relatively short period.

Mr. Prüsmann has summed up his studies on this argument as follows :

1° After the possibility of using hydraulic energy has first been made certain, the utilization of this energy, at the site of a dam on a canalized river, is expedient when the power is produced by means of turbines set in a pier built along the axis of the river and is transmitted to a central station on the shore, this station being completed by a steam reserve plant.

2° This central station may furnish at a low figure the machinery for working the locks and may provide for lighting the navigable highway.

3° No really practical solution has yet been found for the use of electric energy in towing boats, but it is evident that a central hydraulic plant is best able to supply at a low cost the power necessary for the purpose.

Mr. Faber, adopting Mr. Prüsmann's ideas, has studied in a note, regarding the project of a new navigable highway from Kelheim on the Danube to Aschaffenburg on the Main, the possibility of using the hydraulic power available, at the dams to be built in the valley of the Main between Bemberg and Aschaffenburg, so as to obtain a continuous energy of 18,736 HP.

Perhaps we shall have, at the Congress of Stockholm, the happy chance of learning that a further step in this direction has been made in Sweden and in Norway. It is to be wished, in any event, that attempts to use the hydraulic energy, made available when rivers are canalized, may be continued in a way to reach satisfactory conclusions.

## III. — RAFTING

The rafting of wood, after having done such good work, is destined to disappear gradually in favor of other improved forms of transportation. Rafting in large masses, like setting logs adrift in the stream, requires always special works, such as ponds or reservoirs, the straightening of curves, ports, sluices in dams or else special locks, etc. Then too setting logs adrift interferes too much with other forms of water transportation, while the velocity of the current in canalized rivers is so small that the towing of rafts has to be adopted. The logical result of this is the tendency to carry timber in boats rather than to float it. Mr. Ebner's studies on this subject (*Flossschleppversuche in der kanalisierten Moldaustrecke bei Prag*. Zeitschr. des österr. Ing. u. Arch. Ver. 1903 [1]) are well known. In the preliminary studies relating to the canalization of the Elbe in Bohemia up to Melnik and of the Moldau from Melnik to Prague, Mr. Ebner raised the question of replacing ordinary rafting with the partial towing of the rafts by steamboats, or better still with carrying the timber in boats. The results of Mr. Ebner's studies were not favorable to rafting.

Rafting may still deserve even now special attention in coun-

[1] Investigations of the towing of rafts on the canalized section of the Moldau near Prague. Journal of the Austrian Society of Engineers and Architects, 1903.

tries where the trade in and transportation of timber have become very important, as in Scandinavia, Eastern Germany and Russia.

## IV. — DRAINAGE AND IRRIGATION

No work done for the improvement of the navigability of a river or for making it navigable should ever interfere with the water required by agriculture, that is : with the superficial and subterranean water, so that neither drainage nor irrigation should ever be injured.

The raising of the surface of the water which may damage riparian lands is especially to be feared when a river is canalized. As is well known, however, the canalization of the Main has done much toward fertilizing the ground used for growing vegetables, and the same result has been found in other like cases. All the same, works of this sort have done harm in times gone by.

Rivers closed in between high banks and with gentle slopes are best suited to canalization. When, on the contrary, the shores are low and flat, the raising of the level of the stream may place in the way of the running off of the subterranean water such difficulties as to necessitate paying heavy damages to the riparian owners, especially if it be impossible to provide for this outflow a canal which will carry off the superfluous water to points below the dams.

If the rivers carry much matter in suspension, canalization may, by reducing their velocity during small rises, cause deposits of mud, sand and gravel which will raise the bed insensibly, increase the chances of new inundations and cause trouble for the run-off of the subterranean water. This eventuality is greater with fixed than with movable dams. If it be not possible to ward off this trouble by opening the latter works now and then, resort should be had to dredging.

Care should be taken in every canalization not to increase the probability of inundations and not to raise the sheet of subterranean water above the level beyond which agricultural products must suffer. The almost general opinion on this subject is that subterranean waters should lie at least 50 cm. below the level of the soil in the case of meadows and at least 1 metre below the same level in the case of grain fields if no influence hurtful to agriculture is to be feared.

It is well also not to forget, when shores of a river have been raised by successive deposits, that marshes and ponds may be formed at a certain distance from the stream; here again it is well to be on the watch to prevent such things from happening any more.

When dams are under construction, special attention must be given to determining the section required for the passage of the high water. The original section must not be diminished if it be the desire to avoid having more inundations than before. Looked at in this way, it will be well always to place the dams at places where the bed is sensibly flat and corresponds closely with the original bed of the river. And then it will be necessary inevitably to place levees on top of the banks of the river in order to prevent floods, while the effect of the contraction of the stream will be to cause an increase of velocity which will be useful for draining the bed of the river; it will always be necessary to plan and construct the levees in such a way as to provide a cross-section for the flow of the water sufficient to let the highest floods run by, and the crest of the levees must be placed at a height which will give an excess of security.

## V. — RESULTS OF TESTS MADE WITH MODELS, USE OF MODELS FOR THE SOLUTION OF HYDROTECHNIC QUESTIONS.

All the sciences, but especially those which interest the technical knowledge of the engineer owe the greater part of their advance and improvements to the experimental method. Through the search for coefficients of correction, this method has also brought forth the inestimable advantage of banishing empirical solutions by the introduction of others more rational.

In the matter of hydraulics, the application of the experimental method to the improvement of rivers and sea ports has been adopted. For thirty years a solution has been sought for the problem of the action of water on a shifting bottom and for the other, not less important, of the formation of the beds of water courses. And this has been carried still further by endeavoring to reproduce a river in a model built to a predetermined scale so as to study the probable effects of certain works of improvement.

The idea of reproducing a river on a small scale is, probably, very old, but it has only recently been carried out. It dates from 1875, when the happy thought came to Mr. Fargue to propose creating in miniature an artificial river which should represent the conditions of the Garonne.

But the experiments at Bordeaux, like those tried in England, under Reynolds' initiative, for reproducing the estuary of the Mersey, and in France, to study the tidal phenomena in the estuary of the Seine, possessed the defects of all isolated and passing trials. This was well understood by Professor Engels who may be regarded justly as the true propagator of the experimental method. When raised to the professorship, about 1890, he sought to complete the teaching of river hydraulics by experimental demonstrations. After the satisfactory results which he obtained with his modest outfits, the Gorvernment hastened to place at his disposal sufficient funds to build a model laboratory which was finished in 1898.

A similar laboratory was formed in 1900 at Karlsruhe and its direction intrusted to Professor Rehbock. Then the official laboratory was inaugurated at Berlin (Charlottenburg) in 1903, especially for experiments interesting practical hydraulics.

The very satisfactory results of the tests made by Professor Engels in relation to the Weser, the Elbe, the entrance to the Kaiser Wilhelm-Kanal at Brunsbüttel and to the silting up of the channel of the winter harbor at Freudenau are well known, as are also those, not less satisfactory, going on under the direction of Mr. Thiele at Charlottenburg.

Germany has now gone finally and officially into the system of reproducing a river in a model and on a small scale, so as to study the future effects of certain works of improvement. Other countries have followed her or are about to do so. An official laboratory has been constructed in Italy, during recent years, at Stra near Padua. This institution comes under the Magistracy of the Waters of Venice.

The observation has been made, sometimes, that these studies on a small scale cannot always give a complete guarantee of the results. This is what led the late Vernon-Harcourt to say that every river should be the object of a practical study of its own.

Unless there exist already on the river a reach where the natural or artificial conditions are similar to those of which the effects are to be examined, the special practical study of the stream, that is to say : the study which gives the means of understanding the direct effects of the works as well as their indirect effects on the other parts of the river implies necessarily the carrying out of these works.

But this method too, when it is of possible application, is always very difficult to carry out, requires besides a great deal of time and involves great expense. Furthermore, there are cases where this method cannot be carried into effect because the works may lead to such disappointing results that the mistakes made are irreparable.

It follows from this that the study of the effects of any work of improvement cannot always be undertaken on the river itself. But then, as Mr. Alb. Van Hecke has justly pointed out in his interesting work on the experimental method applied to the study of Hydraulics, there is left but one course to be pursued, unless the road toward progress is to be barred, viz : *the artificial reproduction of the stream, at a suitable scale, on which the observations recognized as impossible to carry on, in nature can be made.*

Thence arise the unquestionable necessity and utility of the use of models for the solution of hydrotechnical problems.

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Bologna, Italy, June 1914.