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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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"Canals and Railroads, Ship Canals & Ship Railways."

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CANALS AND RAILROADS, SHIP CANALS AND SHIP RAILWAYS.

THE principles underlying the subject of Transportation, and the important conditions affecting, modifying and controlling its methods, demand a wider investigation than is embraced in the paper under discussion. We have, therefore, treated the subject in its general application under the above caption.

At this epoch in the development of the world's commerce and industry, after less than a century of steam transportation on land and water, it is necessary to contrast the various methods and, in the light of their history, ascertain the best means for the future, especially for international commerce and interoceanic communications.

The gradual abandonment of the canals, and the rapid and general introduction of railroads during the last forty years, are facts so patent that no proofs are necessary, but the reasons for this change in the methods of transportation are not so well known.

There is a vast difference between transportation on the open sea and in the restricted channels of barge and ship canals.

The opposing force that the boat herself creates by her movement through the water, and which increases the cost of transportation, is quite fully described in the following explanation of the controlling conditions given in Vol. 76, page 162, 1883, Transactions of the Institution of Civil Engineers of Great Britain :

" A vessel in its progress is continually displacing a mass of water equal to its own submerged bulk, and proportional to the greatest immersed cross-section of the vessel. In open water the vacuum that would otherwise be left in the wake of the vessel, is filled by the water rushing in from all sides. When the movement of a vessel takes place in a restricted channel, the case is altered. There is no longer an indefinite supply of water all around the vessel to rush into the hollow at the wake. This hollow must be filled by water which flows *backwards*, as a counter current driven by the head due to the height of the wave caused by the vessel. This backward current will be directly as the speed and the cross-section of the vessel, and inversely as the free water way. Consequently, a boat encounters continually an opposing current, so that her speed will be the difference between her own proper one and that of the opposing current."

The practical results obtained in operating canals confirms the above theory. In a canal near Preston, England, about 30 miles long, all the traffic was turned in one direction for one day. This piled up the water at one end 18 inches, and shallowed it at the other end 18 inches. (See Vol. 76, page 201, Trans. Inst. C. E.) A serious resistance is developed if the attempt is made to urge the boat in a contracted channel, like a canal, beyond a speed of from two to three miles per hour. In Vol. 76, page 183, Trans. Inst. C. E., are recorded some useful experiments on the traction power required to move canal boats at different speeds. With a velocity of 2½ miles per hour, the power necessary to move one ton was 2½ lbs.; 4 miles per hour, 7 to 11 lbs.; 5 miles, 20 to 30 lbs. From these experiments it was established that the proper or economical speed for canals was from 2 to 2½ miles per hour. On journeys in a steam launch, in an Indian canal 40 feet wide, near Rangoon, when the depth was slight, the launch could not make over 1 to 2 miles per hour, but in a greater depth, 5 miles per hour. This statement is made by Mr. Robert Gordon, M. Inst. C. E., Great Britain. The resistance to the movement of a "Carrier" wave, that is, a wave in advance of a boat or vessel passing through a canal, decreases as the depth increases. Experiments in

England, showed that at a depth of 1 foot it ran at the rate of 4 miles per hour; with a 5 feet depth, 8 miles per hour; with a 15 feet depth, 15 miles; and with a 20 feet depth, 20 miles. In reference to canal navigation on the Aire and Calder Navigation, England, where steam barges are used, and the boats are about 63 feet long, 12 feet wide, and 6 feet draft, the following statement appears: "The velocity should not be over 4 to 5 miles per hour, as, at higher speeds, the resistance of the water would be so great as to require an unnecessarily large expenditure of power, and the wave created would destroy the bank." The destructive wave is caused, not by the wheel, or wheels, of the towing boats, but by the force of the boats themselves pushing against the confined volume of water. In the restricted channel on the Belgian canals, steam towing tugs are restricted to 2⅔ miles per hour, in wider rivers to 4½ miles. On the canal joining the Tiege and Vistula, steam barges are restricted to 3 miles per hour. Steam tugs on the river Lee, England, tow 50 to 60 ton boats at a rate of from 2 to 2½ miles per hour in the narrow cuts; 3 to 3½ in the larger sections, and 5 miles in the Thames. On the Erie Canal, freight steamers make 40 miles in 24 hours. From experiments made in 1847, by Professor Barlow, on the Irwell and Mersey canal, he derived the conclusion that the power required to overcome the resistance to the passage of boats was as the *cube of the velocity.*

In Vol. 68, page 278, 1881, Trans. Inst. C. E., some facts are given relating to the cost of operating canals in Belgium. They show that when maintenance and interest on first cost are included they cannot possibly compete with railroads. These canals cost $57,500 per mile, and for maintenance $465.00 per mile. The cost of the towing alone is nearly ½ cent per ton per mile. Steam towing on the Willebroeck Canal, with 6 to 7 boats at a time, cost for towing alone, 2 mills per ton mile. Towing by horses on two Belgian canals 11½ feet deep cost about 3½ mills per ton mile. The net cost of canal carriage, applying the foregoing statements to an annual traffic of 600,000 ton miles, would be 5½ to 6½ mills per ton mile for steam and horse towing respectively.

In 1857 (see Vol. 17, page 407, Trans. Inst. C. E.), Robert Stevenson, in some remarks on canals and railways, said, "There could be no doubt that the canals near London are admirable auxiliaries to the railways and especially as a terminus of goods traffic, but when one is compared with the other as regards expense, the experience of the last 20 years is in favor of railways." Mr. Beardmore, at the same time, urged co-operation between railways and canals, saying, "Inasmuch as water conveyance could not compete with railways on a large scale or for great distances." In 1854 (see Vol. 13, page 201, Trans. Inst. C. E.), in a discussion of the subject of canals and railways, Mr. Bidder, Vice Pres. Inst. C. E., stated that he could not make a canal compete with a railway by animal power, and had tried steam but could not gain any advantage owing to the restricted area of the canal. Sir Robert Rawlinson gave an opinion that canals could not compete with railways, and Sir John Hawkshaw said, that in 1831 an act had been obtained to convert the Manchester and Bolton Canal into a railway, but the project was abandoned and the railway was built alongside of the canal, but gradually absorbed the traffic of the canal. "It was a subject of regret that the original plan had not been been carried out, for canals could not compete with railways." These were the opinions of leading engineers 30 years ago. Since then it has not been possible to make any improvement in the speed or economy of canal transportation, but the railroads have greatly developed in both these respects.

The reasons for the reduced cost in railway transportation of late years are, improvements in the condition of railroads by better construction, better maintenance of track, and in more economical administration ; also, in the increase of the amount of freight hauled on one train, which is made possible by the increase in locomotive power and in the capacity of cars. The train load has increased about 75 per cent. The capacity of cars has increased from 20,000 lbs. in 1855 to 1876 ; to 40,000 lbs in 1882 ; and to 50,000 lbs in 1885 ; and the master car builders have recently decided upon a standard car to carry **60,000** lbs. The weight of cars on the Penna.

Railroad increased from 20,500 lbs. to 22,000 only, from 1870 to 1881, but the load capacity increased from 20,000 lbs. to 40,000 lbs. There has also been a great reduction in the cost of repairs on locomotives. In 1865 the cost per one hundred miles run on the Penna. R. R. was $16.48, and in 1881 $6.02. On the Penna. R. R. the locomotive mileage increased from 19,240 in 1870 to 27,644 in 1881, and the average ton mileage increased from 2,100,000 to 5,000,000. These facts are extracted from a paper by Mr. Wm. P. Shinn, before the Am. Soc. of C. E., Vol. 11, page 365, 1882. Great advances in the above respects have also been made in foreign countries. In this country the steadily decreasing cost of rail transportation and the increasing capacity for business have increased the volume of freight over three of the main trunk lines, viz: Penna., New York Central, and Erie, from 10,476,857 tons in 1868 to 46,177,223 tons in 1883. In remarkable contrast the New York State canals have, in the same period, *decreased* in volume of freight from 6,442,225 to 5,664,056 tons.

The mileage of through freight boats on the Erie canal decreased from about 12,000,000 in 1850 to 6,660,000 in 1881.

The history of rates on this canal shows that there was *no* reduction until it was compelled by the reduction on the railroads.

The canals have been kept alive by the money of the State. It is now proposed to galvanize them into new life by the application of $3,000,000 to their beds, banks and dilapidated structures. Even this can result in only a spasmodic revival of activity and nothing but bountiful subsidies and generous gifts to the despondent owners of the rotten boats will keep the mules on the tow-path another five years.

It is a significant fact that in Canada also, which has spent its millions on a complete system of barge and ship canals, the merchants are demanding an abolition of *all* tolls. What more positive proof that the canals do not pay as an investment?

The last report on transportation issued by the U. S. Census Bureau states that about 2,000 miles of canals (nearly one-half of all that have been constructed) have been abandoned. The original cost of these abandoned canals was nearly $50,000,000. Railroads now occupy the beds and banks of many of them.

Notwithstanding this "handwriting on the wall" the stupendous folly of a magnificent *ship canal* from the Lakes to New York is really proposed, and the State or the Federal Government is to be asked to expend about $240,000,000, more or less, on the construction of a transportation line for which there is no earthly need. It is a retrograde movement in a most progressive age; the re-introduction of methods that are not, in any sense, in accord with its spirit, tendencies or necessities.

There is really no comparison between this ancient method of transportation and the modern railway. As well might we compare the antiquated Broadway 'bus with the Elevated Railroad.

On the Penna. R. R., Main Div., and the Phila. and Erie Div., the average cost is about 4 mills per ton per mile, including all expenses except interest on capital. This expense includes the transportation of *local* as well as through freights, handling at terminals and local stations, maintenance of permanent way, motive power and all the incidental and general expenses connected with the operation of the railroad. On the same railroad, Susquehanna Div., the actual cost of *hauling* (average of 5 consolidated locomotives on 816,115 car miles) was *0.6* of a mill per ton per mile, including repairs to locomotives, fuel, stores and train hands. The cost of towing by steam canal boat with consort is *1 mill running cost alone*, but for *all* expenses, but not including terminal cost, 3.15 mills per ton per mile. (See page 109, Vol. 14, 1885, Transactions American Society of Civil Engineers, by John D. Van Buren, Jr.) This method of towing is the least expensive of any by canal. This cost is based on *full loads both ways.* The boats cannot be run except at a loss, if they were sent one way empty.

Again, the kind of freight transported by canal is cheaply handled, being coal, grain and lumber. The railroads carry more expensively handled freight, and run their cars empty or partially loaded if necessary to accommodate business. The speed of the steam canal boat, *running* time is five miles per hour on the Hudson River, and 2.1 miles on the Erie canal, while the average *running* time of the railroads between the west and New York is at least 15 miles per hour. The basis of comparison—actual cost of hauling, as above made, is the only proper one, since the Erie canal is owned by the State and maintained and controlled by it at no cost of interest, or tolls, or other expenses to the boats. Without bringing forward further proof, the reasons are evident for the decay of the canals and the rapid growth of railroads as being better adapted to the needs of internal commerce by affording promptness, convenience and economy.

If we compare ship canals, for interoceanic communication and for shortening the lines of commerce, with ship railways we shall find a still greater difference in favor of the ship railway.

The resistances to be overcome in the restricted channel of an ordinary canal exist to a still greater extent in the ship canal, for while the canal is larger in cross-section, the size of the vessel is also larger and the ratio of immersed section to the available water section is increased. The speed required is also greater and the tractive power consequently increased. It requires for instance, as ascertained by careful calculations, twice as much power to move a lake steamer through the St. Clair Flats Ship Canal, of large dimensions, at 5 miles an hour as it does to propel her on the open lakes at the same speed.

In a paper before the Inst. C. E., (Vol. 68, page 278, 1881,) Mr. A. Gobert, calculating from the resistances and other facts gathered from several barge canals, said that the net cost of *ship* canal transportation would be about *one* cent per ton per mile including interest, maintenance, insurance, wages and fuel. It is a fact that in the narrow part of the river Clyde large steamers cannot make over 8 to 9 miles per hour while they can make 16 to 18 miles per hour at sea. The resistance to steamers and the increase of tractive power and cost of transportation are plainly seen in the operation of the Suez canal. The average time occupied in actual movement through the canal increased from 17 hours in 1876 to 19 hours and 32 minutes in 1884. The speed slackened from 5.88 miles to 5.13 miles per hour and, the time passed in the canal by each steamer increased from 39 hours in 1876 to 49 hours and 58 minutes in the first three months of 1884, or an average speed of *2 miles* per hour. A steamer forced through the canal at about seven knots per hour produced a retarding current of *6 1-2* knots per hour. The speed through the canal is restricted by rules to 5 miles per hour. A practical navigator stated that with a ship drawing 20 feet, a speed of over 4 knots an hour would result in mishaps. (Vol. 76, page 161, 1883, Trans. Inst. C. E.)

Sir Charles A. Hartley stated that the speed in the canal proper is considerably less than 4 miles. On the river Clyde, at points where the channel is about 150 feet wide and 10 feet deep, vessels whose length is 120 feet, have, at rare intervals, been propelled at speeds of from 8 to 9 miles per hour. "At this speed a surge rises at from *2 to 3 miles* ahead, and a wave is produced which measures *8 to 9 feet* from crest to trough, producing a theoretic wave speed of *16 miles* per hour, which shows a loss of *fifty per cent.* due to the restriction of the channel." The immense force generated by the wave was seen in its destructive action upon the slopes of hand-laid stone, 2 to 3 feet thick, along the banks of the canal. The effect produced by a steamer moving through the South Pass of the Mississippi River, whose width is about 700 feet and depth over 30 feet, is very similar to that described above. The great surge, or wave, moves in advance of the steamer and breaks over the low banks, flooding the adjacent land. Yet this channel has about three times the sectional area of a ship canal.

Ordinary sea-going steamers transport freight at a cost of about 0.5 mill per ton per mile, running expenses alone considered, and not including interest, insurance, depreciation of steamer, and profit, or 0.3 mill by the best examples of sea-going steamers. The cost on a ship canal at 2 miles per hour (the economical speed), as against 12 miles per hour on the ocean, and with the same power required, would increase the cost *6* times, or to *3.0* mills per ton per mile. The cost of hauling on a railroad on the same basis would be about *0.6* mill—one-fifth as much only.

Thus far we have compared barge and ship canals with the ordinary railroad. It is necessary now to take a broader basis, and compare the three methods—the ordinary railroad, the ship canal, and the ship railway, in construction, operation and profits. It may be stated broadly that railroad transportation in this country has been so far reduced in cost as to make it possible to haul freight at about 4 mills per ton per mile including all expenses, even the terminal and other handlings of *local* and through freights, also expenses of repairs and renewals, general expenses of management, and the many other charges that go to make up the details of the cost of railroad transportation. The cost of *handling* freight is not perhaps appreciated by even railroad managers, for, while immense and continual reductions are being made in the cost of *hauling*, but little advance has been made in reducing the cost at terminals and stations. It .costs as much to *handle* a ton of goods at the New York terminal as it does to *haul* it to Albany or Philadelphia. Another important item in the cost of ordinary railroad transportation is the labor. An army of employees is required for all the various duties devolving upon railroads, Hundreds of returns and reports require a large clerical force. The relations and connections with other roads in cars, goods, back charges, &c., make a large amount of work necessary. The assorting of goods for different destinations, the handling of cars on sidings, and in terminal and division yards require not only a variety of labor, but expensive power also.

The expenses of doing all this work is however so systematically performed and recorded on the best railroads of the country, that the cost of the various items is fully known. We need not have further to do with it here, but enter at once upon the Ship-Railway method, and its great advantages over the ordinary railroad.

The estimate of cost of operating the Ship-Railway is as follows at the Isthmus of Tehuantepec, which is used as an illustration on account of our greater familiarity with it.

First. The maintenance of the permanent way. The cost of maintenance in this country on a first class double track railroad, including sidings, yards, buildings, &c., in other words, everything but rolling stock, is about $1700 per mile of railroad, sidings being at least 25 per cent. of the whole. The wear on the rails and ties, switches and frogs, is constant and expensive. On the ship-railway, the speed being slower, the rails heavier, and the whole superstructure more nearly perfect, there will be much less wear and none of the expense arising in this country from frost and snow. There is, however, a greater rainfall, probably more deterioration of materials in wooden structures, and an increased cost of labor; also, 50 per cent. more track to be kept up. It will be fair to estimate the maintenance at $2500 per mile, or a total for the whole distance (134 miles) of . .	$335,000
Second. The cost of operating the terminals, from a careful detailed estimate of labor, coal, materials and repairs, will be $350 per day, or for 365 days, $127,750; and for two terminals, per annum, . .	255,500
Third. The cost of operating the five ship-railway turn-tables, at $300 per day, ...	109,500
Fourth. The motive power for hauling vessels, per annum, 4,000,000 tons at 0.52 mill per ton per mile, ...	278,720
Fifth. Telegraph expenses, ...	20,000
Sixth. Incidentals, ...	40,000
Seventh. General expenses, ...	50,000
Total, ...	$1,088,720

Add for foreign and other expenses and contingencies, 10 per cent.; the total then reaching $1,197,592, or in round numbers, *$1,200,000*, or *30* cents per ton on *4,000,000* tons.

The gross income at $2.50 per ton would be $10,000,000, and the profit $8,800,000, which is 12 per cent. on $75,000,000 capital. If the charge is $3.00 per ton, the gross earnings will be $12,000,000 ; the profit, $10,800,000, or 14½ per cent. on $75,000,000. If the full estimate of 6,000,000 tons is reached, the cost per ton will be *23.3* cents ; the profit at $2.50 per ton, *18* per cent.; and at $3.00 per ton, *22* per cent. The working expenses on 4,000,000 tons will be *12* per cent. of the gross receipts at $2.50 per ton; and 10 per cent. at $3.00 per ton.

The cost of operating the Ship-Railway across the Isthmus of Tehuantepec, may be ascertained by another method, as follows :

The cost per ton per mile on the best railroads, is 3 mills per ton per mile for *through* freight. From this should first be deducted the cost of such work as does not pertain to the Ship-Railway. All items of cost appear on page 81, Penna. Railroad Report of 1885.

Deducting irrelevant items we can properly reduce the cost 48 per cent., or to 1.56 mills; but a still further reduction is proper. Much larger loads are carried, the ratio of paying to non-paying loads is greater, the frictional resistance to the motive power is reduced at least 30 per cent., the rails are straight, the track perfect, the grades light, and greater results are obtained with less fuel and service.

The average paying load on the New York Central Railroad in 1883, was 199 tons, the average non-paying load, 350 tons, total 549 tons. The average load on the Ship-Railway may be assumed at 1,800 tons paying load, or 3,000 tons total load ; or about nine times as much paying load as on the railroads. The above favorable conditions allow us to reduce the cost to *1 mill per ton per mile.*

Fifty per cent of the cost of operating is labor, which should be doubled for a tropical country, increasing the cost to 1.5 mills, or for 134 miles, 20.1 cents, which it should be remembered is the *total* cost, not simply the cost of *carriage*.

The cost at the terminals will be so small that the goods may be said to unload and load themselves.

If ten ships are handled daily, of 1,500 tons each, the labor at the dock will be per day,	$174.00	
The coal, stores, wear and tear of machinery,	150.00	
Total,	$324.00	
To cover contingencies, say,		$350.00
Or, per ship,		35.00
Or, per ton,		2⅓c.
Or, for two terminals,		4⅔c.

The cost of operating the five turn-tables in making changes of direction (which, however, will not be more than the cost of operating the sidings on railroads) will be *two* cents per ton.

The total cost per ton will therefore be, 20.1 cents plus 4.66 cents plus 2 cents, equal to 26.76 cents. Adding, however, 15 per cent. to cover any unexpected expenses, we have a total cost of about *30* cents per ton.

This estimate, though made on an entirely different basis, agrees with our previous statement.

In comparing the Tehuantepec Ship-Railway with the Ship Canal, the cost of construction will be $75,000,000 for the Ship-Railway, and probably $300,000,000 for the Panama Canal, and $200,000,000 for the Nicaragua Canal. Major McFarland's estimate for the latter was $140,000,000 with labor at $*1.00* per day. The cost of maintenance will also be much less.

The road-bed of the Railway is above the water, and is nowhere subject to the dangerous floods or engulfing slides from immense cuts. The road-bed is 50 feet in width, whereas the prism of the canal must be at least 200 feet, from which all washed-in material must be removed by very expensive means.

The Suez Canal, where the rain-fall is about *2* inches per annum, required in 1883, in the canal proper, the dredging of 781,282 cubic yards. The annual cost for cleaning the canal is about 2,000,000 francs ($400,000). The total expenses of all kinds in 1883 were over $6,000,000. The expenses of working the canal, &c., were about *$3,600,000*. The material in this canal can be cheaply thrown out on either side by the dredges, and only 40 per cent. of the distance is through cuts over 10 feet high above the water line.

The expense at Panama will be largely in excess of that at Suez, as the prism of the canal will be exposed to a rainfall of about 120 inches per annum, falling on enormous clay slopes, one of them over 400 feet in height.

The dangerous and uncontrollable volume of the Chagres River will be a constant menace to the integrity of the passage way. It may be fairly estimated, therefore, that the working expenses of the canal will not be less than $4,000,000 to $5,000,000, and they will be fully as great at Nicaragua.

At Nicaragua the length is 186 miles, about 20 miles only of which is open water. The remainder is a dredged, excavated, embanked, or walled channel, with several locks to be maintained. The cost of towing sailing vessels through either canal will be considerably more expensive than hauling them on the Ship-Railway; and the cost of propelling a steamer by her own power, will be, as has been previously shown, 3.0 mills per ton per mile, as against say, 0.5 mill per ton per mile by the Ship-Railway.

The development of the plans of the Ship-Railway has been followed so closely by you during the last five years, that it is unnecessary to explain them in detail, or to occupy your time in proving their practicability, particularly as this has already been acknowledged by many members of this Society, who have given the subject special attention.

As to the routes, the Tehuantepec will save, on an average, 1,000 miles on the main commercial lines, which, for a three thousand ton steamer, will reduce the cost of steaming $1,000, and the time 4 days; and this distance will be saved over either Panama or Nicaragua, for on account of the longer time required to go through the latter, it has no advantage over the Panama route in point of time.

The advantage also to the ship in being docked for eighteen or twenty hours, or longer, if her master desires it, should be considered, for it is necessary to take steamers out of the water twice each year to be scraped, cleaned and painted.. It will save to the ship owners $1,000 over dockage in port.

The tolls on the Ship-Railway could be increased beyond those of any canal route to the extent of the saving to the steamer by being hauled instead of propelled by her own expensive power, and to the sailing vessels by being hauled instead of towed.

The comparative rate of economical speed will be as *2* miles to *10*, so that while the Railway is longer than the Panama Canal, the crossing from ocean to ocean can be made in the same or less time, and as compared with Nicaragua, in *one-quarter* of the time.

We therefore summarize the preceding statements by saying that a canal cannot compete in speed or economy or facilities with a railroad, and that a ship-canal must also be much more expensive than a ship-railway in first cost, maintenance and operation, and much inferior to it in despatch, facilities and conveniences ; and that the Tehuantepec Ship-Railway, as compared with any other possible method or route for interoceanic communication between the Atlantic and Pacific Oceans, has every advantage, and is entitled to the support of engineers, capitalists and commercial men, as subserving to such a high degree and at such comparatively small expense in first cost and operation, the necessities of the world's varied and growing industries.