Case Study — The Humber Bridge

Cas d'étude — le pont de Humber

Studienfall — Die Humberbrücke

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SUMMARY
This case study demonstrates how the "British System", employing a Consulting Engineer, works to achieve "better Projects from the Owner's Point of View". The four decades of endeavour in which the Owner was involved before he could achieve Governmental permission to go ahead with his desired project to cross the Humber, is briefly summarised. The manner in which the consulting engineer assists the Owner in such circumstances is illustrated. The study indicates how the design of the Humber Bridge has evolved from those of its predecessors crossing the Forth, Severn and Bosphorus, each in turn being conceived to achieve a better project from the Owner's point of view.

RESUME
Cette étude montre comment le "système britannique" — collaboration d'un ingénieur conseil — mène à de "meilleurs projets du point de vue du maître de l'ouvrage". Un résumé est donné des quatre décennies nécessaires au maître de l'ouvrage pour obtenir la permission gouvernementale de réaliser son projet, le pont sur le Humber. L'aide de l'ingénieur conseil au maître de l'ouvrage dans un tel cas est illustrée. Cette étude indique comment les projets de ponts antérieurs, sur le Forth, la Severn et le Bosphore, ont influencé le projet du Humber Bridge — chaque pont ayant été conçu de façon à résulter dans un meilleur projet du point de vue du maître de l'ouvrage.

ZUSAMMENFASSUNG
An einem Beispiel wird gezeigt, wie das „britische System", durch Einsetzen eines beratenden Ingenieurs, „bessere Projekte vom Standpunkt des Bauherrn" ermöglicht. Ein kurzer Überblick wird gegeben über die vier Jahrzehnte, während denen der Bauherr um die amtliche Bewilligung für die Überbrückung des Humbers kämpfte. Der Bericht zeigt, wie der Entwurf der Humber-Brücke sich aus den früher erstellten Brücken über den Forth, Severn und Bosporus entwickelte, und wie jede von diesen Brücken zu einem immer besseren Projekt führte.

1. INTRODUCTION

1.1 The "British System" for the design and construction of bridges and other major projects, having evolved over a very long period, operates with the Owner's interest in a "better Project" very much in mind. It is usual for the Owner to employ one organisation, frequently a consulting engineer, to appraise requirements, design structures to suit those requirements, estimate costs, advise on contract conditions, and prepare specifications together with contract documents. He usually advises the Owner as to suitable contractors, and upon tenders and supervises construction both in the technical and contractual sense, of the project.

1.2 In this system the contractor is normally but not invariably appointed as a result of competitive tendering for construction only of the consulting engineer's design. However if a contractor considers the consultant's design to be uneconomic, he is usually permitted to enter an additional bid on his own design alternative which, to be successful, must not only be the lowest tender but must meet the criteria of sound design. The contractor is responsible for everything necessary for construction, including the supply of materials, the recruitment of the labour force and its management.

1.3 The "European System", whereby competitive tenders are sought from contractors both to design and build the project, has been little used in UK for bridge schemes, although recently some limited experiment in this direction is taking place. The author's firm however has on a number of occasions acted with success as bridge designer for British and overseas contractors engaged in design and build competitions abroad.

1.4 In the following Case Study, the operation of the "British System" for achieving better projects is illustrated by the development of the Humber Bridge, tracing its lineage through its predecessors crossing the Forth, Severn and Bosporus.

1.5 The author's firm (in association with another firm for the Forth and Severn Bridges) has been responsible for all four structures - he believes to the advantage of the structure, the Owner and, of course, to the design team. In the latter case he refers not only to the obvious kudos attaching to these major structures, but to the fact that big bridge engineering, as for any other large structure, demands an expertise which can only be acquired by experience and maintained by practice.

1.6 The current problems of the Humber Bridge and the consequent delays have received a good deal of publicity, especially in Britain. These difficulties, briefly mentioned later, have arisen largely from causes not of an engineering nature.

1.7 The outline descriptions which follow will suffice to demonstrate how the "British System" works, and indicate its flexibility, whether the gestation period to obtain the "go ahead" for the project is extremely long, or very short as at Bosporus. (3.5.1)

2. THE BRITISH SYSTEM - HUMBER BRIDGE HISTORY

2.1 The time scale for the realisation of the Humber Bridge project is typical of major estuarial crossings in the UK. Proposals and ideas for crossing the river by a tunnel or by a bridge carrying road or rail had been mooted locally for well over 100 years. In the late 1920s the City and Corporation of Hull approached Mr (later Sir) Ralph Freeman (Freeman Fox & Partners) to examine the problem and produce recommendations for a crossing either by bridge or tunnel. After careful study of all the data available at that time, Freeman proposed the construction of a multi-span steel truss bridge, having a navigation span of 900 ft (275m).

The bridge was to carry a 36 ft (11m) wide highway. He estimated the cost (1930) to be about £1.7M and suggested a toll of 3/4d (approx £0.17).

2.2 However, before such an estuarial crossing can be constructed in the UK, an Act of Parliament is required and there was much opposition to the Humber structure, especially from those concerned with the river and its navigation. On behalf of his Client, Freeman attended Parliamentary Committees and was cross-examined for many days by leading King's Counsels acting for the objectors, as to the soundness of the structure he proposed and especially regarding its effects upon the river and navigation. Space does not permit elaboration here upon the problems, which were considerable.

2.3 Such was the strength of his evidence that in spite of its opponents, the necessary Act of Parliament would have been obtained had it not been for the collapse of the Ramsay MacDonald Labour Government in the 1931 UK Financial Crisis. The project was of no interest to MacDonald's successors.

2.4 Fortunately, although politicians and governments may come and go, the desire of people to construct artefacts of lasting use to the community is more permanent. So it was in Hull, and for the ensuing years from then until his death in 1950, Freeman continued intermittently studying the problems of the Bridge for his Client, putting forward a series of alternative schemes. Realising that the force of the objectors' arguments (to be faced again when another Act was sought) would be largely removed if the Bridge could span the river in one leap, he was inspired in the late 1930s by the successful completion of the Golden Gate Bridge (span 4200 ft) and, for the first time, put forward the solution of a very large-span suspension bridge. Subsequently, successive refinements of that design were proposed.

2.5 In 1955, Freeman Fox, under my old chief, the late Sir Gilbert Roberts, prepared a comprehensive report for the Client, proposing a 4580 ft span truss suspension bridge (based on a Forth Road Bridge design then being carried out). The estimated cost was about £16M, including approach roads. That proposal formed the basis upon which the Client again sought to obtain the Act of Parliament necessary to build. The Consulting Engineer carried out all the technical work needed to support him.

2.6 The Humber Bridge Act was passed in 1959, inter alia, creating the Humber Bridge Board and giving them powers to construct the project (and operate it as a toll bridge) - subject to Treasury permission to raise the necessary funds. The Client had, alas, won a Pyrrhic victory, since those last few words effectively laid an embargo upon further progress. The necessary permission was not forthcoming.

2.7 Nonetheless, behind the scenes, Bridge Board and consulting engineer continued to examine the problems: as is usual in such cases with very little money available. As developments occurred, especially with the breakthrough in design and construction of the Severn Bridge (3.4) the consulting engineer kept the Humber Bridge Board informed. The Board, in turn, made persistent overtures to Government.

2.8 The Board suffered a bitter blow in the mid 1960s when the Government Minister responsible for motorway strategy, decided against a bridge over the Humber at Hull forming part of the link between Hull and the north/south Motorway system. Instead, the crossing (free of tolls) was made about 20 miles upstream at Boothferry, thereby effectively duplicating the Humber Bridge when it is finished. The essentials of the arrangement are illustrated in Fig 1.

2.9 In 1967 Government made small sums available to the Board and a geotechnical site investigation was carried out under the direction of the consulting engineer in the areas of the proposed towers and anchorages for the Humber Bridge. Aerodynamic tests were also carried out to verify the viability of a streamlined box stiffening girder.

2.10 In 1969, the now defunct Department of Economic Affairs, published its Report entitled "Humberside - A Feasibility Study". This report concluded that the provision of a Humber Bridge at Hull was essential to the development of Humberside. Indeed, it envisaged a second crossing probably being needed by around the year 2000.

2.11 About this time, a further small sum of money from Government permitted the Bridge Board to commission a Traffic and Revenue Study, to investigate whether or not the bridge could be funded from tolls. The answer was in the affirmative, even if the development envisaged by the "Humberside Feasibility Study" did not occur. Finance constrained this traffic and revenue investigation to be limited to a "desk study" ie based on existing information including Government data regarding forecasts of economic growth, birthrate, car ownership and the like. Of course no assessment of economic benefit to the community arising from the presence of the bridge were taken into account. It was learnt later that an appropriate Government Department had parelled the traffic study and had arrived at similar answers.

2.12 In 1971 the Bridge Board, aided again in all technical details by the consulting engineer, succeeded in obtaining an Act of Parliament (Conservative Government) permitting the construction of the Humber Bridge on the alignment and to a span not smaller than that in the 1959 Act, but with somewhat shorter approach roads. Funding was to be by loans - 75% from Government and 25% privately raised. As in the 1959 Act, loans and interest thereon were to be amortized by toll charges on the traffic.

2.13 The way was now open for the consulting engineer to get down to the business of final design of the project, all necessary technical investigations associated with it, preparation of the contract drawings and documents, advice to the Bridge Board on the forms the contracts should take and on suitable contractors. The Contract for the foundations of the main bridge was awarded in February 1973 and that for the superstructure, one month later.

2.14 The Client - now the "Humber Bridge Board", (apart from their Technical Officer) is a non-engineering body but was and is nonetheless the decision maker with regard to all matters affecting bridge policy. The consulting engineer had been helping and advising the Client (or Owner) for a period of nearly 50 years. In that time, Client and Engineer have become closely acquainted and inevitably the Engineer became aware of and "soaked up" a whole lot of data and background knowledge to apply to the project, which would not have been achieved under another system of working.

2.15 In the meantime also, the team in the author's firm, who had carried out the design and development of the Forth and Severn Bridges, and had been intimately involved in their construction, met with further success in the Bosporus Bridge. The benefit of all the development work, construction experience and in-service "feed-back" related to those bridges, was to be built into the design of the Humber Bridge.

3. FORTH, SEVERN AND BOSPORUS BRIDGE DEVELOPMENTS

3.1 In this section are summarised in order of construction, the major developments in the Forth, Severn and Bosporus Bridges, some of which were to influence the final design of Humber. For ease of reference comparative basic data concerning each bridge appear in Table I.

3.2 The design of the Severn suspension bridge started soon after the end of World War II, but it was the Forth Bridge which was constructed first with the Severn Bridge opening some two years later. The apparently inordinate lapse of time between commencement and opening was not due to inefficiency on the designers' part but reflects the vagaries and vicissitudes, largely political, which these major schemes seem to suffer, certainly in UK, until the final moment of "go-ahead". Good use was however made of this time to develop novel engineering solutions to many problems.

3.3 Forth Bridge

3.3.1 This structure represented, in essence, refinement of design concepts used in major American suspension bridges but introduced many new features of its own.[1,2]

3.3.2 The foundations featured tunnel anchorages rather than massive concrete gravity blocks and the cables were retained by strand shoes bolted to anchor plates held in place by prestressing steel, as opposed to the partially debonded eye bars of American practice.

3.3.3 The towers represented a radical departure, being constructed entirely of shop-welded high tensile steel instead of riveted assembly. Each tower leg was composed of five cells only, vertical seams being grip-bolted without cover plates, in contrast to the trans-Atlantic multi-cell rivetted structures spliced with covers. At each of the horizontal joints in the Forth towers, internally mounted high strength rods resisted tension forces occurring during erection, thereby dispensing with horizontal cover plates also. With regard to stability as a strut, previous practice had been to take the effective length of the tower as twice its free-standing height. For the Forth Bridge, analysis of the tower was treated from first principles, taking account of non-linear behaviour, with the member being fixed at its base and its top suffering deflections imposed by the cable, resulting from the loading and temperature of the bridge structure. All these refinements in tower design resulted in a very light and consequently economic structure.

3.3.4 The design and construction of the cables largely followed American practice, although somewhat higher stresses were employed viz 40 tons psi cf 38 tons psi. Lengthy comparative cost studies indicated an optimum cable sag ratio of about 1 to 11.

3.3.5 The suspended structure was notable again for its employment of welded high tensile steel members in the stiffening girders. Field splices were achieved using specially developed high strength waisted friction grip bolts. Further novelty and saving of dead load resulted from the employment on the main span of a trough stiffened steel orthotropic deck, surfaced with 1½ inches of stone-filled mastic. However, the steel deck did not contribute to the flexural rigidity of the girder, since expansion joints at 60 ft (18m) centres permitted relative movement between the two. Again departing from convention the stiffening girder was designed as a space frame. (3.3.8)

3.3.6 Aerodynamic stability was ensured by the lattice truss form of the stiffening girder which provided a complete torsion system, and the employment of generous longitudinal slots between the highway decks themselves and the footway and cycle units.

3.3.7 The very light suspended structure which resulted, in turn reduced the weight and therefore the cost of the cables and towers and, in consequence, the foundation loads.

3.3.8 To permit rigorous structural analysis, Southwell's treatment of Timoshenko's Method of Analysis of the Stiffened Suspension Bridge was itself refined by Crosthwaite [3] and, for the first time, (those were the days before the electronic computer), full treatment of the stiffening girder was possible. The Crosthwaite method dealt with variable inertia, hanger extension, extensibility of the web system in shear [4] and was adapted to deal with the stiffening girder as a torsion box. In parallel with the design, work was progressing on aerodynamic testing, particularly valuable contributions to the science being made by Fraser and Scruton[5] of the British National Physical Laboratory, especially in relation to the simulation of aerodynamic behaviour by the use of section models in wind tunnels.

3.3.9 Maintenance of the structure was given considerable thought in all detail design especially in relation to access for painting. Much experiment and investigation resulted in a then very high quality protective system, all structural steelwork being grit-blasted, zinc sprayed and painted with micaceous iron oxide.

3.3.10 The low cost (£9.3M) of the Forth Bridge superstructure, when completed, was achieved by the careful examination of every facet of existing types of design and developing new ideas to produce maximum refinement and hence economy.

3.4 Severn Bridge

3.4.1 The Severn Bridge, while carrying on the tradition of refinement from Forth, introduced a new concept. This was of course the replacement of the lattice stiffening girder by a streamlined box section member. This design and the development work from which it issued have been described by Roberts.[6]

3.4.2 The box was constructed entirely by welding, using a steel trough stiffened orthotropic deck plate in side spans as well as in the main span. However, in this bridge the deck surface is continuous and uninterrupted (except at towers and anchorages) in contrast to that of the Forth Bridge. (3.3.5)

3.4.3 Thus in the deck alone, detailing and construction became much simpler as well as eliminating maintenance problems of numerous small expansion joints. However one loss did result from this "cleaning up" of the design, namely the structural damping effects inherent wherever there are movement joints in a structure. To compensate for this loss, Roberts inclined the hanger ropes supporting the stiffening girder, thereby introducing hysterisis damping from these members in asymmetric modes of vibration. Some small tendency to cyclic aerodynamic movement had been manifested in wind tunnel tests on section models at small angles of incidence and this additional structural damping was provided to eliminate any significant amplitudes in the full-size structure.

3.4.4 As a result of the innovations to the deck shape, wind loading on the girder was only about one third of that on a truss with a participating deck, and one fifth of the load on the Forth trusses.

3.4.5 The tonnage of suspended steelwork was substantially reduced with resultant savings to towers, cables and foundation loads. Highly important to the Owner from the maintenance point of view, a smooth easily paintable underside to the structure was provided (access being by gantry) an arrangement vastly easier to paint than the trusses of Forth (also provided with gantries) or, for that matter, any other truss bridge. Additionally, internal access, when necessary, to the box girder provides ease of inspection and maintenance of all its structural parts.

3.4.6 The shallow stiffening girder improved the naturally graceful appearance of the suspension form and the reduction of lateral wind loading permitted a portal braced tower which still preserved great economy. Maximum simplicity was achieved in the tower where the legs themselves consisted of single cells formed of four longitudinally stiffened plates, site spliced by entirely concealed bolts.

3.4.7 The difference in cost between the Severn Bridge superstructure - £5.97M and the Forth is immediately apparent and arose largely from the developments briefly summarised above. Tenders for the fully developed design based on a trussed stiffening girder with a fully participating steel deck indicated costs 13% in excess of those of the box structure.

3.5 Bosporus Bridge

3.5.1 The programme for pre-construction work on the Bosporus Bridge was, for the consulting engineers, in complete contrast to the time scale for the bridges in UK, although tentative engineering solutions had been proposed for the Bosporus in the latter part of the 19th century. A formal agreement was made between the Turkish Government and the author's firm in January 1968. A matter of a mere 9 months was allowed for the collection of site data and for design, with completion of the bridge in less than four years.

3.5.2 Brown and Parsons[7] stated that previous design experience was of value and it was possible not only to introduce several innovations but to consolidate and adapt previous designs to suit the site conditions. The bridge is thus "a design suited to its location".

3.5.3 Although design and all tender documents were prepared by the consulting engineers to schedule, financing arrangements took rather longer and tenders could not be invited from international contracting consortia until June 1969.

3.5.4 For this bridge, a six-lane highway, the consultants preferred design was a 3m deep streamlined box girder. However, bearing in mind the fact that not all international fabricators might be so happy with box girder construction as with the more familiar truss form, a scheme based on an alternative 6m deep truss structure with a fully participating steel deck was also designed and tenders sought upon both schemes.

3.5.5 Bearing in mind that equal expertise went into the design of both schemes it is illuminating to note that none of the four bidders (three European and one Japanese) tendered on the truss scheme, although no American tenders were received. The streamlined box offered considerable economy in first cost compared to the truss, even in an international situation. UK experience seemed confirmed.

3.5.6 Two features about the design are of especial interest in relation to subsequent events at Humber. The Bosporus piers were removed from the water (as opposed to earlier designs by others) thereby reducing costs and eliminating the risks of delay inherent in such construction. The tender design envisaged the use of preformed parallel wire strands for the main cables; however, the winning tender was based upon the aerial spinning method using improved gear developed by the Contractor[8] from that used on the Forth[9] and Severn[10] Bridges. Aerial spinning proved even more successful than it had on the Severn Bridge.

3.5.7 As he did for the UK bridges, so also the consulting engineer supervised construction of this work, not only on site, for his responsibilities included inspection of supply and fabrication sources in Germany, Italy, France, Turkey and UK.

3.5.8 The Contract starting date was April 1970 and the bridge was available to carry public traffic by August 1973.

4. HUMBER BRIDGE

4.1 Against the preceding background, the final design of the Humber Bridge was undertaken. The most notable site-dictated aspects of this structure are the size of its main span and the asymmetry of its side spans (Table 1). In design the most unusual features relate to the south anchorage and pier foundations in very difficult ground, and to the towers. The suspended structure Fig 2 is a clear derivation of those at Severn and Bosporus. Like Severn, this structure carries a 4-lane highway with footways and cycle tracks. With a 40% longer main span, the box section stiffening girder is appreciably deeper than either of its predecessors in order to achieve critical flutter speeds of an acceptably high level.

4.2 The material upon which the south foundations rest is Kimmeridge Clay overlain by alluvial and glacial "muck" and some of the soil problems have been described by Simm and Busbridge[11]. Diaphragm walling was extensively employed in the design of the south anchorage foundations where, to avoid reduced resistance to sliding, it was imperative to minimise heave during excavation and consequent entry of water into the fissures of the clay. Similar considerations governed the design of special open-dredged caissons, sunk with the aid of bentonite lubrication, to support the south pier[12].

4.3 The designers, taking account of known UK costs and attitudes of the different types of construction labour, departed from previous practice and planned the Humber towers in reinforced concrete. They are by far the largest suspension bridge towers to be constructed in this material. The whole design was based on the assumption that construction would be by slip-forming. By this means, concrete towers could approach the speed of construction of their counterparts in steel even if the latter material suffered no interruptions either due to wind, rain or industrial difficulties. Furthermore, the designers decided, in order to speed construction, to omit the lower two portal beams of the second (south) tower to be constructed, until catwalk erection was complete, thereby removing these portal members from the critical path.

4.4 The saving using concrete was, at the design stage 1972, estimated at about £1.5M (minimum) compared to a steel tower, even using all the refinements displayed in the Severn and Bosporus tower designs. Fig 3 gives outline arrangements of the tower types.

4.5 In construction, the decision to use concrete has proved fully justified. The start of the south tower construction was delayed due to various causes, but once slip-forming commenced, it was carried out, irrespective of weather, non-stop except for a short break at Easter and Whitsun (1976), seven days a week, 24 hours a day, the heavily reinforced 152m high legs being "slid" in a period of some 10 weeks. This represented a first-class performance by the specialist subcontractor concerned.

4.6 The asymmetry of the bridge produces steep back stays in the north side span thereby increasing the cable tension in that area. To avoid a larger cable throughout the structure, a similar device to that used at Bosporus has been employed. Four additional strands are provided in each north side span cable and anchored to the saddles on top of the north tower.

4.7 The design of the cable was based on the aerial spinning method in view of the experience at Severn and at Bosporus regarding the winning tender (3.5.6) and the very good performance achieved there[8]. Unfortunately however much time has been lost at Humber due to really and allegedly unsuitable weather conditions.

4.8 Much care has been devoted by the designers and their architectural advisers to aesthetics, not only for the bridge itself, but for the approach structures, roads, administration building, toll plaza and parking areas. All earthworks have been carefully landscaped. To break up the monotonous appearance of the large masses of the concrete anchorages, bold ribbed treatment has been employed. In the towers, engineering and aesthetic requirements have married to produce heavy radiusing of corners to reduce wind drag, while the arrangement and sizing if the portal beams was also carefully considered from both points of view. In relation to total project costs, regard to aesthetic considerations has been a miniscule expense.

4.9 With regard to maintenance, a new paint system considered to offer very good protection in highly corrosive atmospheres is being employed. Again, it is based on blast-cleaned steelwork followed by a blast primer, three coats of zinc phosphate epoxy ester (a single pack material) and two finishing coats of chlorinated rubber paint. Use of concrete rather than steel towers should greatly reduce maintenance of these members.

4.10 In two notable respects Humber is proving more difficult than its predecessors - namely, delays on site and inflation. Construction of the bridge foundations started in 1973 and, since that time, delays have resulted from a wide variety of causes including effects arising from the oil crisis which, additionally, presaged a period of unprecedented inflation in UK. Inter alia, bad weather and unwillingness to work in marginal weather conditions have caused further difficulties. "Pure" engineering problems fortunately, so far, have been few in number, and all related to the construction of the south caissons and cutwater described briefly by Wex[12]. To have eliminated the problems of construction in water (albeit relatively shallow) by moving the south pier to the land, as at Bosporus (3.5.6), would have necessitated a main span of 1940m at greatly increased cost.

4.11 The costs for the superstructures of Humber and its predecessors are given in Table I. The figure of £15.1M shown for Humber is the 1972 tender price. In comparing that figure with the costs of the earlier bridges it should be borne in mind that not inconsiderable inflation occurred between 1966 and 1972 (it became much worse after 1973). The overall cost of each project does not appear since each has contained differing amounts of approach works and the like. Similarly foundation costs cannot usefully be compared since these depend so much on local ground conditions.

4.12 As the clear span of a bridge increases, so does its cost. For large steel bridges it is generally recognised that the cost of the superstructure is roughly proportional to the tonnage of steel it contains. Indeed, in times of inflation it is far more meaningful to compare costs of projects in terms of material quantities rather than money. Fig 4 shows the steel tonnage (including the towers) per lane metre of the superstructures of the world's largest suspension bridges as a function of main span length. The structures appear to fall into three families; truss bridges of pre-war design, truss bridges of post war design and the British designed box girder family. For increasing span the economy of this last form of construction in terms of steel tonnage is apparent, Humber demonstrating very clearly the same economy as its Severn and Bosporus predecessors. In considering Fig 4 it should not be forgotten that British highway loadings are more severe than American.

4.13 Criticism has been levelled at the project within the UK on the grounds that the 1969 Traffic Estimates were over-optimistic with regard to the number of vehicles that would use the bridge (2.11). Of course they appear so now. When those forecasts were made the consulting engineer did not foresee the 1973 oil crisis, the resulting recession in the British economy, or the drop in the birth-rate. Neither, may it be said, did the politicians who have made the criticisms.

However , the 1969 traffic figures were forecasts and so are any of today's estimates, by whomsoever they are made. Forecasts based on current knowledge continue to show the project viable as a toll bridge. The toll for cars is at present tentatively proposed at £.80 by the Bridge Board. This compares very favourably with the figure of £0.17 in 1930 (2.1). The crossing, of course, cannot fail to bring economic benefit to the region.

5. CONCLUSIONS

5.1 This case study has shown how the employment of one consulting engineer operating under the "British system" has permitted the application of technical innovation, refinement and experience to the designs of four successive big suspension bridges to "achieve better projects from the Owner's point of view".

5.2 Local skills, resources and abilities have long been taken into account by good designers. It is clear however that they must be ever more vigilant regarding the attitude towards work of the various types of operatives to be involved in construction. Thus design concepts and indeed details must not only suit all the usual technical and skills criteria, but human attitudes must increasingly be taken into account. These clearly vary from time to time, place to place and from nation to nation. Indeed, clients and potential owners should realise that technically feasible projects which would be straightforward to construct in one place, may be very difficult in another simply because of such attitudes. Against such considerations of course must be weighed the long term benefits likely to result from the completed project.

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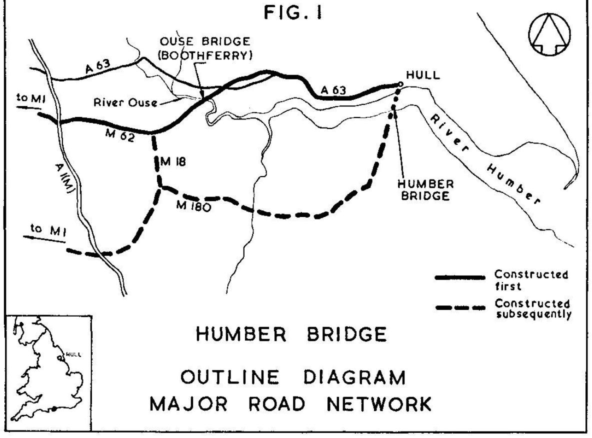
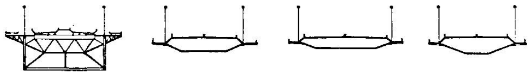
FIG. 1



HUMBER BRIDGE

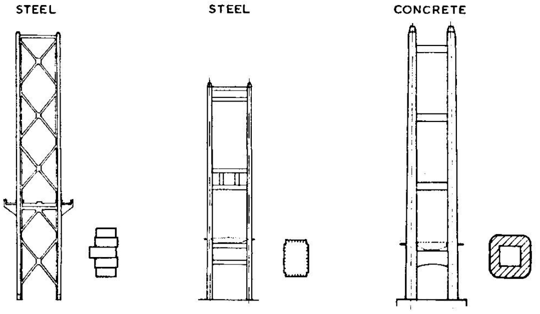
OUTLINE DIAGRAM
MAJOR ROAD NETWORK

FIG. 2



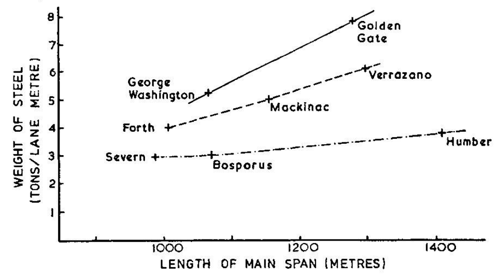
STIFFENING GIRDER CONFIGURATIONS

FIG. 3



TOWER COMPARISONS

FIG. 4



+ Based on total steelwork including towers.
For Humber bridge a weight of steelwork equivalent in cost to the concrete towers is included.

TONNAGE OF STEEL v MAIN SPAN
FOR
MAJOR SUSPENSION BRIDGES

TABLE I

COMPARATIVE DATA - SUSPENSION BRIDGES

	FORTH	SEVERN	BOSPORUS	HUMBER
Main Span metres	1000.58	978.5	1074	1410
Side Spans metres	408.4 408.4	304.8 304.8	255 (non- 231 suspended)	530 280
No of Highway Lanes	4	4	6	4
Footways & Cycle Tracks	Yes	Yes	Yes	Yes
Height of Towers - metres	150	122	165	155
Cable Sag Ratio	1 : 11	1 : 12	1 : 11.5	1 : 12.2
Width between cables - metres	23.8	22.9	28	22
Overall Depth Stiffening Girder	9m approx	3.05 m	3 m	4.5 m
Tower Material and type	Steel diagonally braced	Steel portal braced	Steel portal braced	Concrete portal braced
Approx tonnage in suspended steelwork	14000	11300	8700 + 2950 in sidespans	16000
Approx tonnage in Cables	7400	4300	5400	11000
Tonnage of steel in Towers	5150	2360	4600	4000 * equivalent
Date Bridge completed	1964	1968	1973	Under construction
Approx cost of Superstructure	£9.34M	£5.97M	US$ 29M = £12.1M	£15.1M +

* Approximate steel tonnage equivalent to actual cost of concrete towers

\+ Tender figure 1972 prices