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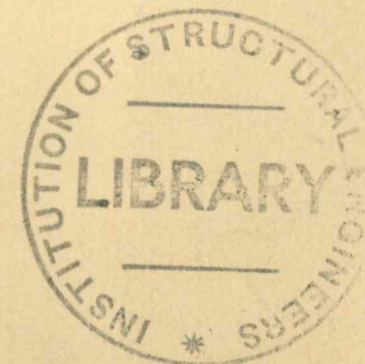
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DEPARTMENT OF THE ENVIRONMENT
SCOTTISH DEVELOPMENT DEPARTMENT
WELSH OFFICE

Inquiry into the Basis of Design and Method of Erection of Steel-Box Girder Bridges

Report of the Committee



LONDON
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and Method of Erection of
Steel Box-Girder Bridges**

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This is an abridged version

LONDON
HER MAJESTY'S STATIONERY OFFICE

1973

**COMMITTEE OF INQUIRY INTO THE BASIS OF DESIGN
AND METHOD OF ERECTION OF STEEL BOX-GIRDER BRIDGES**

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Senior Partner, Sir Fredrick Snow and Partners, Consulting
Engineers.

To:

The Rt. Hon. Geoffrey Rippon, M.P.
Secretary of State for the Environment.

Sir,

In December 1970, following the collapses of the box-girder bridges spanning the Cleddau River at Milford Haven and the Yarra River at Melbourne, your predecessor as Secretary of State for the Environment, in association with the Secretaries of State for Scotland and Wales, appointed us as an independent technical committee with the following terms of reference:

"1. To consider whether the collapse of the Milford Haven and Yarra Bridges necessitates reconsideration of the design and method of erection for any major box-girder bridges about to be erected in the United Kingdom.

2. To examine the design rules and methods of analysis used for steel box-girder deck structures for large bridges, and to draw up an interim technical memorandum for the guidance of bridge engineers, prescribing the rules and methods to be adopted in the design and erection of such bridges, the limits within which such designs may be accepted, and any special matters affecting contract procedures.

3. To recommend what further research and development should be undertaken into this type of construction."

In June 1971 we submitted an Interim Report to your predecessor as Secretary of State, in order to give designers of steel box-girder bridges immediate access to our preliminary conclusions and to avoid serious consequences that delay would have had on bridges about to be erected, in particular those at Avonmouth and Milford Haven. We present now our final Report, though, as with any report on a developing engineering situation, we do not pretend that what we propose will remain unmodified in the future. Our Report gives the best advice we can offer at the present time.

We believe that we have now discharged, to the best of our ability, the task put to us by your predecessor, and we recommend that we now be disbanded as a committee. The British Standards Institution is now preparing a new Code of Practice which will cover steel box-girder bridges and we make recommendations in our Report as to the way the design and erection of such bridges should be supervised until that Code of Practice is available.

We should like to pay tribute to the vital part played in our work by many of your own officials, particularly Mr. David Holland who has been our

Adviser throughout; Mr. B. J. Hardy and Mr. T. J. Carroll, Senior Engineers in the Directorate General of Highways, who acted as successive technical secretaries to the Committee; and Mr. J. N. Thompson, administrative secretary to the Committee during the final stages of our work.

(Signed) A. W. Merrison (*Chairman*)
A. R. Flint
W. J. Harper
M. R. Horne
G. F. B. Scruby

28th February 1973

REPORT OF THE COMMITTEE

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* Appendix 1 to this Report, the Interim Design and Workmanship Rules, is presented separately.

It has four parts:

Part I Loading and General Design Requirements

Part II Design Rules

Part III Basis for the Design Rules and for the design of special structures not within the scope of Part II

Part IV Materials and Workmanship.

Parts I and II are contained together in one document; Parts III and IV are contained in separate documents. The documents are published by H.M.S.O.

REPORT OF THE COMMITTEE

CHAPTER 1: INTRODUCTION

1.1. Our Interim Report* consisted essentially of:

- (a) a commentary on the Milford Haven collapse;
- (b) a general commentary on the situation as we saw it of the state of design and construction of steel box-girder bridges;
- (c) rules for appraising the design of such bridges, aimed specifically at the Milford Haven and Avonmouth Bridges; and
- (d) a commentary on contractual procedures.

As a result of our investigation since our Interim Report was submitted, and particularly as a result of research work we have commissioned, we have gathered together a great deal of information of importance to bridge engineers and we have incorporated this into the advice we now offer. At the same time, it would be right to say that we have learned nothing which has caused us to doubt the principles to which we worked in our Interim Report. Our final Report contains six chapters, including this introductory chapter, and three Appendices, including Appendix I, which is presented separately. In Chapter 2 we consider what lessons are to be learned from the two accidents which were the immediate reason for our appointment and in Chapter 3 we consider further the contractual and procedural aspects of our subject. Chapter 4 deals with the development of the Appraisal Rules, which were set out in Appendix A of our Interim Report, into the "Interim Design and Workmanship Rules" contained in Appendix I of our present Report. In Chapter 4 we also consider the development of the principles forming the basis of the Interim Design and Workmanship Rules into a Code of Practice and we go on, in Chapter 5, to discuss the procedures now in force for updating British Standard Codes of Practice in the civil engineering field and initiating research where necessary. In our final chapter we summarise our conclusions and recommendations.

1.2. On the contractual and procedural side, we have reviewed the proposals and recommendations made in Appendix B of our Interim Report and, as we promised in paragraph 19 of that Appendix, we have given careful consideration to the suitability of the usual contractual arrangements for the building of major bridges. We have followed with close interest the progress of the Joint Contracts Committee of the Institution of Civil Engineers, the Association of Consulting Engineers and the Federation of Civil Engineering Contractors in their consideration of revisions to the I.C.E. Conditions of Contract†. We are

* "Inquiry into the Basis of Design and Method of Erection of Steel Box-Girder Bridges: Interim Report", published by H.M.S.O., September 1971.

† "General Conditions of Contract and Forms of Tender Agreement and Bond for use in connection with Works of Civil Engineering Construction", published by the I.C.E., the A.C.E. and the F.C.E.C., 4th Edition, January 1955, amended January 1969.

grateful to the Committee for giving us the opportunity of making known our views to them.

1.3. In this context we would like to say a few words on a subject which, though not strictly within our terms of reference, we do feel it is right for us to mention, namely the safety of men employed on bridge construction. We are very pleased to note that the revised I.C.E. Conditions of Contract are likely to include a considerably strengthened clause setting out the responsibility of the Contractor for the safety of workmen and others entitled to be on the site. We touch on the question of safety again in Chapter 3.

1.4. In any major highway bridge construction in this country, the Department of the Environment and the British Standards Institution have important roles to play. The Department of the Environment is often the client for major bridges but, in any case, since so many of the bridges for which the Department is not directly responsible are nonetheless funded, in part at least, from the public purse, it still has a part to play even in these bridge projects. In this way, the Department's approval in principle is necessary on technical aspects of the design of most major bridges in England, and in Chapter 3 we mention the Department's proposals for alterations to their approval system. The Scottish Development Department, the Welsh Office and the Northern Ireland Ministry of Development have corresponding functions for major bridges in the United Kingdom outside England.

1.5. The British Standards Institution is the body in this country charged with issuing "Codes of Practice" on which the design of major engineering contracts is likely to be based. We have had a fruitful discussion with Dr. G. B. R. Feilden, Director General of the B.S.I., and we draw on this and other contacts with B.S.I. staff in Chapter 5.

Sources of Information for our Final Report

1.6. In writing our Interim Report we had available to us four excellent reports (listed in paragraph 10 of our Interim Report) on the collapse of the Milford Haven Bridge. Our Interim Report discusses this failure and its cause (paragraphs 9-17), and we discuss it briefly again in Chapter 2. We knew at the time of submitting our Interim Report that two sources of information not then available to us would contribute in an essential way to our final conclusions. The first was the Royal Commission of Inquiry into the collapse of the West Gate Bridge over the River Yarra, which had not then reported. We expected—as indeed has proved to be the case—that there was much to be learned from this Inquiry*. The second source of information was the research projects which we commissioned to throw light on the areas of uncertainty in the field of box-girder bridge design which we had already identified at the time of submitting our Interim Report. The results of this research work, which

* "Report of the Royal Commission into the Failure of West Gate Bridge", published by the Government of the State of Victoria, 1971.

became available during the earlier part of 1972, have been an essential factor in determining our final recommendations.

1.7. In June 1971, the Secretary of State for the Environment, largely as a result of deficiencies discovered in a new motorway bridge on one of the approach roads to the new Mersey Tunnel, decided to impose traffic restrictions on the 51 steel box-girder highway bridges then in use in England, and he decided also that these restrictions should remain in force until the design of these bridges had been checked against the Appraisal Rules contained in Appendix A of our Interim Report. The Committee have been consulted by the Department of the Environment on the more important problems arising during the conduct of these appraisal checks, and this process was of assistance in the preparation of the Design Rules. We deal with the subject of the appraisal checks in paragraphs 5-6 of Chapter 2.

1.8. In November 1971 a steel box-girder bridge collapsed while being erected over the River Rhine near Koblenz, and twelve men perished in the accident. Through the generosity of the Government of the Federal Republic of Germany, two engineers from the Department of the Environment were given every help in making an assessment of the cause of the accident and we received a verbal report from them. Although what we have learned from this disaster has not caused us to alter in any way the advice and recommendations we give in this Report, it serves as a stark example of how vital it is for both designers and those checking designs to understand the limitations of standard design directives. The official final statement issued by the State Attorney of Koblenz on 15 November 1972* also highlights the importance which must be attached to the use of design principles which make clear the basis on which structural details should be devised.

1.9. All the sources of information mentioned above have been useful and important. A major contribution to the framing of the Interim Design and Workmanship Rules set out in Appendix I has been made by the bridge engineering profession itself. Apart from day-to-day contact, we have been able on two particular occasions to obtain from the engineers concerned criticism (some of it sharp!) of the Interim Design and Workmanship Rules, and in return to expose to them the principles to which we have worked. Our confidence in the work we have done has been reinforced by the discussions we have had with these numerous members of the bridge engineering profession.

* "Abschliessende Presseinformation der Staatsanwaltschaft Koblenz zum Einsturz der Koblenzer Rheinbrücke am 10 November 1971".

CHAPTER 2: THE COLLAPSES OF THE MILFORD HAVEN AND WEST GATE BRIDGES

CHECKING OF STEEL BOX-GIRDER BRIDGES IN BRITAIN

2.1. We decided from the outset that to complete our Inquiry under the first of our terms of reference, it would be necessary to identify to our satisfaction the causes of the collapses of the Milford Haven and West Gate (Yarra) Bridges. Principally because of the four reports mentioned in paragraph 6 of Chapter 1, we had little trouble in identifying the primary cause of the Milford Haven collapse as a failure in design. The immediate cause of the collapse was the failure of the diaphragm over Pier 6, and the evidence is that this weakness was not primarily due to any inaccuracy in fabrication. The diaphragm as designed was simply not strong enough to resist the forces to which it was subjected while Span 5-6 was being cantilevered out from Pier 6. It was because this inadequacy had occurred and had not been exposed by the checking procedures which were then current that we recommended in our Interim Report improved ways of checking permanent designs and erection procedures. This we consider again in Chapter 3. Although the guidance in the use and application of the available knowledge was inadequate, we consider that independent checking of some such kind as we have suggested would have revealed the need for further consideration of the strength of the diaphragm.

2.2. The causes of the collapse of the West Gate Bridge were, by comparison with the Milford Haven accident, much more complex, and we should like here to pay tribute to the Royal Commission appointed to inquire into this disaster in which 35 men lost their lives. The Royal Commission under their Chairman, the Honourable Mr Justice Barber, have produced a very full report and we have taken the view that we could not in any way match the careful inquiry they have made into this accident. We have, therefore, accepted their technical assessment of events which led up to the collapse.

2.3. There are three main parties to a major engineering enterprise—the Client, the Engineer and the Contractor—and each of them has responsibilities towards the others. Lack of understanding of these responsibilities or a lack of co-operation between the parties concerned can be disastrous and there is no doubt at all that these were the principal factors contributing to the collapse of the West Gate Bridge.

2.4. Herein lies the important difference between the West Gate Bridge accident and that at Milford Haven for those seeking to apply the lessons to be derived from them in preventing such accidents in future. The lessons from Milford Haven concern the inadequacy of the design methods used for the permanent design and for the calculations of safety during erection and the arrangements for checking such calculations. While there were also funda-

mental defects in the erection procedure and permanent design of the West Gate Bridge, we regard the failures of site organisation and of communication between the principal parties—Client, Engineers and Contractors—as of more general significance in this case. There are lessons to be learned from practically every page of the Royal Commission's Report and we recommend all those connected in any way with bridge construction to study it in detail, as we have done. Those who read the Report will see that the recommendations on contractual procedures made in the next chapter are much influenced by the events at the River Yarra and by the Royal Commission's comments on them. In Chapter 3 we aim to suggest procedural principles which we think should prevent situations like that on the West Gate Bridge project from arising at all. We realise, however, that it is impossible to legislate against every form of human error and failing. In any undertaking involving complex organisation, success depends on a modicum of good sense and good will, and these are attributes which are essential in addition to the application of procedures.

2.5. Our terms of reference relate to the implications of two particular bridge failures, but there have been other instances of steel box-girder bridges collapsing or being found defective in design. It would have been impossible for us to give sufficient study to all these other incidents to arrive at any reliable conclusions from them for steel box-girder bridges in general, and we have made no attempt to do this. We have, however, as we mentioned in Chapter 1, taken note of the one major steel box-girder bridge accident which occurred since our appointment, that at Koblenz in November 1971. We have also considered the implications of the defects in the design of some steel box-girder bridges in England revealed by the series of appraisal checks ordered by the Secretary of State for the Environment following the submission of our Interim Report in June 1971. We mentioned in Chapter 1 that this series of checks covers the 51 steel box-girder highway bridges in service in England in June 1971, and it has so far also covered 37 bridges in England which were not yet in service in June 1971, including some for which contracts had not in fact been let at that time. Of the 51 in service bridges appraised, 19 were found to be completely adequate and the remaining 32 were found to need strengthening. Some indication of the extent of the strengthening required is given by calculating the weight of extra steel used as a percentage of total steelwork in the superstructure. Of the 26 bridges in service for which strengthening schemes have been completed these percentages range between 0.01 per cent and 7.2 per cent. It should be pointed out that the amounts of added steel are influenced in individual cases by considerations other than purely structural requirements, for example method of construction (welding or bolting), availability of material (steel of greater section than necessary has sometimes to be used), ease of fabrication and construction costs generally. Of the 37 unopened bridges which have so far been checked 28 have been found to need strengthening, and in the cases where the appraisal is complete, percentages of extra steel needed apart from 2 exceptional cases range between 0.2 per cent and 12.5 per cent. Here again not all the extra steel was necessary from a purely structural point of view and it would be wrong to infer that in

every case the percentage of extra steel can be interpreted as representing a direct comparison between the Committee's design philosophy and that previously regarded as constituting good practice.

2.6. The 88 English bridges in the two groups referred to above comprise the majority of the steel box-girder highway bridges in the United Kingdom. Checks corresponding to those in England have been carried out on steel box-girder bridges in Scotland, Wales and Northern Ireland by the relevant Highway Authorities and modifications in design have been made where necessary.

2.7. We are confident that all the bridges subjected to these appraisal checks will, strengthened as necessary, give safe service in future. Nevertheless designers should take the deficiencies discovered in the design of so many of the bridges appraised as a warning hardly less serious than the collapses of the Milford Haven, West Gate and Koblenz Bridges. We would suggest that an error which may have led to many of the design defects found in the British bridges is the excessively mechanical use of Codes of Practice which, even if they are directly applicable to the structures being designed (as B.S. 153 is not in the case of steel box-girder bridges), are unlikely to result in a satisfactory design in the hands of a designer lacking the experience to appreciate and allow for the peculiarities which each individual structure invariably exhibits. This is why we stress in Chapter 4 that simple adherence to our Design Rules should on no account be regarded as a substitute for sound engineering judgement and experience in the field of box-girder design.

2.8. The collapses of the Milford Haven and West Gate Bridges between them revealed failings in all aspects of the design and construction of major steel box-girder bridges—synthesis and checking of the permanent design, development and checking of the erection method and supervision of the construction. The first of our terms of reference related specifically to the implications of these two accidents for major steel box-girder bridges then about to be erected in the United Kingdom. Our Interim Report has led to the issue, in August 1971, of the Department of the Environment's Circular Roads No. 22/71* and to the programme of appraisal checks and associated design modifications described in this chapter, and this we regard as discharging our first term of reference. In the following chapters we seek to discharge our second and third terms of reference which extend to the field of large steel box-girder bridges in general.

CHAPTER 3: CONTRACTUAL PROCEDURES

3.1. In Appendix B of our Interim Report we considered the adequacy of the contractual procedures usually adopted for the construction of large steel box-girder bridges. Our recommendations on contractual matters, both in that report and in the present one, should be read in the context of the kind of contract for which the I.C.E. General Conditions of Contract provide a model. In our Interim Report we were primarily concerned with the bridges to which the first of our terms of reference relates, but we consider the principles which guided us there are applicable to the more general class of steel box-girder bridges included under our second term of reference, and indeed to large bridges in general.

3.2. Of the recommendations we made in Appendix B, seven were subsequently accepted by the Government and incorporated into the Department of the Environment's practice in Circular Roads No. 22/71 of August 1971.* Since the Government have a responsibility for the great majority of major highway bridges in the United Kingdom either as the client commissioning the bridge or by providing finance as a grant or loan, their acceptance of these recommendations has had considerable practical importance. We would, however, hope that the engineering profession at large will adopt the recommendations made or restated in our present Report so that the same principles may be applied in other fields of civil engineering construction.

3.3. In the first place it might be helpful to set out some of the main elements which we have come to regard as indispensable to a sound procedure for constructing large steel box-girder bridges. They include:—

- (a) an independent check of the Engineer's permanent design;
- (b) an independent check of the method of erection and design of temporary works adopted by the Contractor;
- (c) the clear allocation of responsibility between the Engineer and the Contractor; and
- (d) provision by the Engineer and the Contractor of adequately qualified supervisory staff on site with their tasks and functions clearly defined.

In the rest of this chapter we will take, stage by stage, the process of designing and constructing a large bridge, commenting on the procedures involved and how they may be improved.

Selection of Engineer

3.4. In selecting an Engineer the Client is faced with a difficult decision which will certainly have profound consequences. He must use all the judge-

* See paragraph 2 of Chapter 3.

* Appendix III contains extracts from circular Roads No. 22/71 and a summary of other recommendations made in the Interim Report.

ment, information and advice he has at his disposal to assure himself that the Engineer he selects will have the necessary resources in expertise and qualified manpower and that he will devote these freely to the project.

Design of Permanent Structure

3.5. We laid emphasis in our Interim Report on the need for an independent check of the permanent design of large steel box-girder bridges. We said there that the independent check might reasonably be carried out by the Engineer's own organisation provided this was acceptable to the Client and that the checkers were not involved in any way with the design concept or analysis. This independent checking is appropriate only to reasonably large and complicated structures and we would now qualify our recommendations by saying that, in the case of steel box-girder bridges whose main span exceeds about 50 m, we consider that the independent check should be carried out by a separate design office which may be selected by the Engineer but which should be approved by the Client. In the case of bridges where the main span is less than 50 m and more than about 20 m, we consider that an independent check carried out by a different team within the Engineer's office would usually be sufficient, although the Client should have the right to insist on a check performed outside the Engineer's office. Bridges of less than 20 m span do not, we feel, come within our terms of reference. The independent check should certify that the design of the bridge, as represented by the drawings and described in the accompanying documents, is in accordance with the relevant parts of the Design Rules contained in Appendix I and it should also certify that the drawings and documents adequately and accurately represent and describe a viable design for the bridge.

3.6. By the time this Report is published, the Department of the Environment will probably have issued a Technical Memorandum setting out a new approval system for motorway and trunk road structures developed in consultation with local authorities and others. This new system is consistent with our recommendations on the checking of designs for steel box-girder bridges, and provides for a differential checking procedure according to the size and complexity of structures. We are satisfied that the new system will serve to expose any serious design defects in the structures to which it applies.

3.7. Before leaving the question of checking the permanent design, we wish to make clear that we mention values of 20 and 50 m as general indications of how we envisage a differential procedure applying to steel box-girder bridges and not as dividing lines to be rigidly observed. Our recommendations should not be taken as involving a rigid categorisation of bridges according to simple factors such as length of span, and the Client will have to consider in each case whether his particular bridge calls for a design check completely independent of the Engineer's organisation.

Tolerances and Quality of Materials

3.8. We recommended in our Interim Report that a complete schedule of all working tolerances which may be permitted during fabrication and erection

should be promulgated by the Engineer to all concerned in contracts for constructing large steel box-girder bridges. We now repeat this recommendation. All fabrication and construction work should comply with the tolerances assumed in the design process, which we think should usually be those set out in Appendix I. Every care should be taken by the Engineer to define working tolerances clearly and to ensure that they are observed. The supervisory site staffs of both Engineer and Contractor should carry out as many inspections as the Engineer considers necessary to ensure that the required standards of accuracy are being attained, and adequate records should be kept of the measurements made for this purpose. We mention in paragraph 3.17 the need for systematic checking of cantilever deflections during erection, and systematic checking for compliance with all other erection tolerances specified by the Engineer should be arranged. The importance of ensuring that the quality of steel and other materials supplied to the Contractor meets that specified by the Engineer cannot be over-emphasised. In order to assist in this we suggest that suppliers should take particular care that the marks they are required to apply to materials correctly indicate the type and quality of the material. It will then be the duty of fabricators to maintain this identification and to ensure that the material is correctly used in the construction of the bridge.

Selection of Contractor

3.9. We said in our Interim Report that we would consider the suitability of the present contractual relationship, procedures and methods of sub-contracting for the building of a major bridge. We have given careful thought to the suitability of the normal procedure for selecting a Contractor by competitive tendering to the case of large steel box-girder bridge undertakings, where highly specialised expertise may be called for from the Contractor. It is widely felt that, where public money is involved, competitive tendering is desirable, if not essential, in all but the most exceptional projects. The aim of competitive tendering is to ensure that the most economical form of reliable construction is made available to the Client and we would like to emphasise in this connection the word "reliable". In judging which of several proposals is the most economical and yet is reliable technically and financially, a very great responsibility is placed on the Engineer which cannot in any way be lessened. The view has been put to us that, once bids have been received from contractors on an approved list of tenderers, then the Engineer will find it difficult—if not impossible—to recommend any but the lowest tender. We do not share this view. The Engineer will still be responsible to his Client for recommending the "best" proposal, and "best" here is not necessarily synonymous with "cheapest".

3.10. We have considered whether it might be possible to issue tender documents at a stage earlier than is usual in present practice but at which the design is nevertheless sufficiently advanced to allow a realistic degree of competition. The object would be to make it possible for the Contractor and the Engineer to work together in devising an erection method and working out details of the permanent design. We concluded, however, that such a

procedure would probably not be practicable except in special cases. We are aware that other forms of contract besides competitive tendering have been used, and used successfully, in large construction projects. We should not wish to comment upon them other than to encourage both Client and Engineer to approach the question of the form of contract with an open mind, and to repeat our view that, used with care and thoughtfulness, the most usual form of competitive tendering should lead to good construction.

3.11. Many large steel box-girder bridge contracts are undertaken either by an ad hoc consortium or by a specialist contractor who sub-contracts the part of the works in which he is not a specialist, whether concrete sub-structure or steel superstructure. We recommended in our Interim Report that main contractors should be reminded of their responsibilities under Clause 4 of the I.C.E. Conditions of Contract, which states that the Contractor is responsible for the "acts, defaults and neglects of any sub-contractor, his agents, servants or workmen as fully as if they were acts, defaults or neglects of the Contractor, his agents, servants or workmen." We have come to the conclusion that, provided this clause is enforced and a proper chain of command is worked out between the main contractor and sub-contractors there is no objection to the sub-contracting of major parts of steel box-girder bridgeworks.

Division of Responsibility between Engineer and Contractor

3.12. IT IS VITALLY IMPORTANT THAT THE ENGINEER AND THE CONTRACTOR, ONCE EMBARKED ON THE CONSTRUCTION OF A BRIDGE, SHOULD UNDERSTAND EXACTLY THE NATURE OF THEIR SEPARATE RESPONSIBILITIES. The basic division of responsibility will be the same in the case of large steel box-girder bridges as it is in civil engineering works generally. The Engineer's primary responsibility is for the permanent design of the structure, while the Contractor's is for the construction and completion of the works in such a way that the permanent design is properly realised. The Engineer, as originator of the permanent design and the chief authority on it, has a duty to the Client to assure himself that the Contractor's erection proposals and the implementation of those proposals will not result in any impairment of the permanent works. The responsibility for the execution of the works, including all temporary works, remains with the Contractor. We feel it is worth pointing out at this stage that in this Report we are concerned, not with legal responsibilities and liabilities, but with procedures to ensure that steel box-girder bridges are safe while under construction and in service. Nevertheless, in any major bridge undertaking, it will be a prerequisite of success that the legal forms of the contracts between the Client and the other parties should reflect precisely the practical engineering responsibilities and how they are divided between the parties.

Method of Erection

3.13. An independent check of the method of erection proposed or adopted by the Contractor is hardly less important to the safe and satisfactory comple-

tion of a major steel box-girder bridge project than the check of the permanent design. In paragraph 9 of Appendix B of our Interim Report we recommended that the Department of the Environment's Model Agreement should be amended in such a way as to require the Engineer to carry out such a check, perhaps by adding a clause in the form recommended by the Institution of Civil Engineers' Committee on Safety in Engineering, which would place a responsibility on the Engineer for "examining Contractors' proposals and details and the checking of the adequacy of the proposed methods of construction and temporary works"*. We have subsequently come to the conclusion that such an amendment would not be the best means of providing for an independent check of the erection method, as it would have the effect of blurring the division of responsibility between the Engineer and the Contractor which we have described in the previous paragraph. There is the further objection that in some cases the method of erection and design of temporary works adopted by the Contractor have been devised by the Engineer himself, so that by analogy with our recommended procedure for the check of the permanent design, a check of the erection method by an office other than the Engineer's would in any event be called for in the case of bridges of sufficient size or complexity.

3.14. For these reasons we now think that the best procedure would be to require the Contractor to obtain a certificate from completely independent engineers to the effect that his erection proposals had been checked and found adequate. We still feel that in addition to this check, the Engineer should be fully informed of the Contractor's erection proposals, and should have the right to veto them if he found them unsatisfactory (cf. paragraph 3.12).

3.15. We said in our Interim Report we would make recommendations to the Joint Contracts Committee of the Institution of Civil Engineers, the Association of Consulting Engineers and the Federation of Civil Engineering Contractors about amendments to Clause 14 of the I.C.E. Conditions of Contract and we felt that provision for a check of the erection method could be made in revisions to this Clause. As a result we wrote to the Committee suggesting that the Clause should include the following points:—

- (a) As soon as practicable after the acceptance of his tender, the Contractor should submit to the Engineer a programme showing the order of procedure and methods he proposes to employ in carrying out the works. Such a programme should be related to time and once submitted should not be amended without the approval of the Engineer. The submission of such a programme should not relieve the Contractor of any of his duties or responsibilities under the contract.
- (b) Where the Contractor finds it necessary to use the permanent works to assist him in his construction or erection (i.e. as temporary works) and at the same time requires to carry on alterations or modifications to the permanent works or proposes to stress or distort the permanent

* "Report on Safety in Civil Engineering", I.C.E. Proceedings 1969 Volume 42 (January).

works in a manner different from the original designer's intention, the Contractor should submit to the Engineer details and full calculations of such alterations or modifications for the sole purpose of enabling the Engineer to assure himself that the completed permanent structure will not be impaired in any way.

- (c) As soon as practicable after the acceptance of his tender, the Contractor should submit to the Engineer a statement prepared by a properly qualified independent engineer certifying that the calculations of all structural elements in the Contractor's temporary works have been checked and that the details and arrangements for carrying out the works, including the construction plant and temporary works, are satisfactory and safe for the purpose.

3.16. We understand that the revised Clause proposed by the Joint Contracts Committee substantially embodies these points, with the exception of the requirement for a certified independent check of the Contractor's erection proposals. We accept that this requirement may not be sufficiently important in all civil engineering projects to warrant inclusion in the I.C.E. General Conditions of Contract, but we firmly recommend that in the case of contracts for large steel box-girder bridges, the General Conditions should be supplemented by a provision on the lines of sub-paragraph (c) above*. We would not expect such a check to be necessary in the case of bridges whose main span is less than about 20 m, and, as we have indicated elsewhere, we do not consider that bridges in that category could be regarded as "large bridges" in the context of our terms of reference. This does not mean that we think a check of erection proposals will necessarily be called for in the case of all steel box-girder bridges of more than 20 m main span and, as with the check of the permanent design, it would be for Clients to decide, in consultation with their Engineers, whether a particular structure was such as to make a check of the erection proposals desirable.

3.17. We have already discussed the need for a schedule of tolerances to be drawn up by the Engineer, and this schedule will be of particular importance in the case of deflections and distortions arising in the bridge structure during erection. The appraisal of the condition of the permanent structure during erection should be in accordance with the Design Rules set out in Appendix I. Where it is necessary to submit the permanent structure to a condition which is different from that likely when it is complete, it is vital that all stresses, deflections and other anticipated distortions should be assessed by the Contractor and the calculations submitted to the Engineer so that regular checks can be made during erection in the interests of safety. As we said in our Interim Report, it is important that there should be a reliable estimate of the bounds within which the deflection of the cantilever in a cantilever erection condition, or indeed any other substantial deflection or distortion during erection, should lie. Deflections and other distortions should be accurately measured at whatever

* In our view this recommendation could usefully be applied in the case of large bridges of other kinds (cf our remarks in paragraph 3.23. about the wider application of our recommendations).

intervals the Engineer considers necessary and at a time of day at which the ambient temperature can most easily be correlated with that assumed in the calculations. If a disparity between the measured and calculated deflection or other distortion exceeds the permitted tolerance defined by the Engineer, erection should be discontinued until the Engineer is satisfied about the reasons for the disparity and has established that the safety of the bridge during the remainder of the erection and in its permanent condition has been in no way impaired.

Programming

3.18. One effect of the two checking procedures we have recommended in the preceding paragraphs may be to require some lengthening of the programme for steel box-girder bridge projects, although we would expect that to some extent both checks could be carried out simultaneously with the design process or other preparatory work prior to the start of erection of the superstructure. We do not propose to make any recommendations as to exactly when the checks should be carried out, as this will depend on particular circumstances. It is, however, clearly necessary in the interests of safety that the check of the permanent design should be complete by the time work is started, and the check of the erection method by the time erection of the relevant part of the superstructure begins. Apart from the obvious risk of partial or total collapse if erection goes ahead before the completion of independent checks, the disruption which would result from modification of the design or erection method would itself constitute a safety hazard as well as causing expense and delay. It is appropriate to mention here the importance of developing a good working relationship between the Engineer and the Contractor as soon as the contract is let, so that the Contractor has ready access to the design information he will require in devising his erection method. Poor communications between Engineer and Contractor can have disastrous results, as the Royal Commission's Report on the West Gate Bridge collapse illustrates.

3.19. In the general context of programming, we would like to recall a conclusion of the Banwell Committee which was appointed to consider the placing and management of contracts for building and civil engineering work. In Chapter 2 of their report* that Committee said "It is natural that the client, having taken the decision to build, should wish to see work started on the site at the earliest possible moment. It is the duty of those who advise him to make it clear that time spent beforehand in settling details of the work required and in preparing a time-table of operations, from the availability of the site to the occupation of the completed building, is essential if value for money is to be assured and disputes leading to claims avoided. It is also necessary for the client to be told of the need to give the contractor time to make his own detailed arrangements after the contract has been let, and of the penalties of indecision and the cost of changes of mind, once the final plans have been

* "The Placing and Management of Contracts for Building and Civil Engineering Work: Report of the Committee" H.M.S.O. 1964; reprinted 1967.

agreed". The Banwell Committee were mainly concerned with the loss of productivity and waste to which poor programming and hurried initial preparations may lead. We consider that, in the case of major civil engineering undertakings, such as large steel box-girder bridges, it is particularly important in the interests both of safety and economy that the Client and the Engineer allow the Contractor sufficient time after the contract has been let to prepare for the start of work, and that they should not unduly pressurise him during the construction period itself. The Client should be prepared to accept that there may be sound reasons for modifying the Contractor's original programme and the Engineer for his part should not hesitate to advise the revision of the programme if he judges that the Contractor can no longer keep to it without risk of mistakes occurring.

Site Supervision

3.20. The respective roles of the Engineer and the Contractor in supervising the works should reflect their respective overall responsibilities, which we discussed in paragraph 3.12. The Engineer's responsibility during the actual construction process is to see that the work is executed satisfactorily in accordance with the contract, and in particular with the programme and any additional erection scheme submitted to him by the Contractor, and to supervise the situation as necessary in the event of unforeseen difficulties affecting the permanent works. It is important that the Engineer should avoid the temptation of complacency and give equal attention to his obligations during the construction phase, as he does when designing. The importance of prompt and patient attention by the Engineer's head office to communications from his representatives on site is clearly demonstrated by the events leading to the collapse of the West Gate Bridge. The Contractor is responsible for executing the works, and his staff will be responsible for giving directions to workmen and other routine matters. Clauses 13, 15 and 16 of the I.C.E. Conditions of Contract give the Engineer powers to direct the Contractor in all matters relating to the construction of the works, to approve the appointment of the Contractor's senior site staff and to require the dismissal of any of the Contractor's employees, including (by virtue of Clause 4) sub-contractors' employees, if he considers them incompetent or negligent. We consider that these powers provide for the establishment of an efficient site organisation and ensure, as far as any rules can, a sound working relationship between the Contractor and the Engineer. We suggest it would in addition be helpful and sound working practice in constructing large bridges if all important communications between the Engineer, the Contractor, the Resident Engineer and the Contractor's agent were put in writing without delay.

3.21. We discussed in our Interim Report the importance of having adequately qualified and sufficient site staff, both on the Contractor's and on the Engineer's side. The Contractor's site staff are subject to scrutiny by the Engineer, and the Client should similarly require the Engineer to satisfy him that his site staff are sufficiently qualified and experienced and adequate in number. In accordance with Clause 2 of the I.C.E. Conditions of Contract, the Resident Engineer's terms of reference and delegated powers should be put

in writing to the Contractor. A working brief should also be issued in writing to the Resident Engineer by the Engineer and a copy made available to the Client if required. This brief should make clear the extent to which the Resident Engineer is empowered, without reference to the Engineer, to approve changes in the design of permanent or temporary works or any other changes in fabrication or erection procedure proposed by the Contractor. The Resident Engineer should not be permitted to agree any other changes without permission from the Engineer. No variation from the erection scheme submitted to the Engineer by the Contractor should be allowed unless the Engineer or the Engineer's representative (if authorised) gives written consent to the proposed variation. We believe these points have been covered in the Joint Contracts Committee's revision of Clauses 2 and 14.

Safety of Workmen

3.22. As we said in paragraph 3 of Chapter 1 this subject is not strictly within our terms of reference but we are aware of the concern of those representing the labour side of the construction industry about the safety of workmen employed on steel box-girder bridge erection. We have received written representations from the Constructional Section of the Amalgamated Union of Engineering Workers (formerly the Constructional Engineering Union) and we have had a meeting with H.M. Chief Inspector of Factories whose duties extend to the safety of workmen on construction sites. We consider that our recommendations in this Report will, if properly implemented and observed, prevent total or partial failures of steel box-girder bridges under construction and so remove one source of risk to workmen. There will remain other safety hazards in the construction of these bridges which are common to many major construction projects, and it is not our task to make recommendations on this question. We would however like to mention three of these general safety matters which are of relevance to box-girder bridges and which are of particular concern to the Chief Inspector. Firstly, it is essential if hazards involved in major construction projects are to be minimised, for those devising the erection scheme to pay careful attention to the safety implications of a proposed sequence of operations. For example, it may be no more difficult to equip box-girder sections with balustrades before erection than afterwards, while the former sequence of operations is clearly preferable from the point of view of providing safe access. The second safety issue is the provision of access for regular maintenance of bridges in service: access to the sides and bottom of a smooth faced box-girder can be difficult if temporary scaffolding and cradles have to be employed, and it is much more satisfactory if designers provide for a permanent means of reaching these surfaces to carry out maintenance. Finally, there is the health hazard which may be caused by fumes due to welding within enclosed spaces such as girder boxes. This necessitates provision for adequate ventilation and access and requires consideration at the design stage. Contractors should always be on the alert for problems of these kinds which may arise from changes in structural design and fabrication technology. Reverting to the general question of safety during erection, we very much welcome the likely inclusion in the revised I.C.E. Conditions of Contract of wording which will place the Contractor (and where applicable, the client in

respect of his own workmen) under a specific obligation to have full regard for safety of all those entitled to be on the site and which will, in particular, require the Contractor to provide supervisory staff on the site who have sufficient knowledge to take effective precautionary measures against accidents. We would add that it is equally important that those site staff who are given specific responsibility for safety should have the necessary authority to bring effective influence to bear on procedures adopted on site. We are grateful to H.M. Chief Inspector of Factories for explaining to us the work of the Inspectorate in promoting safety on construction sites and we would urge all those involved in the construction of major bridges, especially contractors, to give the Chief Inspector and his staff their fullest co-operation. In particular we would encourage discussions with the Inspectorate about safety precautions at an early stage of planning.

Conclusion

3.23. Our terms of reference relate to a specific kind of civil engineering undertaking, the construction of steel box-girder superstructures for large bridges, and our recommendations are therefore made with these structures in mind. However, as we say elsewhere, we believe that many of our recommendations have a wide application in the civil engineering field. We therefore hope that this part of our recommendations will receive the careful attention both of potential clients and of the engineering profession. Those already experienced in construction of this kind should take the tragic events at Milford Haven, and particularly those in Melbourne, as a warning against over-confidence, and examine their own procedures in the light of what we say. We noted at the beginning of this chapter that a large part of the recommendations on contractual procedures in our Interim Report have already been incorporated into the Department of the Environment's procedures where steel box-girder construction is involved, and we welcome this. In addition, it seems likely that the current revision of the I.C.E. Conditions of Contract will provide a framework for contract management which will be very much more satisfactory for complex undertakings such as large steel box-girder bridges. In our final chapter we summarise our recommendations on ways of improving the contractual side of steel box-girder bridge construction.

CHAPTER 4: SOME NOTES ON THE DESIGN RULES RECOMMENDATIONS FOR FUTURE RESEARCH

4.1. In order to meet the second of our terms of reference, we initially prepared a set of design Appraisal Rules for the purpose of checking the adequacy of existing bridges or structures in the course of fabrication or erection and we mentioned in Chapter 2 the series of checks which are being carried out using these Rules. The Appraisal Rules set down some general principles which, if followed, should demonstrate the safety of the structures. They were based on available theory and existing test results, and also made use of relevant parts of other design directives which we considered to be applicable. There was at that time an almost complete absence of experimental evidence as to the behaviour of box-girder structures and we had very little knowledge of the standard of workmanship which had been achieved in previous construction. Our Appraisal Rules were therefore intended to be conservative and were of necessity complex in application. They were not suitable for design synthesis.

4.2. To provide guidance to bridge engineers engaged in design, we have now prepared Interim Design and Workmanship Rules (elsewhere referred to as the "Design Rules"), which are presented in Appendix I. These are intended to be used as a satisfactory basis for the design of steel box-girder structures. They are not, however, intended necessarily to be comprehensive for a given design, and we consider it essential that the Design Rules should be used only by designers fully experienced in the field of stiffened steel-plate structure design. It is our view that the designer should be made aware that he must consider all aspects of a particular design, and not assume that compliance with the Design Rules alone will necessarily achieve a satisfactory performance. We said in paragraph 7 of Chapter 2 that it may have been just this assumption that led to the faulty design of many of the bridges found defective in the course of appraisal checks. We said in paragraph 5 of Chapter 3 that the independent check of the permanent design should certify not only compliance with the relevant parts of the Design Rules, but also that the design is in other respects an adequate one. Conversely, we do not here insist that designs should necessarily be certified as complying with the Design Rules in every respect, and it may be that checkers will quite often consider a design to be adequate, even though it contains features for which the Rules do not provide. In such cases it would be useful if both the British Standards Institution and the Department of the Environment were given details of the features falling outside the scope of the Design Rules and of how the problems involved were overcome.

4.3. In order to develop the simplified rules, the Department of the Environment sponsored on our behalf both short-term work and analytical studies, and this programme of work is summarised in Appendix II. We have been able to

take note of the results of the tests in verifying or modifying the basis of the earlier Appraisal Rules.

4.4. In parallel with the research into the strengths of box structures,* a series of surveys of existing structures has been undertaken which has provided us with information about the imperfections of workmanship to be expected. There have been investigations into the locked-in stresses induced by welding processes, the results of which we have used in the development of design strength criteria.

4.5. A number of parametric studies has been undertaken, by means of which we have extended the basis of the Appraisal Rules in such a way that we could use it to derive design data in a condensed and simplified form applicable to the principal components of a box-girder bridge. In Appendix II† we give a list of the parametric studies on which we have received reports. After we had drafted the simplified Design Rules we had design checks carried out,‡ in which each major section of Rules was applied to a sample of box-girder bridge elements. This enabled us to compare the conclusions obtained using the Design Rules with those which would have been obtained by using (a) the Appraisal Rules and (b) other design directives, and assisted us in checking errors in the Design Rules and ensuring that they cover most aspects of design.

4.6. A new British Standard Code of Practice for bridge design and construction is in the course of preparation by Committee B/116 of the British Standards Institution. The drafting of the sections on loads and load factors and on fatigue and workmanship by Committee B/116 has progressed sufficiently to enable us to incorporate many of the provisions of the draft code in the corresponding sections of the Interim Design and Workmanship Rules. It has been our hope throughout that the new British Standard Bridge Code will, for its part, incorporate the essentials of our Design Rules and will in consequence be capable of superseding them as a design directive for steel box-girder bridges. It is in this sense that our Design Rules are an interim measure. In order to ensure that the Design Rules emerged in a form in which they could be incorporated by Committee B/116 into the new British Standard Bridge Code, a special Sub-Committee known as B/116/6 was formed to comment on drafts of the Design Rules as they were produced. In December 1972 this Sub-Committee issued the following statement:

“B/116/6 having met 16 times to comment on the Interim Design and Workmanship Rules, agreed them to be based on principles generally acceptable as a basis for development into a section to be issued as a draft for comment of the Bridge Code. In the meantime the rules are of adequate scope and in a form that can be used by designers and fabricators.

* Section C of Appendix II.

† Section A.

‡ Section B of Appendix II.

The Committee appreciate the work of the Merrison Committee and those assisting it in collecting and developing existing information, and carrying out the research programme which has led to these rules.

The sections of Part I of the rules concerning loading and load factors mainly correspond with the relevant provisions in the draft of the Code. Analytical procedures specified have been agreed. The simplified rules for the design of elements have been shown to be workable and although generally conservative in certain cases offer some economy of material in comparison with designs to B.S. 153. Workmanship standards have been fully discussed with B/116/3/1. Because the fabricators expressed concern that the cost of demonstrating compliance with the rules might be high, it is accepted by all concerned that further study is needed before tolerances can be properly related to economy”.

4.7. The liaison between Committee B/116 and ourselves provided by the Sub-Committee has been most valuable and we would like to say here how grateful we are to Dr. O. A. Kerensky C.B.E., F.R.S., Chairman of Committee B/116, who also acted as Chairman of the special Sub-Committee and in that capacity arranged several meetings at short notice to consider drafts of our Design Rules. We hope that as a result of the contact between Committee B/116 and this Committee the development of the new Bridge Code will be facilitated. We appreciate however that the development of a major Code is a lengthy process and it seems likely that there will be an interval of 18 months or perhaps longer between the publication of our Design Rules and the appearance of the new Bridge Code. During this interval the Design Rules should be regarded as fulfilling the role of a Code of Practice. This creates a need for some authority to which designers can refer for interpretation of the Design Rules and which could make modifications to the Design Rules where this appeared desirable in the interests of safety or economy or to cover cases which we may have overlooked. We consider this function would best be performed by the Department of the Environment, and we recommend that the Department should set up a team which could handle questions of interpretation or modification until the Design Rules are superseded by a British Standard Code of Practice. This team should consult with Committee B/116 regarding any modifications made to the Design Rules.

Codification

4.8. As Committee B/116 will be making use of Design Rules developed by us in drafting the new British Standard Bridge Code, we hope it will not seem out of place for us to offer at this point some general thoughts on codification. The present practice in codification of structural design principles results in directives which in our view attempt to be unnecessarily comprehensive and whose scope of application is ill-defined. There are consequently serious risks that rules will be applied inappropriately and that the use of improved knowledge will be inhibited. Moreover, the form of structural Standards and Codes has not reflected the extensive use now made of high speed computers.

4.9. Consideration should be given to the merits of a more flexible Code for major bridge design, defining performance requirements completely and setting out loading and safety provisions but specifying only the framework of constraints within which design for strength must be conducted. Such a Code would be unlikely to demand frequent revision and would facilitate the use of new information after rigorous verification, perhaps to be issued in the form of data sheets. Our Design Rules could be of immediate use in the application of a Code drafted in this way. Used in conjunction with the procedures for independent checking of designs which we have proposed, this approach to codification would, we consider, offer the least risk of code-assisted failure and the greatest freedom for economical design. It would be particularly suited to the fluidity of the present stage of collaboration with European organisations.

Future Research

4.10. In the remaining paragraphs of this chapter, we move on to our third term of reference and make recommendations on topics for future research and development in the field of steel box-girder bridge construction.

4.11. The theoretical and experimental studies undertaken on behalf of the Committee have been of an ad hoc nature and related to forms of construction currently in common use. The test results have been used as a basis for comparison with our Design Rules, but there remains the need for extensive analysis of all the data obtained. This should be undertaken at once before the research teams which were responsible for the testing are disbanded. Also to be completed are the programme of wind tunnel testing in the parametric study of aerodynamic stability, and the analysis of imperfection surveys and residual stress measurements on bridges under construction. These should all be carried through in accordance with the original briefs.

4.12. We recommend that further research be promoted both to provide additional information for the British Standard Bridge Code in the short term, and to offer greater economy in design in the longer term. Such research should be planned by a single organisation, and we consider that the Working Group on Steel Box Girder Research formed by the Department of the Environment's Transport and Road Research Laboratory and Headquarters Bridges Division is that best suited to the role. In planning the work to be undertaken we recommend that consideration be given to the following matters. (paragraphs 4.13-16.).

4.13. The design loading section of the Interim Design and Workmanship Rules has been based largely on the work of the relevant B.S.I. Code Sub-Committee. This Sub-Committee has been handicapped by inadequate field observations both in respect of vehicle loading and fatigue spectra, and regarding wind effects. We consider it necessary to continue to improve knowledge of these factors and to keep them constantly under review.

4.14. Research into the structural problems of steel box-girders is being undertaken all over the world and close collaboration between the sponsoring bodies is desirable. We have in our search for reliable test evidence found notable shortcomings in the design and conduct of investigations and in the presentation of results. The parameters influencing box-girder behaviour are numerous and in many instances either some have been overlooked or vital observations have been omitted, in either case precluding use of the test results. We therefore recommend that all research briefs be prepared in a way which will avoid these omissions. In particular, full consideration should be given to material properties, and all aspects of geometric imperfections, boundary conditions and residual stresses.

4.15. We have furthermore found that much of the academic research in the field of box-girder design has been directed to verification of theoretical stress analysis. It is our view that the prediction of the collapse strengths of box-girders can never be based on theory alone. Economical design must therefore be empirically based and the major part of the research effort should be deployed in the establishment of the parameters governing the physical behaviour of such structures. There has been remarkably little testing of plated elements to destruction under compound states of static and repeated stress with all practical boundary conditions, and there is an immediate need for series of such tests and a theoretical framework on which empiricism may be based. Investigations should cover the behaviour of stiffened elements in the post-buckling and post-yield range, including the determination of in-plane stiffness up to and beyond the ultimate load. It is also important to reproduce under test conditions the behaviour of panels as components of complete boxes. There is a particular need for immediate further studies into the fatigue behaviour of steel decks with a variety of surfacings.

4.16. In preparing the workmanship section of the Interim Design and Workmanship Rules we have been made aware of the costs involved in fabricating to specified tolerances and with certain constraints on welding procedures when using present techniques, and in making the necessary measurements. Our Design Rules are based on the attainment of certain standards of flatness and straightness which appear to offer overall economy, but the implications of such standards deserve detailed scrutiny and review if design is to be broadly optimised. We recommend that these matters be the subject of an investigation conducted in close collaboration with fabricators and designers with the aim of simplifying the Design Rules and of encouraging sound design for low total cost. It is to be hoped that one of the benefits of such a study would be the regular provision to designers by the fabricators of sufficient costing parameters to enable designs to be synthesised in a more rational way than is presently possible. There is a similar need for investigations into the optimum cost of designing. The balance between extreme simplicity with its requisite conservatism, and the use of refined analytical procedures needs to be established for all classes of bridge structure before completion of the new British Standard Bridge Code.

CHAPTER 5: REVISION AND INITIATION OF CODES OF PRACTICE

5.1. The fact that the drafting of a new British Standard Bridge Code applicable to steel box-girder bridges has been undertaken only quite recently is, we fear, a poor reflection on past arrangements within the civil engineering profession for revising Codes of Practice and initiating new ones where necessary. The regular use of the steel box-girder as an element in large bridges dates back as far as the immediately post-war years, and yet at the time when the West Gate and Milford Haven Bridges were designed in the 1960s, the best available design directive was B.S. 153, a Code of Practice for simply supported steel girder bridges, not wholly applicable to box-girder structures nor sufficiently comprehensive. We are therefore pleased to see that recent changes in the arrangements at the British Standards Institution (B.S.I.) appear to provide a much improved system for revising existing Codes of Practice. Under the new system a Code Drafting Committee continues in being after the completion of work on a new or revised Code and maintains a check on the progress of research work needed for the next revision of the Code. There is a procedure for the regular review of Codes of Practice on a five-year cycle, although not all Codes would necessarily require revision after each review. The research work which would be needed for the revision of a Code is defined by the drafting Committee itself in an Appendix to the published Code. In addition, an arrangement now exists between the B.S.I. and the Department of the Environment for the Department's Directorate of Research Requirements to assist in finding sponsors for the work who could include the Department itself and the Construction Industry Research & Information Association.

5.2. This procedure seems to provide a satisfactory basis for the regular revision of existing Codes but we are not entirely satisfied that the new arrangements provide a reliable means of identifying needs for new Codes relating to bridge works. The body primarily responsible for considering whether new Codes are needed in this field is the B.S.I.'s Codes of Practice Committee for Civil Engineering. Sources of advice to this Committee include the B.S.I.'s own staff, the Construction Industry Research and Information Association and the Department of the Environment but the B.S.I. themselves regard the Institution of Civil Engineers and the Institution of Structural Engineers as together providing the main source of advice. The two Institutions each have a specialist committee to consider matters relating to Codes of Practice in the civil engineering and building fields. The constitutions of these two committees and of the corresponding B.S.I. Codes of Practice Committees for Civil Engineering and Building ensure cross-representation between the Institutions and the B.S.I. in both cases, and there is also cross-representation between the I.C.E. and the I. Struct. E. Committees. In addition there are arrangements for liaison between the B.S.I. and the Construction Industry Research and Information Association and between the B.S.I. and the Department of the

Environment aimed at bringing to the B.S.I.'s attention the areas where new civil engineering Codes appear to be needed.

5.3. This liaison is very welcome but we are nevertheless left with the impression that the B.S.I. rely more heavily on the various outside bodies advising them, to tell them where new Codes are needed, than these advisers themselves appreciate. In particular, the B.S.I. would apparently wish to see the I.C.E. and the I. Struct. E. acting as pressure groups for new Codes, although the B.S.I. is the final arbiter on whether or not a new Code shall be drafted. In view of this, we recommend the Institutions to give careful consideration to their role in the initiation of new Codes.

5.4. The responsibility for initiating new Codes of Practice of relevance to bridge works is divided somewhat indistinctly between several heterogeneous organisations, and we suspect that the situation in other fields of civil engineering is similar. We doubt whether many members of the civil engineering profession, if they felt that a new Code was needed in the bridge field, would know to which organ of the B.S.I. a suggestion for a new Code should be put, or what help the Institutions could offer in promoting a proposal of this kind. We therefore recommend that, as a first step towards putting right this situation, the Department of the Environment should carry out an investigation of the existing procedures for initiating new Codes of Practice in the civil engineering field, and make their findings available.

CHAPTER 6: SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

6.1. The first of our terms of reference* called on us "to consider whether the collapse of the Milford Haven and Yarra Bridges necessitates reconsideration of the design and method of erection for any major box-girder bridges about to be erected in the United Kingdom". We have described in Chapter 2 (paragraphs 5-6) how Highway Authorities in the United Kingdom have used our Appraisal Rules to check and where necessary modify the design of many steel box-girder bridges, some recently completed, others at various stages of design or construction. We repeat here that we are confident these bridges, strengthened where necessary, will give safe service. We suggested in Chapter 2 (paragraph 7) that the explanation of the defects in so many box-girder bridges may be found in the automatic application of design directives.

6.2. In our second and third terms of reference we were asked to consider the whole field of steel box-girder highway bridge design from both technical and contractual points of view and we have set down our general recommendations in Chapters 3, 4 and 5. These recommendations are directed primarily to Clients for major steel box-girder bridges. For ease of reference we summarise the main ones below (numbers in brackets refer to paragraphs).

Contractual Procedures

- (i) Four essential elements in procedures for constructing major steel box-girder bridges are:—
 - (a) an independent check of the Engineer's permanent design;
 - (b) an independent check of the method of erection and design of temporary works adopted by the Contractor;
 - (c) the clear allocation of responsibility between the Engineer and the Contractor; and
 - (d) provision by the Engineer and the Contractor of adequately qualified supervisory staff on site with their tasks and functions clearly defined. (3.3.)
- (ii) The Client must assure himself that the Engineer will have resources appropriate to the project. (3.4.)
- (iii) A certified independent check should be carried out to establish that the permanent design complies with the relevant parts of the Design Rules and is in all respects an adequate one. (3.5.; 4.2.). A differential approach to checking according to the size and complexity of structures would be appropriate. (3.5-7.).

- (iv) Adherence to tolerances and fabrication procedures assumed in the design and systematic checking of fabrication accuracy and distortions during construction are essential; suppliers should take care to mark materials correctly; fabricators should maintain this identification until after assembly (3.8.; 3.17.).
- (v) Competitive tendering, handled appropriately, should lead to good construction. (3.9-10.).
- (vi) Provided Clause 4 of the I. C. E. Conditions of Contract is properly enforced, there is no objection to sub-contracting major parts of steel box-girder bridge works. (3.11.).
- (vii) A clear division of responsibilities between Engineer and Contractor is vitally important; contracts between the parties in a major bridge undertaking should reflect their practical engineering relationship. (3.12.).
- (viii) A certified independent check of the erection method should be performed by engineers other than the design Engineer, who should nevertheless be given full details of the erection method and have a right of veto over it. (3.13-16.).
- (ix) The Contractor should submit to the Engineer for his approval a construction programme specifying time scale. (3.15.).
- (x) The independent checks of the permanent design and of the erection method should be complete by the time work starts and the erection of the relevant part of the superstructure starts respectively; the Client and the Engineer should allow the Contractor sufficient time to prepare himself for the start of work and should be prepared to consider a revision of his programme in the event of slippage. (3.18-19.).
- (xi) The Engineer should carefully watch the progress of construction to ensure compliance with the agreed erection method; he should scrutinise the Contractor's site staff and where necessary exercise his powers under the contract. (3.20-21.).
- (xii) The Client should satisfy himself as to the adequacy of the Engineer's site representatives; the functions and tasks of the Engineer's site representatives should be defined in writing. (3.21.).
- (xiii) Those devising the erection scheme should pay careful attention to the safety implications of proposed sequences of operations; discussions with the Factory Inspectorate about safety precautions at an early stage of planning are to be encouraged. (3.22.).

The Design Rules

- (xiv) The Design Rules should be used only by designers fully experienced in the field of stiffened steel plate structure design. (4.2.).
- (xv) The Design Rules should be used in the design of steel box-girder bridges until a relevant British Standard Code of Practice is available. (4.7.).

* See Foreword for terms of reference.

(xvi) The Department of the Environment should be available to interpret the Design Rules where necessary, and should make modifications if desirable. (4.7.).

(xvii) Consideration should be given to a flexible Bridge Code. (4.9.).

Future Research

(xviii) Research programmes begun at the instigation of the Committee should be completed without interruption. (4.11.).

(xix) Short and longer term research should be planned by a single body and the joint Working Group on Steel Box-Girder Research of the Department of the Environment's Transport and Road Laboratory and Headquarters Bridges Division should carry out this function. (4.12.).

(xx) More work is needed on vehicle loading, fatigue spectra and wind effects. (4.13.).

(xxi) Close international collaboration in research on box-girder design is needed. (4.14.).

(xxii) Greater care should be taken in the design of research projects and the presentation of results. (4.14.).

(xxiii) The emphasis in the research effort in this field should be empirically oriented although aided by theoretical studies, rather than directed merely to verification of theoretical stress analysis. (4.15.).

(xxiv) There is an immediate need:

(a) for testing of plated elements to destruction under compound states of static and repeated stress;

(b) for further studies into the fatigue behaviour of steel decks. (4.15.).

(xxv) There should be investigations:

(a) into the implications of flatness and straightness tolerances for the achievement of optimum design;

(b) into the influence on total cost, of expenditure on design. (4.16.).

Codes of Practice

(xxvi) The I.C.E. and the I. Struct. E. should give fresh consideration to their role in promoting new Codes of Practice in the civil engineering field. (5.3.).

(xxvii) The Department of the Environment should examine the existing procedures for initiating Codes of Practice in the civil engineering field and publish their findings. (5.4.).

6.3. These recommendations call for initiatives principally on the part of the Department of the Environment, in co-ordinating a continued research effort in the box-girder field, and on the part of the British Standards Institu-

tion, in drawing up a new British Standard Bridge Code fully applicable to box-girder bridges. We anticipate that the Joint Contracts Committee's revision of the I.C.E. Conditions of Contract will already have gone much of the way to meeting our recommendations for improving contractual arrangements, though clients for large steel box-girder bridges should always consider whether a modification to the I.C.E. Conditions may not be more satisfactory for their particular circumstances.

6.4. In conclusion we would like to recall a paragraph of our Interim Report. There we said:

"The collapses of the Milford Haven and Yarra Bridges will have raised questions and doubts—very understandably—about the safety of the steel box-girder as a general element in bridge building, and we assume that this is one of the reasons, if not the primary reason, for the existence of this Committee. We have now considered this problem in the light of the general expertise in design and erection of large structures which is available within the Committee, and we can say with complete confidence that such general fears are without foundation. At the same time, in spite of the simplicity of the box-girder as a bridge element, when large areas of thin steel sheet are used in its construction there is no doubt that considerable skill and care must be exercised by both designers and those responsible for construction. But again . . . the methods available to the Engineer are adequate to deal with the problems involved although not necessarily as yet in the most efficient manner. With general guidance of the kind in the appendices to this report, there is no reason for doubting the safety and general soundness of such structures. Indeed, we would go further and say that a good deal of the advice we offer . . . is no more than what we should regard as sound engineering practice which could well be applied to other engineering structures, certainly to other types of bridge structure, and it would be unfortunate if this general advice were to be restricted in its application".*

In preparing our final Report we have seen no reason for departing from the conclusions in that paragraph; indeed, we would say that our investigations have now led to design rules which will enable the engineer to design structures which will be both efficient and safe and we would expect the box-girder principle to remain popular in the design of large steel bridges both in this country and abroad.

* Interim Report Paragraph 29.

APPENDIX II: SUMMARY OF RESEARCH WORK UNDERTAKEN FOR THE COMMITTEE

This Appendix lists the Parametric Studies, Design Studies and short term Research Projects mentioned in Chapter 4, together with the organisations, and in some cases the test directors responsible for the studies and projects.

A. PARAMETRIC STUDIES—contracts were placed as follows:

STUDY	INSTITUTION/FIRM
1. (i) Restrained Warping	Imperial College of Science and Technology
(ii) Distortion due to eccentric loading	Imperial College of Science and Technology
2. Shear Lag.	Imperial College of Science and Technology
3. Webs	G. Maunsell & Partners
4. Flanges	Cambridge University
5. (i) Diaphragms	British Iron & Steel Research Association
(ii) Unstiffened Concentrically Loaded Diaphragms	Sir Owen Williams & Partners
(iii) Large deflection study	Imperial College of Science and Technology
6. Residual Stresses	Sussex University
7. Cross Frames	F. R. Bullen & Partners

B. DESIGN STUDIES—contracts were placed as follows:

1. Diaphragms	Husband & Co.
2. Residual Stresses	G. Maunsell & Partners
3. Webs	Freeman Fox & Partners
4. Cross Frames	F. R. Bullen & Partners
5. Flanges	Rendel Palmer & Tritton
6. Analysis	Mott Hay & Anderson

C. SHORT TERM RESEARCH PROJECTS

1. Box-Girder models at Imperial College

Tests on eight box-girder models to investigate the collapse strength of stiffened flanges and webs under combined bending moment and shearing force representing support conditions and pure bending moment representing conditions within a span. Spacing and inertia of stiffeners varied.

Tests directed by Dr. P. J. Dowling
Department of Civil Engineering
Imperial College of Science and Technology

2. Plate Girder models

Tests on plate girder models to investigate the collapse strength of web panels. The plate girder flanges were of longitudinally stiffened thin plate to simulate battle deck construction.

Tests directed by Professor K. C. Rockey
Department of Civil and Structural Engineering
University College, Cardiff

3. Plate panels with transverse welds

An investigation into the effect of transverse welds on the compressive strength of plate panels. For ease of testing, four identical plate panels are welded together to form a box.

On one series of tests the cusp and step of the plates at each transverse weld have been carefully controlled.

Tests directed by Mr. J. B. Dwight
Engineering Department, Cambridge University

4. Compression Tests on Stiffened Plate Panels

Tests on twelve full size stiffened plate panels to investigate the influence of type and spacing of the stiffeners on ultimate strength and mode of collapse.

Tests directed by Mr. A. P. Dorman
Constrado

Tests carried out at the Department of Civil Engineering
Polytechnic of Central London

5. Tests on Continuous Box-Girders

Tests on continuous box girders to investigate the capacity of the box to redistribute shear, the load distribution due to continuity over a support and effect of lack of fit of the bearings.

Tests directed by Mr. J. E. Dibley
Constrado

Tests carried out at Military Vehicles and Engineering Establishment
Christchurch

6. Bolted Splice Tests on Box-Girders

An investigation into the ultimate strength of high strength friction grip bolted splices in a box-girder, with particular reference to the capacity for accommodating high peak stress by controlled bolt slip.

Tests directed by Mr. P. J. Clark
Department of Civil Engineering
Imperial College of Science and Technology

7. Torsional Stability of Diaphragm Stiffeners

A series of tests to determine the torsional stability of a stiffener on a plate subject to compression and to compare the results when a second stiffener is added to the other side of the plate in a direction perpendicular to the original stiffener. The type of stiffener is varied.

Tests directed by Professor M. R. Horne
Department of Civil Engineering
University of Manchester

8. Diaphragm Tests

Two boxes, each with two end diaphragms and one central diaphragm, tested to investigate the collapse strength of plate panels and stiffeners and to determine the effect of lack of fit at the bearings.

Tests directed by Dr. P. J. Dowling
Department of Civil Engineering
Imperial College of Science and Technology

9. Trapezoidal Diaphragm Tests

One box with three diaphragms to investigate the collapse strength of trapezoidal diaphragms.

Tests directed by Mr. J. A. Loe
Transport and Road Research Laboratory
Crowthorne

10. Box-Girders with High Flange Shear Stresses

Three box-girders to investigate the influence of shear on the collapse strength of stiffened plate panels and to determine whether the von Mises-Hencky principle applies.

Tests directed by Mr. H. M. Nelson
Department of Civil Engineering
University of Glasgow

11. Static Shear Tests on Fillet Welded Connections

A series of tests to investigate the ductility of long fillet welds.

Tests directed by Dr. T. A. Gurney
The Welding Institute
Abington Hall
Cambridge

12. Unstiffened Diaphragm Tests

Four tests to investigate the collapse strength of rectangular, unstiffened plate panel diaphragms.

Tests directed by Dr. P. J. Dowling
Department of Civil Engineering
Imperial College of Science and Technology

13. Aerodynamic Stability Tests

A series of tests on sectional models to investigate parameters governing aerodynamic stability of box-girders.

Tests carried out at the National Physical Laboratory

14. Deformation Surveys

Partial surveys were made on seven bridges of the magnitude of deformations in plates and stiffeners. The results were used to set the basis for allowable deformations in the workshop.

Surveys directed by Mr. B. J. Hardy and Mr. J. P. Dinsmore
Directorate General Highways
Department of the Environment

APPENDIX III: RECOMMENDATIONS IN THE COMMITTEE'S INTERIM REPORT

1. Circular Roads No. 22/71, issued by the Department of the Environment on 31 August 1971 to the Clerk of the Greater London Council, County Councils, County Borough Councils, non-County Borough Councils, the Common Council of the City of London and Urban District Councils, gave effect to seven of the recommendations made in the Committee's Interim Report.

2. The following are extracts from the circular:

"A number of recommendations relating to contractual and erection procedures for the construction of steel box-girder bridges are made in the Appendix B to the Interim Report of the Merrison Committee.

Seven of these recommendations which involve a tightening-up of existing practices have been accepted by the Secretary of State who will require them to be implemented forthwith for this type of construction for all current and future trunk road and motorway contracts . . . Their adoption by local and other authorities is strongly recommended.

The recommendations which are to be implemented are:—

- (i) The Engineer's permanent design should be checked by an independent engineer both for the design concept and the method of analysis of stresses and a certificate furnished to this effect and for compliance with the criteria set out in Appendix A to the Interim Report. The independent engineer should have experience and qualifications commensurate with the magnitude and complexity of the design in question.
- (ii) The checking of stresses in the structure during erection should be in accordance with the criteria given in Appendix A to the Interim Report.
- (iii) In cantilever construction deflection should be accurately measured at regular intervals agreed by the Engineer at a time of day at which the ambient temperature can most easily be correlated with that assumed in the calculations. If the disparity between the measured and calculated deflection exceeds the permitted tolerance defined by the Engineer erection should be discontinued until the Engineer is satisfied as to the reasons which have caused the disparity and that the safety of the bridge during the remainder of the erection and in its permanent condition is in no way impaired.
- (iv) The Employer should require the Engineer to satisfy him regarding the sufficiency of the qualifications and experience of the site staff and the adequacy of their number.

- (v) Any of the powers and authorities delegated to the Resident Engineer should be put in writing to the Contractor.
- (vi) A complete schedule of all working tolerances and imperfections which may be permitted during fabrication and erection should be promulgated by the Engineer to all concerned in existing contracts and specified for future contracts and should not exceed those given in Appendix A to the Interim Report.
- (vii) Where the superstructure for bridgeworks is undertaken by sub-contract the main Contractor should be firmly held to the obligations imposed by Clause 4 of the I.C.E. Conditions of Contract.

In addition recommendations (iii) (iv) (v) and (vii) are to be adopted for all forms of bridge construction to which they can be applied."

3. In addition to these seven, the Committee made the following other recommendations in their Interim Report (references in brackets are to paragraphs in Appendix B to the Interim Report):

- (a) The Department of the Environment's Model Agreement should be amended to require the Engineer to carry out a check of the Contractor's proposed erection method (paragraph 9).
- (b) All agreements between Employers and Engineers in respect of major steel box-girder bridges then (i.e. in June 1971) about to be erected in the United Kingdom should include this requirement for a check of the Contractor's erection proposals (paragraph 11).
- (c) The Resident Engineer should be given a written working brief, a copy of which should be available to the Employer (paragraph 15).
- (d) The Contractor should satisfy the Engineer as to the adequacy of his site staff (paragraph 17).
- (e) Where sub-contractors are employed, the Engineer should include wording in the Specification to remind the main Contractor of his responsibility to ensure the compliance of sub-contractors with the terms of the Contract (paragraph 20).

Recommendations (a) and (b) above have been superseded in the Committee's present Report (see Item (viii) of the list of Conclusions and Recommendations in Chapter 6). The substance of Recommendations (c) (d) and (e) above is restated in the present Report (see Items (xii), (xi) and (vi) respectively of the list in Chapter 6).

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