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4, Church Lane,
Linton,
Cambs.

Tel. Linton 545.

[illegible]. Simpson,
Economics Department,
Stormont Castle,
Belfast 4.

2nd September 1964.

Dear Mr. Simpson,

As promised in my letter of 21st August I now enclose a copy of a paper prepared for examination on the seabed tube proposal for an Ulster tunnel. It is marked "in confidence" and "copyright reserved" solely to make it clear that I should not like to have the report published at this stage. Nevertheless, I have sent a copy to Dr. Sayers of the Belfast Telegraph together with the same injunction, because of his evident interest in the matter. I have no objection to these copies being shown to anybody that you would require to nominate.

You will find in a concluding section of the proposals that I have described some of the research that I feel ought to be done at an early date in order to supplement the appraisal of the scheme. I have suggested that the projects which might be handled at the Department of Civil Engineering, Queens University, could be financed by the Northern Ireland Government. My reason would be to create confidence that would encourage other bodies to contribute. I am sure that you will appreciate that I am not yet in close contact with the way in which things are done in Belfast and perhaps other means of support might be more appropriate. I, therefore, hope that these proposals for support of research will be considered in association with the reasons for making them.

Yours sincerely,

A A Wells

enc:

PROPOSAL FOR AN ULSTER TUNNEL

(Submitted in confidence by A. A. Wells to the Government of Northern Ireland to permit an appraisal to be made)

Summary

A single rail track tunnel is proposed, to run from Float Bay on the Galloway Shore to a short distance south of Donaghadee in County Down, a distance of 23 miles. The principal purpose of the tunnel would be to transport passengers and road vehicles between points close to the two shores, but the rail link would be of 4 ft. 8½ in. gauge, electrified through the tunnel at 25,000 volts 3 phase AC, and could be joined by a single unelectrified line to British Railways at Dunragit junction and to the Ulster Transport, Bangor line at Carnalea if the additional link were to be economically justified. An attractive possibility would be to use the 3 phase conductor system as an independent 69 MW interconnector between the electric power systems in both countries. Gas and telephone transmission lines could also be laid through the tunnel.

A case is presented for the construction of the tunnel as a sea-bed tube, sections of which would be constructed at each shore end, to be continuously projected in straight lines along the seabed to be joined at the middle. It is anticipated that the cost of this construction, including the rail connection and terminals would be £35M, and that it would take 3 years to build, after a survey and planning period of 3 years.

It is suggested that the initial annual use of the link in 1971 could be 1.1M and 0.6M passenger and vehicle journeys respectively, rising 2.4 times to saturation in the succeeding 20 years. At a charge of £2 per vehicle and £1 per passenger journey the fare recovery in the same period could be £80M, which should offer a surplus over the operating, maintenance, interest and depreciation charges, assuming the whole capital cost to be written off over this period. Thus the scheme should attract private capital, especially if the Central and Northern Ireland Governments were to foster it in the early stages, and provide suitable connecting roads by the time of completion.

The need for a tunnel

Although the transport facilities to and from Northern Ireland may be held to satisfy existing needs, they mostly do not encourage travel, nor do they appear to possess much reserve for expansion. Long forward bookings are necessary in summer months on the air routes, and by sea when vehicle transits or overnight berths are required. It is considered that many potential journeys are never made, because they are too difficult to organise and too expensive.

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Vehicle registrations and tourism are increasing in Northern Ireland at a rate comparable with the national pattern, doubling every ten years. The private car is important, accounting for over half the total vehicle registrations, with one car to every three households, and a national average of two people on every car journey. Some idea of the potential for private car transport to Northern Ireland can be gained by comparison with journeys made between England and Scotland. On any one of the main roads the vehicle rate is measured in thousands per hour. On the Northern Ireland ferry services the rate is measured in hundreds per day, that is perhaps a hundred times less, even when correction has been made for the differing sizes and populations of Scotland and Northern Ireland. A tunnel which offered easily managed transits without forward booking and delays at substantially lower tolls than now required on sea or air crossings, would help to create a travelling habit such that the annual number of private car transits might be increased tenfold within a short time.

Dependability of winter travel would also be much increased by the existence of a tunnel. The airways are deserted by experienced travellers in the three winter months because of the serious delays and discomforts caused by cancellation of services in fog. Rough weather in addition to fog causes unreliability even on sea services. Overnight rail sleeper services are probably the most comfortable and reliable for winter travel, and the tunnel would permit inauguration of a sleeper service to Belfast. Offering a day's business with travel on consecutive nights, and no intrusion on second and third working days, together with reduced fatigue from the elimination of multiple transfers from train to boat, such a rail sleeper service could be expected to be popular.

The drive on ferry service for road transport is important and successful, and it might be thought that it should not be eroded by competition with an alternative tunnel facility. However, if more ferries are required to expand the service in accordance with needs, the carrying capacity yielded for unit investment in tunnel and ferry should be compared. It is likely to be found that the tunnel investment would be more productive, and it is therefore assumed that the tunnel would carry the growth element of commercial vehicles in excess of the present ferry capacity.

The remaining fraction of potential tunnel traffic consists of rail freight. Advantage would be offered by the tunnel in terms of minimising trans-shipment, giving somewhat greater speed at less cost. However, this might be offset by the difference of rail gauge between Ireland and the rest of Britain, which would confine the advantage to the Belfast region alone. In the case of mineral traffic, it might be offset by the existing advantage of direct sea transport. Such would apply to coal from South Wales ports, but coal from the English Midlands and Fife might be carried more cheaply by rail through a tunnel. Other attractive freights might be perishables, where greater speed could help, and Ulster roadstones for inland designations in England. It is concluded that the through rail link should be provided from Dunragit to Belfast, but revenue from passenger and freight operations by rail has been discounted in the ensuing estimates.

Prospects for use

It is concluded above that the significant revenue to be earned by a tunnel would come from the carriage of passengers with private cars, and commercial vehicles in excess of present capacity by sea. The Ulster Year Book 1960-62 gives certain statistics, including rates of growth which when extrapolated appear as follows:-

		Estimated	
	1961	1970	Growth 1961-70
Registered vehicles, excluding cars (thousands)	108	170	62
Registered private cars (thousands)	136	250	114
Tourists from outside Ulster (thousands)	300	550	250

It would seem reasonable to assume that each growth unit isolated thus would use the tunnel once each way each year. Further, for every commercial vehicle there would be one passenger, and two on average for every private car. Each pair of tourists can be assumed to use one private car.

The usage in 1971, the first year when a tunnel might become available, appears from this crude analysis to be 0.6M vehicles and 1.1M passenger journeys. It may be noted that commercial vehicles visiting Ulster from England and Scotland have been neglected in this analysis, for want of statistics, as has potential use of the tunnel from the Irish Republic.

Capacity of the tunnel

It is estimated that one train of 100 vehicles could pass from shore to shore in each direction every hour, so that 4,000 vehicles could be carried with their passengers each day leaving 4 hours probably during each night for rail transits. This would give a maximum annual capacity of 1.46M vehicle journeys, which is 2.4 times the initial usage calculated above.

Costs

The foreseeable direct costs at 1964 prices for the tube, end works, rail bed, rails, electric equipment, plant and labour have been approximately estimated to be £20M, to which a 75% contingency allowance has been added, making a total cost of £35M. For 23 miles of single track tunnel this may be compared with the 1955 estimate of £75M for the 35 miles of twin tunnel across the English Channel. This should be increased to somewhat more than £100M at 1964 prices, but the estimated cost per mile of tunnel is seen to be comparable in the two cases.

Charges

Neglecting all but the dominant shore to shore vehicle traffic, a charge of £2 per vehicle and £1 per head per journey would permit an estimated initial recovery of £2.3M per annum, which could rise to £5.6M per annum with traffic saturation, say after 20 years if current expansion rates are maintained. The average annual revenue of £4M over 20 years would give a total recovery of £80M which should embrace interest and complete depreciation over this period, together with operating and maintenance charges.

On this basis, the scheme ought to attract finance from large investment companies, if the Central and Northern Ireland Governments were to command it, and supplement the road links to bear the resulting increased traffic. Their benevolent and catalytic intervention in the formative stages of such a scheme would be particularly desirable.

Construction of the tunnel

Seabed tubes have long been considered and are used by the Dutch for short river crossings. It is usual for the tube sections to be floated into position and sunk in prepared trenches, after which watertight joints are made. Such methods are utterly impracticable for submarine crossings. The length of time during building means that storm conditions must be encountered, and methods do not exist for joining such tunnel sections either afloat or on a deep sea bed.

The scheme now presented obviates the principal difficulties that could be envisaged. Construction is to be confined to the shore ends, where the conditions can be protected and safe. Projection of the completed tubes along the sea bed avoids the commotion existing on the sea surface during storms, and avoids even the ocean currents, which are considerably attenuated by friction at the sea bed. The convenience of almost neutral but slightly negative buoyancy in the tubes greatly simplifies moving them along their axes into position. It is possible that a tube could be hauled along the sea bed from one shore to the other, but hawsers of the required strength and corrosion resistance are not available, except in the short lengths of suspension bridge cables. Their provision, if feasible, would add greatly to the cost.

The alternative of jacking the completed tubes out from each shore station has now been examined in great detail as a technological operation. Two problems are recognised; 1) avoiding buckling the tube during jacking and 2) guidance towards a central meeting point. The second problem is soluble with conventional survey techniques, with the difference that the survey stations en route would be moveable, so that the operation would require more frequent repitition and correction of errors than with a bored tunnel. Even so, the exercise of directional control would not be significant in terms of costs.

How to correct an error? / See guidance below.

For the avoidance of buckling it may be assumed that the tubes will each rest lightly on a prepared bed of pumped concrete, which need not possess great strength, as the pressure upon it will be of the order of that upon a snow shoe. The function of the bed is not only to cover scattered rocks and other obstacles up to intermediate sizes, but also to provide a transverse restoring force from riding up the bed if the tube should tend to move sideways. Under such conditions, applying the conventional methods of elastic stability analysis, it is found that there is a characteristic wavelength for buckling deformations of each amplitude, at which the permissible compression load is a minimum. This buckling load has been computed to be equal to the frictional resistance to forward movement arising from a distributed load equivalent to the 2% negative buoyancy of more than 50 miles of the chosen tube, if laid with a transverse error of ±1 ft. over the critical wavelength of 1070 ft. It has only been possible to conduct small scale model experiments with rubber garden hose to check the assumptions made in this calculation, but there would appear to be a wide margin of safety against buckling.

The 2% negative buoyancy of 10 miles of the chosen tube of 24 ft. outer diameter is 13,000 tons, so that jacks of 4,000 tons total capacity should be readily capable of moving such a length. These jacks would be neither difficult nor relatively expensive to construct and would require only a few driving horsepower, because of the slow speed required of them. With the very low bearing pressure (0.3 lb/in^2) of the tube on its bed and presence of water at the sliding face, scoring damage to the tube would not be anticipated. Friction peaks from stick/slip behaviour would be smoothed out by the longitudinal elasticity of the long length of tube.

In addition to suitability for the laying operation, the principal properties required of the tube are watertightness, corrosion and erosion resistance, pressure strength, toughness and flexibility. These are considered to be provided to the optimum extent with a welded ¾ in. thick outer skin of aluminium, 4% magnesium alloy N8, and a 3 ft. thick inner lining of precast blocks of high quality concrete, the latter providing mass, pressure strength and crushing resistance.

The chosen aluminium alloy is now used extensively in welded form for large passenger ship superstructures, where lightness, flexibility and resistance to a highly corrosive marine environment are required. More recently the alloy has also been used for large scale very low temperature containment of liquefied natural gases, imported to Britain from North Africa. In this application its superlative toughness is utilised to the full. It is pleasing to note that the alloy in its welded form is largely a British development, and that the most highly developed expertise in welding it exists at Harland and Wolff in Belfast, Vickers at Barrow, and a number of British pressure vessel construction companies. Welded fabrication of this material is now so advanced that a British Standard has just been issued.

This alloy is customarily welded automatically with argon shielding, and the shore conditions for fabrication in a clean, protected enclosure would be ideal, with repetitive quantity production, employing albeit only 2 or 3 skilled welders on each of 3 shifts at each station. Full automated quality control would be employed, but with a negligible anticipated weld repair rate.

The scale of this operation would be large, but not monopolistic. The total alloy consumption of about 40,000 tons spread over three years would represent a small fraction of one per cent of the present world aluminium production.

Steady production to high standards in quality control would also be a feature of the manufacture of the precast concrete lining blocks. Sufficient quantities of the aggregates should be found close to both shore ends and the quantities required, 500 yd^3 per day at each end for precast blocks and pumped bed, would not be large on modern standards. The blocks could be cured sufficiently before use, and would possess a crushing strength from four to eight times the imposed pressure stresses by the time of arrival of the tube at the deepest underwater sections. The inside of the tube would also be dry, apart from condensation effects, and the concrete blocks would be fully protected from the ravages of sea water.

300 cyd/day + bed ?

In order to facilitate delivery of the concrete bed, the rails in the tube would be laid progressively at the shore end to permit the use of rail trucks and an electric battery locomotive. The aggregate would be mixed near the nose of the tube and the concrete pumped as slurry from that point. The pumping horsepower would be small for the delivery of 4 yds^3/hour, but careful and duplicated protection from back pressure would be required to permit plant maintenance to be thoroughly conducted.

100 yds/day

Shore works

Although the tube could follow the natural shore profile into the water, it would suffer the dual rigours of wave buffeting and alternate exposure to air and sea water, and would also hinder coastal navigation. The additional cost of cut beds of short lengths at 2% gradient to the 5 fathom lines would thus be considered imperative, so as to permit the tube to be immersed at all times. There would be no unusual problems presented by the rock cutting, which could be minimal. The tube building pens would be some yards back from the cliff edges, and would be served both by the short approach tunnels or cuttings and broad vertical shafts overhead. The single approach rail track at each shore end would be in commission through to the interior of the tube during the whole laying operation, and would greatly facilitate off loading of materials by means of overhead travelling cranes installed through the shafts. (Figure 1)

It is not anticipated that cofferdams would be required in preparation of these works, since the tube nose or shield could be installed at each end, mounted against its jacks, prior to blasting the remaining rock wall out of the way. The jacks would provide excellent absorption for the shock of blasting and sudden entry of water.

The rock cuttings within the building pens would also provide serviceable jacking supports. The dozer blade would be bolted to each tube nose following emergence from the shoreline cut into the shallow water.

Tube assembly

A convenient length module for the tube would be 7½ ft., if the aluminium plates would be obtained at this width, since it would fit the railway or road loading gauges, both for plates and precast concrete blocks. There would be two plates and four concrete blocks in the periphery of each module, and 8 modules would be laid each day. The order of assembly of each module suggested from figure 1 would be:-

1) the two longitudinal welds, 2) the circumferential weld,
3) non destructive examination and repair if needed,
4) assembly of four concrete blocks, 5) jacking the blocks into position, followed by forward jacking of the whole tube by one complete module.

Step 4 would proceed concurrently with steps 1 to 3. Since welding speeds for this material are of the order of 2 ft/minute, and there would obviously be a liberal provision of positioning equipment for the plates, there would be ample time for the completion of each weld, followed by inspection and minor repair.

In order to facilitate a close connection between the concrete and aluminium, the radial faces of each block would be given a slight taper in the axial direction. They would then be permitted to enter the tube easily, to be tightened during the jacking operation. The radial joints would also be staggered in successive modules to give the equivalent of a brickwork bond.

The route and seabed conditions

Valuable information on the nature of the bed, areas of which appear to be composed of ooze, sand, shells or stones, is given on the 1/75000

Admiralty chart, North Channel, Southern part, 2198, published in 1960 and amended to 1959. Soundings appear at approximately ½ mile intervals. Although shore locations for the tube have been provisionally chosen in relation to depths, slopes, absence of large cliffs, road and rail access and absence of population centres and potential wayleave difficulties, it may not be possible to choose a straight path between the chosen terminal points, because of the special conditions at Beaufort's Dyke. The route selected and shown in figure 2 requires the two straight lengths of tube to meet at an angle, in a manner that is described below. This route represents the best attempt that can be made from the chart to minimise depth and the approach gradients within the Dyke, and succeeds in reducing these to 126 fathoms and 3 to 4% respectively. (Figure 3). It is hoped that more favourable conditions would be located by detailed survey, using precise echo sounding and underwater television. The survey in this way would be carried out in great detail in any case, so that the position of each rock, hillock and valley would be known in advance of laying the tube. The tube profile and imposed stresses would be calculated beforehand, together with plans for pushing out of the way those small obstacles amenable to such treatment, and for riding over others. The chart does not indicate the presence of any large escarpments, but small ones could be bridged over spans up to 350 ft. Even here the permissible span is determined not so much by strength as by live load deflection conditions. It is not anticipated that underwater obstacle removal would be attempted in deep regions from the surface of the sea, except in one circumstance. Beaufort's Dyke has been used in times past as an explosives dumping ground, and any suspicious debris on the intended path of the tube encountered on the television survey might be dispersed by firing depth charges placed with the same aid. Even in the unlikely case of massive explosives remaining undetected, the tube would possess surplus intrinsic strength to resist non contact detonations. A minor obstacle of another nature would be a submarine telephone cable. Care would require to be taken to negotiate past it in a way that would avoid inflicting damage upon it.

It is not easy to prescribe an optimum concrete bed thickness, but 5 ft. has been provisionally chosen, with the object of smoothing the path over many minor obstacles. The nose of the tube would carry a dozer blade of cowcatcher shape, which would be extended back about 60 ft. to operate as a moveable form for the bed concrete, which would become self-supporting over this length in about 24 hours. This form would be necessary, because concrete discharged into water has a small natural angle of repose. As stated earlier, the strength required of this bed concrete would be negligible.

Guidance

In spite of the certainty with which an accurately oriented traverse line could be carried through the tube, it must be assumed that the tube nose would wander off course and require correction. This would be performed by controlled flexure of the first hundred yards of tube behind the nose, preferably by means of hydraulically loaded metal pads or capsules inserted in the joints between the blocks lying in the plane transverse to the axis. Those pads on the left and right hand sides of the tube would be connected to separate hydraulic circuits. With a permissible radius of flexure of 12,000 ft. for the outer skin of the tube the nose could be moved transversely by ±4 ft. In fact, with the constant small disturbances from ocean currents, this transverse control would be continuously exercised to fractions of an inch by a simple hydraulic servo, governed by a sensitive transverse accelerometer (seismometer), and only periodic manual correction would be required.

Flexure

The seabed undulates, with gradients apparently not exceeding 2% in all but Beaufort's Dyke, and the tube would hug the bed as closely as possible. The curvatures so required of an initially straight tube are well within the capability of the aluminium alloy and concrete block combination. The analysis of this situation is again performed with the assumption that the bed profile can be described as the sum of a number of sinusoidal undulations of differing amplitudes and wavelengths. The critical wavelength is the one which just leaves the tube unsupported in the troughs when carrying the full live load. It is appropriate to calculate with disregard of the concrete blocks which will not sustain tension loading. For a permissible stress of 4 ton/in^2 this wavelength is 700 ft. and the consequential sag is 0.9 ft. When the wavelength is increased to 1 mile the corresponding permissible sag is 51 ft., but the tube must be fully supported over this length. These calculations are suitably conservative. The minimum failure stress of the aluminium alloy is 18 tons/in^2 with 12% elongation, and equal strength in the welded joints.

Joining the tubes

The joining operation would consist of aligning the tube ends while they were in close proximity, to be followed by jacking them into close contact, over the peripheries of the prepared outer flanges (figure 4). The water trapped between the two end bulkheads would then be relieved in pressure by draining, which would cause the flanges to be held together with a force approaching 10,000 tons. This would permit a seal to be made, so that bolting to complete the joint at the internal flange could proceed under safe and comfortable conditions. The bulkheads used during tube laying would then be removed.

As stated above, the tubes would probably be joined on a large radius curve near the deepest point. This would entail fitting the hydraulic pads over a somewhat greater length near the nose of each tube, but it would confer an advantage in control of the joining operation, in that the last inching movements of the tube flanges towards one another would be controlled on the spot by slightly shortening the radii of curvature. The elasticity of each ten mile tube length would be such that alternative control from the shore jacks would be coarse by comparison, and somewhat more likely to cause damage from bringing the flanges into sudden contact.

Ventilation and drainage

It is uneconomic to ventilate a long tunnel by means of internally ducted air because the friction losses are too great, unless the duct occupies an appreciable fraction of the tunnel cross section. Separate pilot headings are often used for this purpose in excavated tunnels. It is proposed in the present case that natural ventilation and the chimney effect from distributed internal heating should be utilised. Meteorological records suggest that pressure differences between the tunnel entrances might frequently be as great as $\frac{1}{4}$ millibar. Such a pressure difference would induce an airflow through the tunnel of 2 ft/second, and a complete change of air in 16 hours. In the absence of this effect, a uniform temperature difference of $4\frac{1}{2}^{\circ}$F between the air on opposite sides of the lowest point in the tunnel would induce the same velocity. This would allow heat to be lost through the walls of the tunnel at a rate of $8\frac{1}{2}$ watts/ft, or 600 KW for the half section. This could readily be obtained with the use of electric filament lamps of, say, 200 watts each at three module spacings or less. The lamps would be well placed at the roof of the tunnel to create an orderly transverse circulation to be superimposed on the axial movement, and would inhibit incipient condensation. The lamps in one half of the tunnel would be switched on at any one time, leaving a skeleton distribution for illumination in the other half, and the choice would depend upon the direction and strength of the natural airflow at the time in question. The cost of the steady electrical load would be negligible compared with calculated revenue.

In order to maintain a comparable ventilation air velocity during construction, with reversed flow at the top and bottom strata in the tunnel, the heat input rate could be increased to 14 watt/ft or more.

It is worth consideration that the complete change of air every 16 hours with the tunnel in service should permit the passage of several diesel locomotives each day, provided that they were fitted with equipment to complete the process of combustion of carbon monoxide and carbon, as fitted to underground mining locomotives.

It would be necessary to arrange for drainage in the tunnel to cope with unusual condensation and the possibility of unforeseen leakage. It would be appropriate to discharge this to the sea from the lowest point, and consideration would be given to using the concrete pumping system for this purpose after completion of the tunnel. For the most effective emergency use the pumps would be submersible with waterproofed electric wiring.

Rolling stock and electrification

The vehicle service would be operated initially by three simple flat car trains each about 1500 ft. long, two of which would be loading and unloading at the two ends while the other was travelling. These trains would receive vehicles over the rail end, and the latter would drive on in the order of arrival, with no segregation of private and commercial vehicles. No advantage would accrue from two storey stacking in a private car section, because of added windage from the increased frontal area. In a tunnel of this length the air must pass around the train rather than before it, for air resistance to be reduced efficiently. With end loading and without stacking the costs of the two terminals would be greatly reduced.

With this simple organisation the trains could be driverless, under intrinsically fail-safe conditions. They would be provided with induction motor drives to the majority of axles, which would assist greatly in dealing with the gradients by using a high proportion of the train weight for providing tractive effort. Also, because of the constant speed characteristics of the induction motors (and the trains) when tied to a fixed frequency, the trains would be subject to regenerative braking. Peak electrical loads at starting and stopping would be diminished by use of the gradients into and out of the tunnel, and control would be accomplished by running the overhead pantographs on to dead sections of conductor, and assisted by the fitting of rail mounted retarders. The trains would be fitted with end ramps which would be lifted during transit to protect the end vehicles, and which would allow the loading bays to be flush with the track, so that there would be adequate latitude in the stopping positions. Emergency brakes would be provided on the trains to deal with power failure, but the electric supply would also be arranged to draw alternatively from the power networks at both ends of the tunnel, with the possibility of automatic change from one to the other. Interconnection of the phase reversal, of the rail switching points at both terminals and the retarders, would then allow the system to be operated by one attendant at each end, whose main function would be to collect tolls, and who would be unable to permit a train to commence its journey until the next one had arrived. As an additional safeguard it would be impossible for two trains to travel in opposite directions in the tunnel, by virtue of the phase connections.

A variant on this system, which could be discussed with the Ulster and Central Electricity Generating Boards, would be to use the 25,000 volt 3 phase, balanced conductor system in the tunnel as a power interconnector in permanent and independent use, since it could carry a 60MW electrical load at 10% regulation. Phase reversal in train operation would then be arranged from the trains themselves, and other features of the control would be modified from the proposals described above.

In view of the possibility, suggested above, of using one or more diesel locomotives fitted with exhaust treatment equipments for several tunnel journeys each day, and also in view of the small scale of the expected rail traffic, it is suggested that the 8.3 miles of single track from Dunragit junction to Float Bay, and the 7 miles from Donaghadee to Carnalea should not be electrified. This would permit substantial economies, firstly because the ideal 3 phase system and the 60 MW interconnector could be used in the tunnel instead of the single phase 25,000 volt system which would be modern standard practice for British Railways. Secondly, there would be a saving of 26 miles of uneconomically used track electrification.

Other services

The possibility has already been mentioned of using the high voltage balanced 3 phase electrical conductors in the tube as a 60MW power interconnector as well as a means of driving the trains. Other possibilities include the provision of additional telephone circuits, and a high pressure gas main. The latter is likely to prove of interest in connection with the gas grid recently laid in England to use North African natural gas, and interest would intensify if there were substantial natural gas strikes from the prospecting in the North Sea. It is anticipated that room could be found for the equivalent of two 12 in. diameter mains in the roof of the tunnel, where they would be safe from accidental impact damage.

Cost breakdown

The most expensive material item in the tunnel would be aluminium alloy plate, of which just over 40,000 tons would be required. The present market price is 3s.3d./lb. (£365/ton) for small orders. On such a large regular order it ought to be possible to negotiate a price of £300/ton for edge prepared and curved plates. (The market price of ingot aluminium is of the order £200/ton, and with Japanese export intervention, there is a substantial surplus manufacturing capacity.) The cost of delivered plates has therefore been assumed to be £13M.

With somewhat less knowledge of the ruling local conditions, the cost of concrete lining blocks in place and pumped concrete, of which 2.5M tons of continuous quantity production would be required with the minimum of labour participation, has been taken to be £2/yd^3 or £1.2/ton. The estimated total cost is therefore £3M.

The cost of rock excavations at the shore ends under conditions of easy access and disposal, no shoring and rough finishing has been taken to be £1/yd^3, or £0.1M in total. The cost of the other works at both tube ends, including the tube building pens, vehicle loading bays and services, but excluding rail track and electrification has been estimated as £0.5M.

The cost of 12 miles of prepared single track rail bed outside the tunnel with an assumed one bridge per mile has been estimated to be £0.6M. The cost of 50 miles of single rail track without signalling or rail switches has been estimated to be £0.5M.

The cost of electrification, including power feeders, rolling stock and control equipment has been roughly estimated to be £1M.

An allowance of £1.3M for surveys, full scale tests, specialist services including welding of the tube and other labour, and plant and equipment written off during tunnel construction allows the total to be rounded off to £20M, and the 75% contingency brings it to £35M.

Assuming that all the conventional works including the approaches, building pens and concrete block manufacture would be let as separate contracts, estimated as above, the tube laying operation would probably not occupy more than 50 men at each shore, including the workers on three shifts.

Subjects for research

Although this proposal has been supported by an economic argument which favours it, together with estimates of cost, these matters are complex, and fit subjects for expert attention. The purpose served by their inclusion is to convince that the proposals are of sufficient merit to be expertly examined in this way. It is hoped that they will receive this attention.

The theme of the proposals concerns the employment of existing well tried construction and transport techniques, albeit in new combinations. From the technological viewpoint the risk of failure if they are employed as described is considered as negligible. Certain tests would however be prescribed to give public proof of the authenticity of the proposals. For instance, a short section of the proposed tube construction could be prepared at comparatively small cost together with a pair of end bulkheads. This would then be fully instrumented, towed by means of a boom defence ship to a deep ocean area and lowered to a depth at which it would fail by crushing. The specimen would then if possible be recovered for examination. At a later date a similar full scale section could be subjected to depth charge attack. The participation of the Naval Construction Research Establishment would be sought in both these tests.

All the arrangements for flexing and projecting the tube could be examined by means of model tests in the laboratory. Since the facilities exist at the Department of Civil Engineering, Queen's University, Belfast for the testing of hydraulic models with regard to current flow and sedimentation, the likely behaviour of the tube bed could be studied, with reference to effects both on the tube support and on coastal navigation.

The question of corrosive attack on the aluminium alloy in sea water should receive early and thorough study. Buried welded pipelines of this and similar alloys have shown excellent resistance to corrosion over a number of years, but routine tests in the precise environment should be undertaken. It is anticipated that the most serious problems are likely to be encountered with marine growths, which would affect the shore ends more than the deeply immersed middle section. This would ease the control of any such corrosion, but it would be even better if surface treatments could be developed that would act as significant inhibitors.

The most important matter for early attention is the preparation of a pilot survey of the seabed along the proposed path of the tunnel, and suitable alternative paths. This could be completed in the available periods of calm weather during 1965 with a vessel of minimum displacement 7 ton T.M., equipped with precise navigational aids, a precise recording echo sounder, a sensitive current meter and an underwater television camera. If manned by the staff of the Department of Civil Engineering, Queen's University, Belfast, with the help of one or more research students on grants from the Department of Scientific and Industrial Research, and voluntary help from others, it is anticipated that this survey could be prepared, and presented, together with a continuous underwater photographic montage embracing the whole path of the tunnel, for an expenditure of £5,000 on equipment and services including the vessel.

In the event of the Government of Northern Ireland becoming further interested in these proposals, it is requested that this survey should be put in hand, with the aid of an initial N.I. Exchequer grant of £5,000 for purchase by the University of the equipment mentioned above, or with the loan of equivalent marine survey facilities now in the possession of the Government.

In the event of serious Government interest in the scheme it is also requested that a sum of £5,000 should be allocated from N.I. Exchequer funds to permit commencement of hydraulic model studies, corrosion studies at a North Channel shore site, and construction of a 5,000 ton capacity compression testing facility for 3 ft. cubes of concrete made from Northern Ireland and Galloway aggregates. The latter equipment would be derived from the design of the 4,000 ton tensile testing machine for steel plates constructed by the author at the British Welding Research Association, and Harland and Wolff would be asked to build it on terms favourable to the University.

Given the assurance of these grants, it is anticipated from the fruits of initial publicity, that the firms and trade associations likely to be concerned with aspects of the possible construction would come forward with further offers of research funding and facilities. An approach would also then be made to the Navy Department for assistance on aspects of submarine model testing.

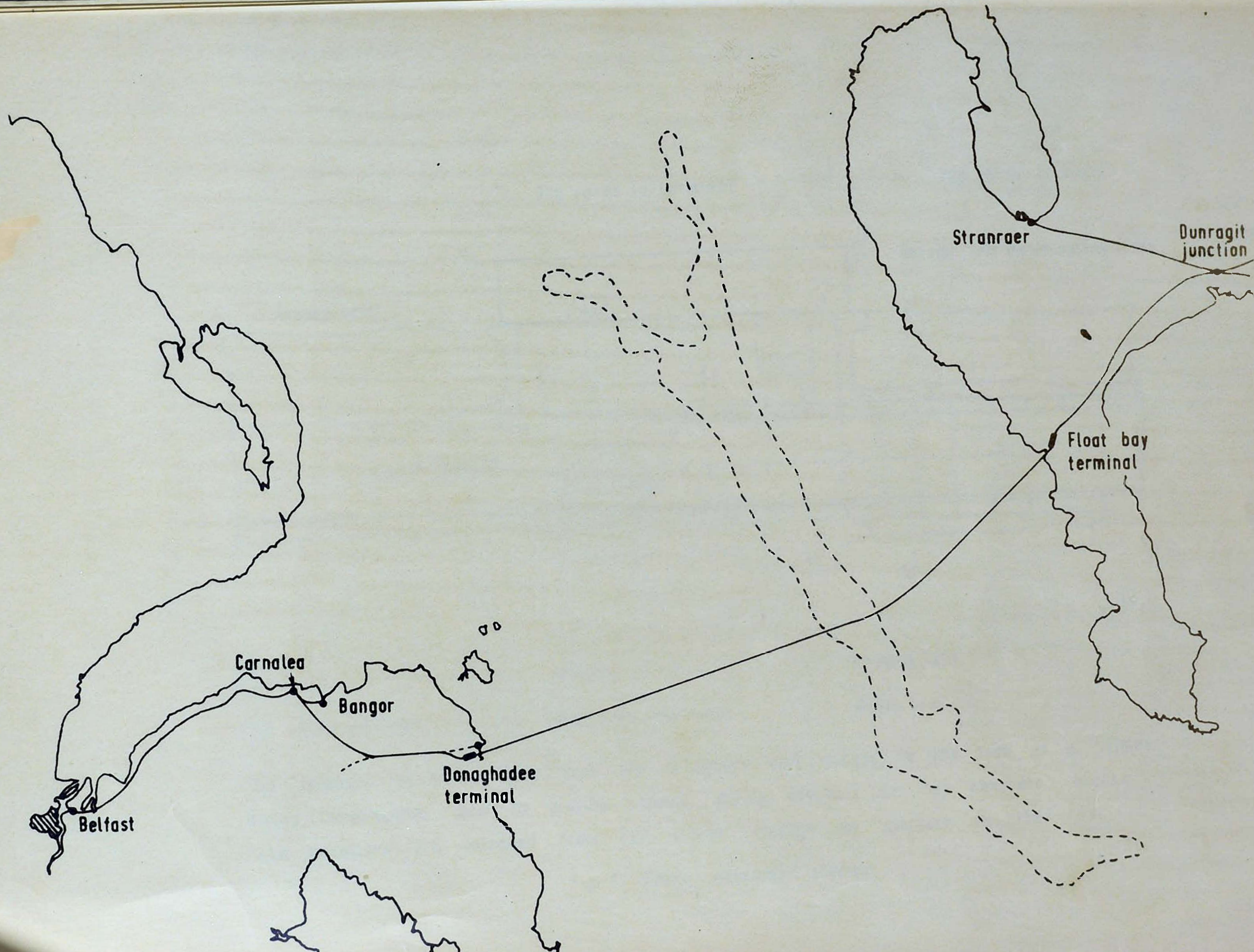
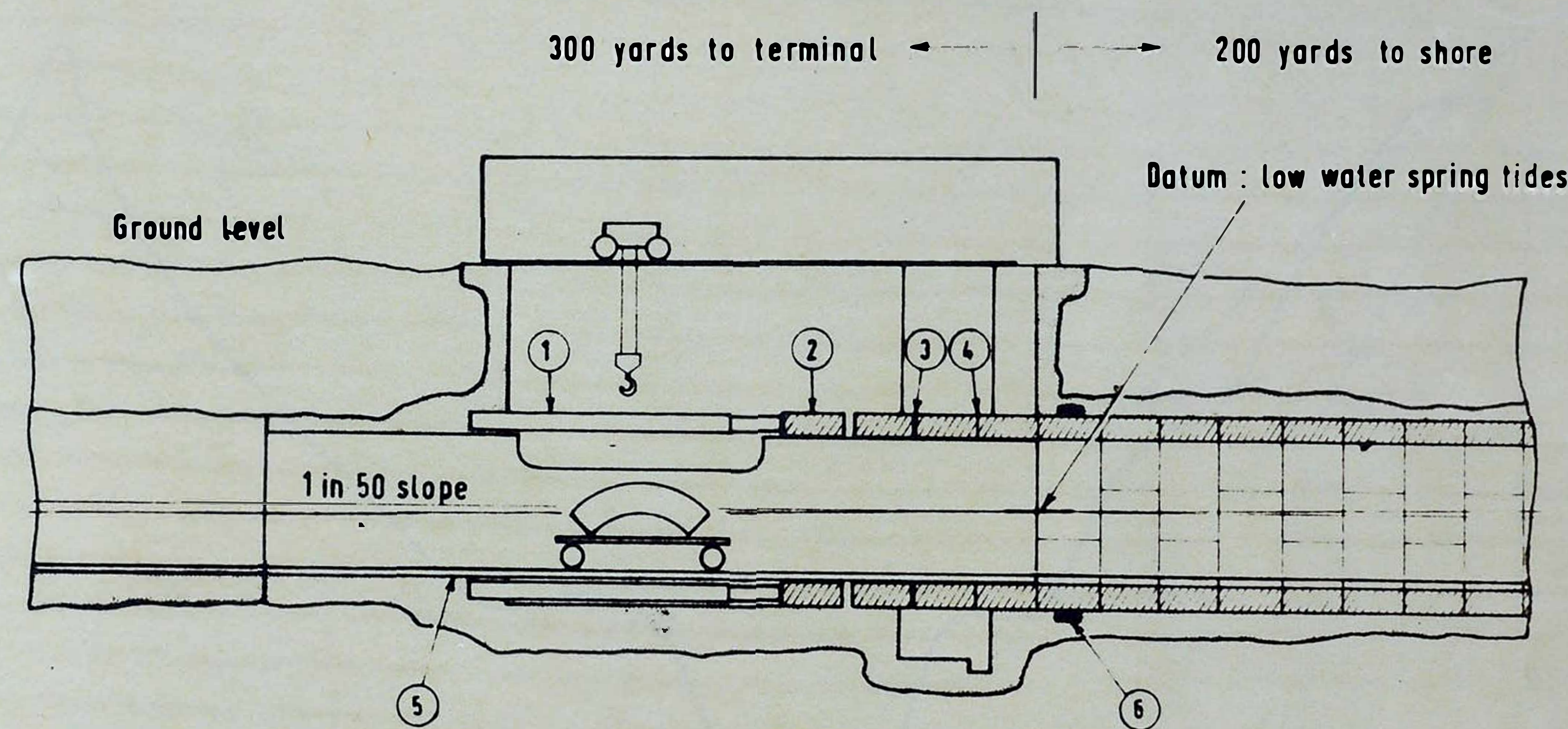


Fig. 2. Provisional choice of route



(1) Jacks
(2) Block assembly
(3) Welding
(4) Inspection and repair
(5) Bridging tube
(6) Water seal

The functions of the bridging tube are to permit rail access to the tube at all times during construction, and to provide support during assembly for the concrete blocks. Tube materials are unloaded from rail trucks through an aperture in the roof.

Fig. 1. Shore assembly station

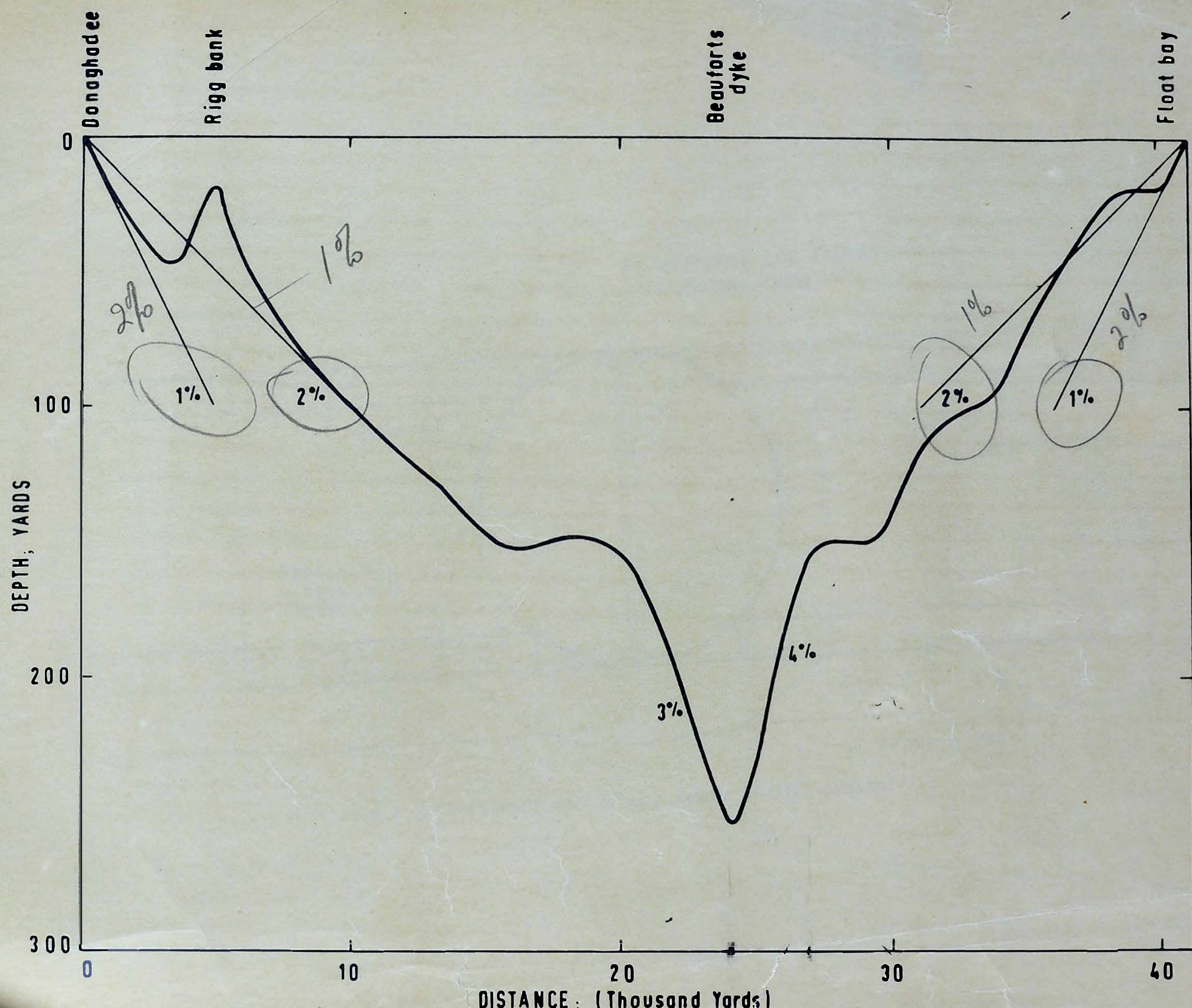


Fig.3 Sea bed profile

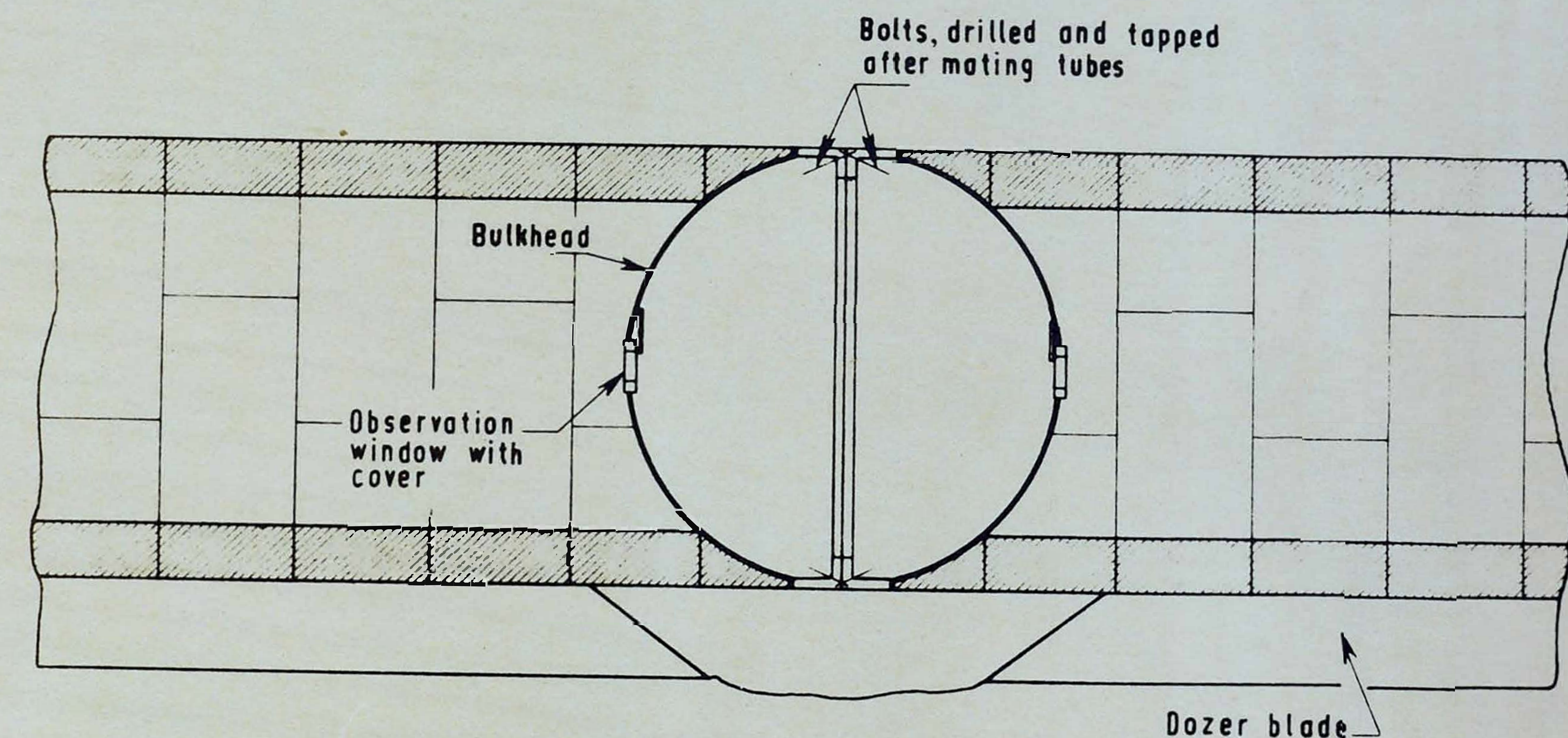


Fig. 4 Arrangements for joining tubes at mid-channel