S. I - C. I

The relation between, on the one hand, the form of cross-section, the nature of the ground, the method of revetment and the distribution of the water-velocities in a waterway (*), and on the other hand, the resistance to movement, the efficiency of the screw (propellers) and the permissible speeds of the vessels in relation to the cost of maintenance of the waterway.

GENERAL REPORT

by

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1. GERMANY :

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In the paper by these authors, we first find a discussion of the requisite conditions for the cross-section of a navigable canal.

The large sized German canals are intended for barges of 1000 tons having a length of 67 or 80 metres (220 or 262 ft), a beam of 8.2 or 9 metres (27 or 29 1/2 ft) and a draught of 2 or 2.5 metres (6 1/2 or 8 1/5 ft). The navigation is two-way.

Navigational requirements have gradually led to the adoption of a wet section of 117 m^2. For craft of 8.2 x 2.5 metres the classical ratio n is 5.7; for craft of 9.0 x 2.0 metres the said ratio is about 6.5.

The conditions required for the former category of craft are therefore more onerous.

According to the calculation, when these craft cross each other at a speed of 4 Km/h., they sink about a further 10 cm. into the water. A boat plying alone on the axis of the canal at a speed of 8 Km/h. causes a depression of nearly 20 cm.

At these navigation-speeds the mean velocity of the return-flow amounts to 0.7 m/sec., according to the calculation, both when boats cross each other or when a boat is moving singly.

On large German canals the revetment of the banks consists of rockfill on a layer of rubble, on an incline of 1 : 3. As a rule, the revetment extends to 1 metre above and 1 metre below the normal waterline.

(*) « Waterway » is understood to mean rivers, streams and canals.

On canals carrying a lot of traffic (e.g. the Dortmund-Ems-Kanal), experience has shown that the talus ought to be faced down to the bottom and that they should have an incline of 1 : 4.

On excavated sections the bottom is not protected.

Coarse gravel and marl can withstand a return-current of up to 0.70 m/sec. In their paper, the authors discuss a velocity of the return flow that does not exceed 1 m/sec.

The H.S.V.A. (Hamburg Shipbuilding Test-Institute) recently made some tests on models to find out what advantages might be obtained from a deepening of the Kiel Canal as regards : admissible speeds on the Canal (tractive effort required and depression of the craft), handiness of the craft and the effect of navigation on the canal (lowering of the waterline), velocity on the bottom and erosive action on the talus.

They started on the basis of the present wet section of the Canal which has a surface of 828 m^2, a maximum depth of 11 metres and a width on the bottom of 44 metres. A deepening to 14 metres, which produces a width on the bottom of 14 metres, gives a wet section of 915 m^2, so that an increase of the depth of the water of 27 % produces an increase of the section of 10 %.

As a typical craft they selected a tanker of 158 m. length, 20 m. beam, which was subjected to draughts of 6.0, 9.5 and 10 metres.

The tests covered seven section-profiles, in order to also study the influence of forms. They obtained the three first profiles (in addition to the present profile) by deepening to 11 to 12, 13 and 14 metres.

For profiles of the same value of cross-section they found that, with equal resistance, the speed increases when the width of the waterline decreases, i.e. the rectangular section is the most advantageous and the trapezoidal section is the least advantageous.

From the aspect of the diagrams of actual tractive efforts by the aforesaid craft, it is possible to draw the conclusion that, from the navigational standpoint, there is no advantage in navigating at speeds that require considerably more than 100 E.P.S. (effective HP) tractive effort, equivalent to a propulsive power of about 200 EHP.

For a constant effort of 100 EPS developed on the boat, we can deduce, as a result of the tests, that for the same wet section of the canal the relative value, as regards the speed reached, is (having set the value of the trapezoïdal profile as = 100) : 101.5 % for the parabolic profile; 105 % for the rectangular-trapezoïdal profile; 106.5 % for the rectangular profile.

In a restricted wet section the running-speed is affected by the velocity of the translation-wave.

And finally, it can be said that the tractive effort required for a craft navigating along a canal depends above all on the velocity of the translation-wave and the ratio u . For ratios of more than 6.5 it is only the velocity of the translation-wave that is practically the dominating factor.

Tests made to define the effect of the propeller on depression of craft show that at low speeds the bow of the craft inclines downwards. After exceeding a speed of about 0.5 of the velocity of the translation-wave, for deep draughts, and about 0.6 for slight draughts, it is the stern of the craft that inclines downwards, and that is much more appreciably so for small than for deep draughts.

For an identical speed on a canal, the extent of the greatest depression lessens when the depth of water increases and when the wet section also increases and, for an identical wet section, the depression lessens with the width of the water-line.

Steering tests were also made, with a view to safety of navigation, the aim being to ascertain the requisite effort to keep a craft on a straight line through successive different profiles.

As to the effect of the size of the cross-section on steering, it was ascertained that, with a given draught, a craft steers all the better when the cross-section of the canal and consequently the depth of water are greater.

As regards the effect of draught, it was found that boats steer better with a slight draught, i.e. with a high ratio of **n.**

Moreover, boats steer better in a rectangular profile. In a decreasing order, there follow the rectangular-trapezoïdal and the parabolic sections.

Nevertheless, the differences are so slight that they do not enforce the selection of one section in preference to another, if other more important reasons dictate the selection.

As to the effect of navigation on the canal, they first of all measured the velocity of the return-flow near the bottom of the canal (by means of a Pilot tube) when boats were passing. The tests and the measurements were made with propulsion by propeller and without propeller propulsion.

The return-flow is greater in the first instance and there is a slight lack of symmetry as regards the axis of navigation.

It was noticed, for example, that at a return-flow velocity of 1 m/sec., 40 % is due to the effect of the propeller (without shield).

The velocity of the return-flow created by small propellers revolving at a high rate is greater than that caused by large propellers revolving slowly.

With an identical wet section and an identical depth of water, the velocity of the return-flow is only affected to a very slight extent by a change of profile in the canal.

A reduction of the velocity of the return-flow is obtained more efficaciously by adhering to the same wet section, but increasing its depth. The same advantage is obtained by keeping to the same depth of the canal, but by increasing its wet section. Of course, the greatest advantges are obtained from a simultaneous increase of the wet section and deepening of the canal.

As regards the erosive effect of navigation on the banks, it was wished to ascertain whether the protected part of them, mentioned earlier, was sufficiently extensive if the canal were deepened and the wet section increased.

When proceeding to make undermining tests, they removed, on certain sections of the canal, the concrete revetment and replaced it by coarse sand. Then they subjected the aforesaid revetment to the effects of high-speed navigation (50 voyages) and at the same time they kept the draught and speed constant on each section investigated. These tests showed that the undermined surface of the section and the extent of the attack increase constantly with the number of voyages made. Below a certain water-level the undermined material deposits again.

At speeds that are practically realisable the attack does not extend beyond 0.70 metres downwards. That is why they were able to conclude that a rubble revetment between the limits of ± 1 m. is sufficient if the traffic plys along the axis of the canal. But if a craft diverts towards the bank, the attack on the talus goes deeper. To counteract that, it is considered advisable, if possible, to extend the protection of the talus to 3 metres below the water-level.

The more a boat is immersed, the more pronounced the attack on the talus becomes. That is a consequence of the fact that the height of waves increases correspondingly.

From the tests as a whole we can deduce that, from a navigational standpoint, a rectangular profile of the section is the most favourable solution because it enables the most economical use to be made of the tractive effort and, from a maintenance point of view of the canal, the parabolic profile is the best solution because it causes the slightest attack on the bed of the canal.

Having also sought the greatest depression of the water-level along the banks, comparisons were made between the results of calculation and of the tests.

At low speeds, the greatest depression of the water-level occurs at about the centre of a craft; when the speed increases, it moves more and more towards the stern, and at high speeds it becomes visible in a much depressed form of the cross-current astern.

The depression caused by a craft has a very varying repercussion on the banks, according to all the elements in play and which affect the size of the return-wave. The depression of the water-line on the slopes, within the scope of speeds that we have for large depressions, corresponds roughly to the depression shown near the centre of a craft. On the contrary, for higher speeds of boats and with small draughts, the phenomenon is more uncertain, and all that would agree with the characteristics of the velocities of the return-flow.

The paper ends with a few specific considerations concerning the effect of the shape of the cross-section on maintenance costs.

2. — BELGIUM :

M. G. Willems, Directeur Général des Ponts et Chaussées et de l'Administration des Voies Hydrauliques, Professeur à l'Université libre de Bruxelles.

M. De Rudder, Ingénieur en Chef-Directeur des Ponts et Chaussées. Directeur Général de l'Office de la Navigation, Liège :

M. Van Cauwenberge, Ingénieur en Chef-Directeur des Ponts et Chaussées, Chargé de cours à l'Université de Gand.

These authors commence their paper by pointing out the great importance of inland navigation in Belgium because there are 5 1/2 Km. of canals to 100 square Kilometres of land. In 1952 this traffic amounted to about 40 million tons, viz. more than half the tonnage carried by the railways.

They point out the importance of certain details of the shape of the cross-sections of waterways to navigation. The maximum practical speed of craft is determined in function of their dimensions. The Gerbers-Engels formula was checked by tractive tests made on the Canal Albert. Information is given as to the methods of protection of banks.

Navigable waterways in Belgium have a total length of 1649 Km. After completion of improvement works now proceeding on the Meuse, the Sambre and the Upper Scheldt, 19 % of the navigable waterways will be suited to navigation by craft of 1350 tons, 34 % to boats of 600 tons and 38 % to boats of 300 tons. The remainder of the network, viz. 9 % of the total length, of a gauge of less than 300 ton-craft, is not much used. The peripheral canal round Ghent can accommodate barges of 2000 tons.

The paper includes drawings of the cross-sections of several canals of the aforementioned dimensions and supplies statistics of the present Belgian fleet, representing a total tonnage of nearly 2 1/2 million tons.

The authors go into a detailed study of the movement of a craft on a navigable waterway. Presuming that the movement takes place in a canal on which the water has no velocity of its own, starting from the equations of Bernouilli and Castelli and following an original method, they succeed in calculating the value of the return-flow and the depression of the level in function of the absolute speed of the craft and the geometrical elements of the section.

The result shows that, among all the sections having a given wet surface, the one of which the mean depth is the greatest gives the least resistance to the advance of the craft and that to lessen the tractive effort the largest possible wet surface is required.

A rectangular section clearly fulfils the said conditions ; but, with the exception of a few particularly favourable places, the creation of such a section is uneconomic. It follows that in most instances more or less inclined slopes should be constructed, which can withstand the breaking of the waves and which must be suitably protected.

Basing themselves on the formulae of Krey and Schijf, they discuss the depth which the water should have close to the bank in order to prevent breaking of the waves and they give the extent of this depth for speeds comprised between 1 and 3.5 m./sec. and for ratios n comprised between 5 and 10.

Next they calculate the energy P of a wave capable of destroying the talus. This energy increases rapidly with the speed v of the craft but decreases when n increases. They draw a diagram giving P in function of v for different types of craft plying on the canal Albert.

They state that the Gebers-Engels formula, giving the resistance to movement in function of the speed of the craft, is only valid for moderate speeds. When the speed approaches the critical speed, the phenomenon undergoes a change and the resistance to advancement increases much more rapidly.

That speed cannot be exceeded by self-propulsion and only if the craft is hauled from the bank. For speeds of more than the critical speed, the depression of level disappears and there is a superelevation of the water in front of the boat, which sets up an intolerable increase of the resistance and consequently of the tractive effort.

As to the speed of the boats, it is pointed out that it is very difficult, even in the case of supervised navigation, to have reliable data because the speeds are affected by the intensity of the traffic and therefore by the frequency of crossing and overhauling.

A pertinent example is given by the ratios between the average speeds including stoppages and the authorised speeds on the Canal Albert for barges of 300, 600, 1350 and 2000 tons ; they are respectively : 0,9, 0,7.5, 0,6.5 and 0,4.

Banks must be protected against damage caused by rippling, by the return-flow, by rain, and by lowering the ground-water, by creating along the banks a sufficient depth of water to prevent waves from breaking and by ensuring a sufficing stability by consolidating the talus under the water if the return-flow is capable of washing them away.

Three main types of bank-protection can be quoted : screens of sheet piles, pitchings with or without benches, revetment of talus.

Protection by means of a screen of sheet piles, anchored or otherwise, of various types, surmounted by a masonry pitching or turfing, is very expensive but it has the advantages of durability, perfect stability of the banks, of less resistance to advancement of the boats and better laying alongside.

They give examples of consolidation of the talus created on the Terneuzen and Ghent-Bruges canals.

As everything is very expensive, protection by sheet piles has the advantage of practically no expense for maintenance.

Revetments of stony materials give satisfactory stability provided they are well laid on piles, on trestles or else on a beam resting on the ground and fitting a berme at a certain depth below the water-line.

As a rule a revetment of this type rises to about 1 metre above the water-line.

The authors next mention consolidation of the talus created on the Bocholt-Herenthals canal. The concrete revetment rests on a screen of sheet piles behind which a gravel drain is placed. The berme is situated at 40 cm. beneath the water-level and the upper part of the talus is protected by turfing.

They point to the constantly increasing use of bitumen to consolidate slopes, as they have the advantage of : elasticity, watertightness, absence of joints, durability and economy.

Again, on the Nimy-Blaton canal, on embanked sections the revetment of the slopes consists of a layer of bituminous mastic 6 cm. thick placed on top of a layer of 10 cm. of asphaltic concrete. The bituminous mastic consists of 74 % of sand, 13 % of filler and 13 % bitumen. The asphaltic concrete consists of 47.5 % of rubble, 28.5 % of chippings and 19 % of sand with 5 % of bitumen. The revetments must be stable of themselves or else anchored by pickets.

If fascine-work loaded with rubble is used, a breaking of waves is almost certain to be caused. For that, concrete and bituminous carpeting revetments are adopted nowadays.

The Canal de la Nethe was revetted with concrete at the rate of 250 Kg. of cement per cubic metre.

The comparatively steep banks of the canalised Sambre are protected by a layer of concrete 60 cm. thick.

The bituminous carpetings have a thickness of 5 to 10 cm. They comprise a central reinforcement of jute or metal trellice-work, round which is poured a bituminous mortar (e.g. 12 % of bitumen, 22 % of filler, 66 % of sand). These carpetings are suspended from cables fastened to the reinforcement. They can be wound on large drums to facilitate their transport.

Next we have results of studies and tests made in Belgium to establish the ratios between the shape of the cross-section of canals and the resistance to advancement of boats. These results were published in articles in 1935, 1939 and 1949. Details are given of tests made in 1952 on boats plying on the Canal Albert, by the Office de la Navigation and the

Service d'Etude des Ouvrages d'Art de l'Administration des Voies Hydrauliques. These tests were made on a sector where the wet section of the canal had a surface of about 150 m^2 and a width on the water-level of about 47 metres. They used boats of 300, 600, 1350 and 2000 tons and a standard tug. These tests are particularly interesting because they were made at various speeds and consequently they enable the terms and coefficients of the Gebers-Engels tractive formulae to be checked. In that formulae the value of the coefficient varies between 0.14 and 0.28 and that of K between 1.7 (for a craft with fine lines and empty) and 3.5 for a laden craft of a massive shape. Now, the values of λ and of K which were found during the tests on the Canal Albert are all situated between the extreme values given by Gebers-Engels, because λ remained between 0.14 and 0.27 and K between 1.7 and 3.4.

They also proceeded to determine the output of the propellers of the various craft and at various speeds (from 1.55 m/sec. to 2.81 m/sec.) and they adopted the value 0,9 for the mechanical efficiency of the transmission of the motive power to the propeller-shaft. They found efficiency-values of about 31 % to 44 %.

And finally, they studied the resistance to going ahead encountered by a craft advancing on a circular curve To simplify the question, we presume that the craft is plying on an unlimited sheet of water. By setting the problem in the form of an equation it is possible to ascertain the increase of the propulsive power required. The applying of the formulae to the current types of craft of 300, 600, 1350 and 2000 tons, for a speed of 1 m/sec. and for the practical minimum radii of curve, shows an increase of the propulsive power of about 15 to 20 % as compared to the power required to drive a craft in a straight line. The increase of the propulsive power drops rapidly to negligible values, as soon as the radius of curve increases somewhat. That is why tolerable minimum radii should not be used except in case of absolute necessity.

3. — U.S.A. :

Mr. **Albert J. Dawson,** Chief Engineer Marine Department, Dravo Corparation, Pittsburg,
and

Colonel Conrad P. Hardy, District Engineer, Pittsburg, Corps of Engineers U.S. Army.

The traffic recorded on the rivers of the United States in 1950 can be summarised as follows :
341.130.000 tons ; 40.465.932.000 ton/miles.

In the inland navigable network of the U.S.A. that of the Manongahela-Ohio is very important because these rivers are entirely canalised and because they have a system of reservoirs to control floods and permit navigation throughout the year.

The paper supplies information as to the navigable conditions on the two rivers, discusses the economic limitations due to those conditions and draws conclusions as to the possibility and extent of an ulterior development.

The hydrographical basin of the Ohio covers an area of 203.900 square miles and that of the Monongahela 7.380 square miles.

The necessity and importance of improving navigation conditions were recognized in 1824 when the Government granted the first credits. A considerable progress was achieved when the Louisville-Portland canal was constructed in 1830.

The first dam and the first lock were inaugurated in 1885. The complete canalisation was finished in 1929. Canalisation works on the Monongahela were commenced in 1839 and the first series of dams for navigation was completed in 1884. Navigation on these two canalised rivers, for the period 1930-1950, amounted in short tons (1 short ton = 907 Kg. or 2000 lbs) to :

OHIO : year 1930 : 22.300.000 T. (roughly)
year 1950 : 48.600.000 T. (roughly).

Total for 1930-1950 : 628 million T.

MONONGAHELA : year 1930 : 25.800.000 T.
year 1950 : 28.500.000 T.

Total for 1930-1950 : 507 million T.

When the requirements for the transport of goods on a waterway have been defined, the problem of the extreme capacity of the fleet depends on the following conditions : hydraulic feed ; inclines and flows of the water ; depth to the bed ; surface of the cross-sections ; minimum radius of curves ; capacity of the locks ; economy of towage.

As regards hydraulic feed, the authors show in a Table the maximum and minimum discharges of the Ohio and a few tributaries, as they are regulated for irrigation and reservoirs.

The capacity of the reservoirs now regulate floods and the discharges used for navigation and have rendered the use of dams superfluous in the Ohio below Louisville, during a period of four or five months in the year.

The inclines do not exceed 9, 10 or 15 cm. per mile on the Mississippi at Wheling, about 27 to 31 cm. from Wheling to Morgantown on the Monongahela and it is only from this locality to where navigation starts that the incline reaches 65 cm. per mile.

When the weirs are lowered, boats can safely ply up to the maximum velocity of about 2 m/sec. During the 1937 floods near Cincinnati it was found that the maximum velocity on the Ohio was about 4 m/sec.

As a result of canalisation, the mean depth of the Ohio is about 4.90 to 5.50 metres. That depth enables boats to have a draught of up to 2.75 m. In the Monongahela the average depth hardly exceeds 2.75 m.

The surfaces of the cross-sections of the Ohio are such that the ratio n reaches the values of 7.5 to 13.4. Nevertheless, even when the latter value pertains navigation is not appreciably hampered, as craft proceed downstream laden and return upstream empty. Consequently, when barges cross each other the resistance to plying does not increase to the same extent as if two laden trains crosses.

On the upper reaches of the Monongahela navigation is more difficult and the traffic is very slight.

The minimum radii of the three sharpest curves on the Ohio are : 550 metres (angle 137°), 610 m. (angle 91°), 671 m. (angle 117°). Trains of barges scarcely ever exceed 366 m. in length. They can ply in two rows in the locks of 183 m. Fortunately, the section of the river near the curves mentioned is sufficiently wide to permit navigation at normal speed.

On the lower reaches of the Monongahela there is the Greenfield curve (50 miles above Pittsburg) which is characteristic. It has approach radii of 945 - 1052 m. and a minimum of 366 m. with a total angle of 180° and a minimum angle of 90°. To negotiate this curve requires skilful steering. In spite of that, trains sometimes have a length of 200 metres.

On the upper reaches of the Monongahela there are some very sharp curves, for instance: a radius of 228 m. and an angle of 68°; a radius of 185 m. and an angle of 95°. Consequently, navigation is very difficult.

As regards the capacity of locks, some very detailed figures are given of the locks on the Ohio and Monongahela, viz. the maximum number of times a lock can be negotiated in 24 hours; the average load for each passage (presuming one direction for laden craft and another for empty craft); the annual capacity of the locks expressed in tonnage.

The primitive locks on the Ohio. that had small rises (Amer: lifts) of 1.80 to 2.70 metres, have been successively changed and now rises of even close upon 8 metres are reached.

When canals were arranged, they always built temporary locks in order not to have to interrupt traffic when the final locks were in course of construction.

The progress achieved by technique shows more than ever the advisability of increasing the capacity of the locks and consequently the length of the reaches between two locks.

The four dispositions made on the Ohio on these lines have given such satisfactory results that permission has been given to build three other locks which will replace the twelve small locks in existence.

The example of the Montgomery weir, which regulates a stretch of 18 miles and has replaced three minor weirs, is stressed. The ratio between the depth of water and the draught of craft has increased from 1.61 tot 2.19 and the ratio *n* from 14 to 23.9.

By the regulation made, on the stretch of 18 miles an increase of traffic of 36 % in ton/miles has been achieved.

As a result of the achievements during many years of navigation, the programme for the future comprises:

1) the increasing of the rises (lifts) of dams, as and when delapidation of the structures make that necessary;

2) the increasing of the length of the locks. For those on the Ohio the length will be increased from 188 to 366 metres, so as to allow a whole train to pass through in a single locking. The time saved will be about two thirds;

3) the increasing of the average depth of the bed which will be at least 3.70 metres.

The results obtained after completion of this programme are expected to bring about an 80 % increase of the total capacity of each locking and an increase of 18 % of the average load of the barges. The cumulative effect of these creations will mean an increase of the capacity of the locks from 51.400.000 tons to 108.800.000 tons, if we admit a draught of 3 metres, or up to 125 million tons for a draught of 3.50 m.

1. — FRANCE.

M. Leroy, Ingênieur des Ponts et Chaussées, Sous-Directeur de l'Office National de la Navigation, Paris.

These factors of resistance increase remarkably and progressively when menae that accompany a boat in motion, either in a unlimited area of water or in restricted waters.

In the first case you have two sets of oblique and cross-waves which interfere with each other ; in the other case the cross-waves tend to disappear and become oblique waves which, when the speed increases, unite at the bow and at the stern. If a vessel reaches the speed of a solitary wave, then the water runs perpendicularly to the vessel.

In restricted areas of water, by the effect of proximity of the bottom there is set up an acceleration of the water as compared to the vessel and round about it, with a loss of load and depression of the surface of the water.

The resultant return-flow is strengthened or weakened according as to whether the vessel is plying upstream or downstream. The depression of the water-line is influenced in the same way.

In a similar manner, the waves created by the ship are braked by the current going upstream and accelerated going downstream. In the first case they become higher whereas in the other case they acquire a greater velocity. It is the latter that acts in a preponderating way on the banks. The phenomenae we have just discussed increase owing to the fact of the restriction of the section. The return-flow then makes itself felt over the whole length of the vessel ; it is greatest in a zone situated longitudinally towards the centre of the craft and transversally about half way between the craft and the bank. If the width of the water-level is fairly large, there is a certain uniformity and account can be taken of a mean velocity of this return-flow.

In the paper there is a mention of tests now being made at the Grenoble Hydraulic Laboratory on behalf of the Suez Canal C° for the purpose of verifying and coordinating the experimental data which it already possesses as regards hydraulic effects and erosion due to the passing through the canal of ever larger ships.

The model of the canal was made on a scale of 1/25th. In respect of the model-ship, the ratio $n = \frac{F}{f} = 4.7$ which is very near those found on French inland navigable waterways.

In function of the velocity, they recorded the variations of the return-flow and the depression of the water-level for instances of self-propelled craft and towed craft.

Within the limits of normal usage, the depression of the water-line is about 10 % greater for self-propelled craft than for towed craft.

At a speed of 15 Km/h the depression of the water-level very much exceeds 1 metre, which causes very remarkable attacks of the bank. The velocity of the return-flow would exceed 2 m/sec., viz. half the speed of the craft.

As to resistance to movement of a craft in deep water, it is pointed out that it is caused by waves, by eddies and by friction.

The former increases with the speed ; the second increases approximately as the square of the speed ; the third depends on several elements (see Besnerais' formula).

These factors af resistance increase remarkably and progressively when boats cross either on a river or a canal.

Before passing on to a discussion of the various elements which practically condition the determination of the resistance to movement the author discusses the question of the common factor of selection of the shape and dimensions of the boats.

We clearly see that speed is not the only factor that determines the advantage of inland water-carriage, but rather the resistance per ton burthen. It has been proved that for craft moving at a low rate of speed this resistance depends very little on the lines of the craft and much more on the ratio *n*.

In his analysis of the resistance to movement by a boat on a river, he takes into account the influence that is exerted by the depth of the water, by the incline and by the distribution of velocities. The depth acts very appreciably both on the resistance to movement and on the efficiency of the propulsion. The first factor predominates the second ; the increase of resistance (for most river boats) is 10 % when the ratio of the depth to draught is equal to 3 and this percentage rises to nearly 100 % when the ratio is less than 1.25.

On this question, the paper gives the characteristic results of tests made on the Rhone and on the Rhine at Strasbourg from 1948 to 1952.

The incline of the river adds its own effect to the other particularities of a waterway. In the upstream direction it causes an additional resistance, whereas in the downstream direction its effect is to increase the velocity (on the Seine a few cm/sec., on the Rhine or the Rhone nearly 1 m/sec.).

The distribution of velocities has no appreciable effect on ordinary canals nor on canalised rivers, except at flood times.

But the effect of the distribution of velocities is fairly marked on rivers having a free flow and where the velocity may vary appreciably (for instance, at Strasbourg on the Rhine the velocity varies in a ratio of 1 to 2, from the bottom to the surface of the water).

That is why it is very difficult to speak of the ratio between the velocity of a current and the speed of a craft.

What one actually determines is the mean velocity of the flow and a corresponding average speed of a boat, including stops.

In dealing with the question of canals the author makes comparisons, for various French canals, of the influence of the ratio *n* and he draws the following conclusions :

1) that on the old canals a ratio n = 3.3 causes a resistance four times that on modern canals ;

2) that on canals where the ratio *n* is less than 4 it is impossible, in actual practice, to exceed a speed of about 4 Km/h. and that in order to reach speeds of over 6 Km/h. it is necessary that the ratio *n* should have values comprised between 7 and 10. The effect of this ratio makes itself felt very noticeably on crossings and overhauling.

As to the shape of the cross-section, the author points out that, theoretically, for a given section and for a contant velocity the return-flow and consequently the resistance to movement vary in the same sense as the width, i.e. in an inverse ratio to the depth of the section.

In practice, that is also confirmed by the results of tests made recently on the Seine, in the Joinville tunnel and on the Vaires canal.

These results agree perfectly with those of an investigation made in 1937 by the Bassin des Carènes at Strasbourg and with the results of tests made on the Suez Canal.

All the observations therefore agree in confirming that in the cross-section the depth of the water plays an essential role.

Since it is incontrovertible that, given an equal wet surface, it is the rectangular section that is the most favourable, if one passes on to a trapezoïdal section one notices that when the banks have slopes of 3/2, the section is nearly equivalent to the rectangular profile and that a profile having a talus of 2/1 would be a little less satisfactory.

In any case, the difference is not very appreciable if the width is fairly large and it disappears when the ratio *n* exceeds values of 7 or 8.

As to the influence of the soil in the banks on the resistance of the incline, this resistance can be considered as practically nil on ordinary inland canals. This conclusion was reached after tests carried out on the Canal des Houillères de la Sarre (Sarre collieries) and on the canal de Briaire and the canal de Roanne.

When everything is weighed up as regards economy of transport, the task should be to lessen as far as possible resistance to movement.

Consequently it is necessary to seek an improvement of boats' lines to keep in touch with a progressive increase of speeds.

On another hand, care should be taken to see that boats are well adapted to the navigable waterways on which they are to ply. In case of need, the characteristics of loading should be changed, viz. the ratio between the draught of boats and the depth of water available. And finally, a study should be made of the arranging of canals so as to obtain a ratio *n* of more than 5 for canals and a ratio of more than 1.5 between draught and depth of water on canalised rivers.

The phenomenae of erosion of the bed and banks are caused by hydraulic movements (eddies, return-flow, depression of water-line) and the action of propellers.

The action of a propeller is not of great importance when a craft plies along the axis of a navigable waterway but it can become dangerous when a craft approaches the banks unloaded and harmful to the bed when it is a case of craft laden.

The action of propellers is most intense when a craft starts up or increases its speed.

Nevertheless, the major erosive effects are due to hydraulic disturbances. Their energy changes into action against the banks but this transformation will be all the slighter when the prior dispersal of energy is greater. It follows that the phenomenon of erosion is of lesser importance when the section is greater.

If, on a navigable waterway, craft are driven at a speed that is incompatible with the wet-section, it becomes apparent that the latter adapts itself to the creation of a sufficient wet surface by setting up erosion. If the profile is trapezoïdal it finally changes into a parabolic profile by laying bare the bank-protections, easing the talus and making the bottom oval.

On canalised rivers, erosion caused by the plying of craft is usually exceeded by erosion caused by natural phenomenae such as floods, as soon as the current exceeds the velocity that can be withstood by the soil of which the bed consists.

On rivers having a free flow, boats running dowstream at high speeds cause serious damage to the protective pitchings and also to the groins over which they pass at high-water times.

In conclusion, with the exception of the action of propellers, the hydraulic phenomenae which cause erosion are effects that increase with the speed and the value of the ratio n. Consequently, if it is desired to maintain the speed without damaging the substructure, the banks must be properly protected or else the navigable waterway must be so arranged as to increase the value of the ratio *n*.

The former solution is not very satisfactory because, in effect, it does not act on the cause and does not produce any noticeable advantage as regards resistance to movement.

In the second instance, as the author remarks, it is not always possible to re-arrange or widen the waterway. That is why, in some cases, it might be advisable to enforce restrictions of speed, according to the loading of the boats.

The various conclusions can be summarised in a twofold proposal : craft should be adapted to the navigable waterways on which they usually ply and inversely the waterways should be suited to the traffic they have to carry.

The former proposal concerns owners of craft and the latter concerns the public at large.

5. — ITALY :

Dr. Torquato Rossini, Ingénieur en Chef du Bureau d'Inspection du Po.

The subject set for perusal when planning a navigable waterway has a different effect when it is a matter of a natural stream to when it is a matter of a canal. As regards navigable rivers, the shape of the section is made in accordance with their layout and physical characteristics, whereas for canals the determinating factors are : velocity of the water, dimensions of craft extent of the traffic and nature of the surrounding soil.

Without stopping to discuss the well known formulae used to decide the section of canals, the author recalls the sections which offer the least resistance and are therefore the most advantageous. He explains the reasons for which the section of minimum resistance is chosen, viz. usually a trapezoïdal shape, in regard to a first group of passive coefficients, i.e. nature of the soil, consistancy of the banks, altimetry and consequently the incline and velocity of the water ; and to a second group of active elements : means of transports and systems of propulsion.

He next discusses the movement of water in canals and the resistances according to a coefficient of form, which practically is replaced by the mean radius. He consequently discusses the question of the resistance set up by craft in motion ; the more noticeable resistance of friction, eddies, wake and waves, as well as the lesser resistances. These resistances are compared to the effort required to keep a boat on its course when encountering a current that is the resultant of the flow of the water and the speed of the boat.

He refers to Froude's and Gebers' formulae for friction and Taylor for resistance of waves. He draws the conclusion that in order to reduce these resistances it is advisable to make the sections of canals as large as possible.

The tests made by Du Buat show that the resistance of a boat to movement is, within certain limits, independent of its length and that the more dangerous disturbance to canal banks is that of the wake of the boat, whereas the systems of propulsion only have almost negligible direct effects. This effect of wake (or wash) is directly proportional to the speed of the craft and its fine lines and inversely proportionate to the length of the craft and the surface of the canal's section.

The author discusses the various systems of propulsion, not forgetting that for inland navigation reasonably low speeds are the rule.

The efficiency of a propeller is considered in respect of local conditions, i.e. the canal's section and the depth of water beneath the ships' keel. A reduced depth lessens the efficiency all the more when $\frac{V}{\sqrt{L}} = 1.63$ (V being the speed in knots and L the length of the boat in metres). This condition is verified in inland navigation, for which this coefficient has the value of $\frac{3}{\sqrt{60}}$ = about 0.40.

The coefficient of wake is sought in respect of the data of speed of the propeller and the ship, the pitch and number of revolutions of the propeller and in function of regressions of the propeller ; normal, real and apparent.

The value of the coefficient of wake is found in special Tables which give, in function of regressions of the propeller and its pitch $\frac{p}{D}$ (p = pitch of the propeller an D the effective effiency, as well as the ratios C_A and C_D used by Froude calculating propellers.

The author discusses the possibility of propulsion by means of an aerial propeller which is considered only realisable on canals having very favourable conditions because it is a matter of high rates of speed and craft having particularly fine lines. As already stated, these characteristics are directly proportional to the dangerous effects of wake and are consequently capable of disrupting the banks and bed of canals.

For the moment it appears that the above system of propulsion and the system of reaction by turbo-jet cannot yet be applied practically, also on account of lack of experimental data.

The conclusion is reached that, for navigable rivers, the surface of the cross-section, the protection of the banks, the layer of water beneath the keel and other elements are not fixed as regards navigation, but that on the contrary they depend on the physical characteristics of a river, viz. the velocity of the water, the nature of the soil, the stability of the bed, the undermining of the materials etc. All these elements may or may not permit the arranging of a river for navigation.

On the contrary, for canals to be built for navigation, it is considered that it is necessary to adhere to the following main rules :

a) Trapezoïdal sections ;

b) Surface of the wet section, as far as possible, more than 5 times the midship frame of the boats ;

c) Talus with slight inclines. For their protection, pitchings and turfing are considered sufficient ;

d) The layer of water beneath the keel should never be less than 1 metre ;

e) The maximum speed should never exceed 0.50 m/sec. ;

f) Banks having a concave surface and those where waves form should always be protected ;

g) The radius of curves should never be less than 1000 metres. There should always be a long transitional section from curves to a straight section.

6. — NETHERLANDS :

Messrs. Jansen, Conseiller du Rijkswaterstaat ; and
Schijf, Ingénieur en Chef du Rijkswaterstaat.

In the Netherlands there is a tendency to constantly make use of faster craft, as far as their dimensions, the form of the canals' sections and protection of the banks allow it to be done.

A self-propelled craft cannot exceed the speed which the power of its motors provides. But if it is towed from a towpath it can, theoretically, exceed that speed-limit (see the Dutch Report presented at the XVII Congress).

The value of the speed-limit depends on the ratio between the midship-frame of the craft and the canal's section, as well as on the average depth of the water.

Consequently, if higher speeds are to be reached, the canal must have sufficiently large sections, suitable depths and banks that are suitably protected.

Under such circumstances the cost of running boats is lessened, whereas the cost of the waterway is increased. An economic balance could be struck if one knew in advance the development of future traffic.

As the Dutch canals were built in different epochs, they inevitably have traffic limits. The modern canals can accommodate barges of even 2000 tons, but with a few elementary restrictions as to speed, taking into account erosion of the banks because they often consist of friable soil.

The Dutch inland navigation fleet is very varied, extending from the old scows to more modern types of craft.

The traffic shows very important figures in comparison to goods carried by rail or by road. In 1951 the percentage were : 38 % by water, 15 % by rail and 47 % by road (in tons carried). In t/Km. 52 % by water, 32 % by rail and 16 % by road.

In the Dutch paper presented at the XVII Congress the movement of the water caused by a craft in a canal and the accompanying phenomenae were explained on the theoretical plane, admitting a few hypotheses to simplify the questions.

Next, the results thus obtained are discussed in the light of results obtained from tests made with the aid of models and observations in nature. The tests were made in the Dutch laboratories for Naval Research and in the

David Taylor basin, whilst the observations from nature were made on the Amsterdam-Rhine canal. They also used an observation made in the Suez Canal. The results confirmed the existence of a natural speed-limit for self-propelled craft. In a few tests on models they came very near the theoretical limit but it was not exceeded. On another hand, that limit was slightly exceeded during the tests on the Amsterdam-Rhine canal and on the Wilhelmina canal.

Checking of the depression of the water-line was deduced from tests, with the aid of charts in which there was placed as ordinates the ratio between the recorded depression and the calculated depression, and as abscisses the ratios between effective speeds and the extreme speeds.

From that they came to the conclusion that the depression of the water-line is not uniform over the whole width of the canal (as had been allowed in the calculations) but, on the contrary, that the depression was deeper near the vessel and less so near the banks. The difference is all the greater when the width of the canal is larger.

As a rule, the value ρ tends to increase as it approaches the speed-limit. According to the above mentioned tests, the authors feel they can admit, for the depression of the water-level near the banks, a value of ρ that is comprised between 1 and 1.4, whereas for depression of the craft limits of $1.2 \div 1.6$ must be reckoned.

For a keel of a hydrodynamic form the theoretic difference of value is slight ; in that case ρ will be approximately the value 1.

In the case of a hauled craft the depression of level is 8 to 15 % less than what has been found for self-propelled craft.

The paper also contains comparisons between the resistance to movement in an unrestricted area of water and the resistance to movement on a canal. The latter is higher than the former.

The additional relative resistance (i.e. the ratio between the difference of resistance on a canal and that in an unrestricted area, divided in the case of the latter) has been found to be even three times the resistance in an unrestricted area for an equivalent speed.

When on a canal there is an ordained speed, the results are still valid provided account be taken of the values of the relative speed.

For the purpose of avoiding restricted traffic-speeds on waterways that have an ordained speed, ample cross-sections must be adopted in order to increase the speed-limit and lessen the resistance.

In canals that have an ordained speed, the velocity of the water near the banks during the passing of boats is the total of the return-flow and the ordained speed.

As to the conditions of craft in movement, the craft alone is considered, whether it can follow the canal's axis or wether it cannot do otherwise than approach one of the banks. The difficulty of navigation in the latter case is stressed.

Next, the paper discusses the running of boat-trains, crossings and overhauling. At the moment of crossing or overhauling the two trains are obliged to move aside and each of them is subjected to the effects of approaching the bank, currents and rough water caused by the other train. In crossings this disturbance is less prolonged than in overhauling and the difficulties can easily be overcome.

In overhauling, on the contrary, the difficulties increase especially when the speed of the two trains is about equal. When that happens it is advisable that the train having a lesser speed should still further reduce it, in order to shorten the critical moment.

Economy of transport is, after all, based on the possibility of creating conditions that are favourable to fast navigation. It follows that the principal factor is the canals's section. The author points out all the conditions that must be complied with by the cross-section to reach higher speeds, to regulate the depression of the water-line and the return-flow, to assist intensity of traffic as regards crossings and overhauling. As a conclusion, the author states that owing to the complexity of the conditions with which a canal must comply, from the standpoint of economy of present traffic and traffic to be anticipated in the future, general rules cannot be framed. The question must be studied for each individual case.

He merely remarks that the more important question is that of the probable necessity of future enlargening of the waterway. From that point of view, a canal of great width and with a comparatively shallow depth has the advantage of its section being increased by dredging, without having to have its banks altered.

In the past, in the Netherlands, protection of banks was ensured by economic means in keeping with the type of craft used and the extent of the traffic. With the progress of speeds, dimensions of craft and traffic, it became necessary to carry out extensive alterations to the protection of banks.

The attack on canal-surfacings is caused by rough water and the return-flow. The revetment of banks is but the protection of a talus or embankment, intrinsically solid, to a height of the area liable to be damaged. A distinction must be made between rigid and flexible protections, as also between impermeable and permeable protections. The reasons for selecting one or the other are evident. In all cases, the base of the revetment must be ensured. A permeable revetment is not subject to hydrostatic pressure, whereas the contrary applies to an impermeable revetment. The static conditions depend on that.

Consolidation-works can be made by screens of sheet piles, anchored or otherwise, or by walls resting on piles. Those are usually impermeable works. The combining of consolidation and revetment works is fairly frequent in the Netherlands. This question was fully discussed in a paper handed in to the XVII Congress at Lisbon. A few types of modern protection are mentioned in the present paper. Bituminous products are used for the twofold purpose of waterproofing and flexibility. With the latter, the protection can subside with any settling of the soil. On the new Amsterdam-Rhine canal, recently inaugurated, the bituminous carpeting was reinforced by rubble to prevent subsidence.

As regards the depth to which the soil of the banks is liable to be eroded, the author recalls that, als already reported at the XVII Congress, it should be 2 ½ times the maximum depression of the water-line. To be prudent, it is advisable to adopt for the said depth a value of 0.55 to 0.60 times the mean depth of the canal.

If the banks are well protected, high speeds should not be precluded. On the other hand, the latter do not practically exceed nine tenths of the speed-limit because, otherwise, owing to increased resistance, navigation would become uneconomic.