Health and Safety Executive

Final report of the Advisory Committee on Falsework.

London: Her Majesty's Stationery Office £2 net

To the Right Honourable Michael Foot, MP, Secretary of State for Employment and the Right Honourable Anthony Crosland, MP, Secretary of State for the Environment

Sirs,

We were appointed on 13 March 1973 by the Right Honourable Maurice MacMillan, MP, then Secretary of State for Employment and the Right Honourable Geoffrey Rippon, MP, then Secretary of State for the Environment to be a Committee with the following terms of reference:

"To consider and advise on the technical, safety and other aspects of the design, manufacture, erection and maintenance of temporary load bearing falsework used to support formwork or permanent structures, particularly bridges, during construction, and, in particular, to:

(a) identify any inadequacies in present knowledge, standards and practices, recommend such steps as may be needed, and indicate an order of priority;

(b) draw up interim technical criteria, for use in advance of the publication of a British Standard Code of Practice, together with such procedural guidance as the Committee may consider appropriate;

(c) recommend what research and development should be carried out in the short and long term; and

(d) advise as to the training, organisational and manpower implications of the Committee's recommendations."

Our Interim Report was published in April 1974. We now have the honour to submit our Final Report.

This report has taken a considerable time to prepare because we have not allowed ourselves to be deterred from discharging our task in as thorough a manner as the nature of the enquiry demanded. The volume of information considered, the numbers who have given evidence and the difficulty of the problems involved have required a sustained effort over the whole period since the Committee began its enquiries. We sincerely hope that our work will result in an improvement in the standards of falsework in this country and also that some of our recommendations may benefit those who work in the construction industry in activities outside the scope of our immediate enquiry.

S L Bragg

Chairman

Members of the committee

S L BRAGG MA MSc FIMechE FRAeS (Chairman)
Vice-Chancellor and Principal of Brunel University

P AHM MSc FICE MInstHE
Senior Partner, Ove Arup and Partners

F M BOWEN FICE FIStructE
Senior Partner, Scott Wilson Kirkpatrick and Partners

S CHAMPION PhD MSc(Eng) FIStructE FICE M Soc E (France)
Consulting Engineer and Consultant to Scaffolding (Great Britain) Ltd and Consultant to the National Association of Scaffolding Contractors

L C KEMP
National Secretary of the Transport and General Workers' Union (Building, Construction and Civil Engineering Group) and Operatives' Secretary of the Civil Engineering Construction Conciliation Board for Great Britain; Deputy Chairman, Construction Industry Training Board

J C S MOTT FICE FIStructE
Chairman, French Kier Holdings Ltd

C J WILSHERE BA BAI FICE
Head of the Temporary Works Department of John Laing Design Associates Ltd

W E J GREVILLE (Secretary)
Health and Safety Executive

I J HUME (Assistant Secretary)
Department of the Environment

Introduction

The interim report of the committee was published in April 1974. In publishing our preliminary findings and indicating the lines on which we were working our aims were to prepare all those involved in falsework design and construction for our final report, and to stimulate them to provide additional evidence on which we could work. We were much heartened by the response. Various authorities and firms have already taken action on our early recommendations, and we received most valuable and constructive views from contractors, engineers, architects, agents and representatives of employees. We take account of all this additional information in our final report, and in particular have expanded on parts of our interim report where it was apparent that a more complete exposition was desirable.

The problem

The constraints set by the need to temporarily support construction works in exactly the right position are severe. Each project is unique. There are few guides to good practice and there is often considerable doubt about the actual loads which will occur. Much reliance must be placed on the few skilled men who have experience of falsework design. The need to dismantle the equipment afterwards sets fresh problems. The contractor has his own materials and equipment which must be used where possible.

Working conditions on an exposed site are far from ideal. Good planning is needed to ensure that skilled men, materials and equipment are available at the right time. New hazards arise from weather, unexpected site conditions, and from the non-availability of critical resources of men or materials, which make modification and improvisation necessary.

Another complication is that so many different specialist organisations are involved. The design of the permanent works may be done by one group of consulting engineers and the design of the falsework by another specialist group. A preliminary design may be needed for estimating purposes and then the final design may have to be done in a great hurry when the contract has been awarded. Equipment may be supplied and erected by specialist sub-contractors who have not previously worked together. This diversity introduces difficulties of communication and a confusion of responsibilities which is worsened by complicated or imprecise contractual arrangements.

Finally the work force itself is often transient. Men sign up to work on one site but may not be prepared to stay with the contractor and move to another part of the country for his next job. This exacerbates the problems of providing training and maintaining the discipline on which safety depends.

Over all these activities hangs the need for economy and speed. The contractor is committed to completing the structure for a fixed cost by a certain date. The designer must provide a safety margin, yet he cannot afford to waste material. Safe construction practice must be followed in detail, faults must be corrected, yet the next critical step must not be delayed. Good planning, preparation and inspection are needed to ensure that corners are not cut.

In spite of all these difficulties most falseworks are designed, constructed and dismantled without accident. The aim of the Committee was to find out why accidents occurred and to recommend how they might be avoided.

Operation of the Committee

The committee decided at its first meeting, on 5 April 1973, to study evidence from known collapses. It read reports in technical journals and government publications; received evidence from those involved in the collapses at Loddon Viaduct (1972) and Birling Road (1971); and from other firms and organisations, and much help was received from HM Inspectors of Factories who were able to abstract the relevant technical points from a number of reports covering a wide range of conditions and causes of failure.

Simultaneously we solicited information from overseas. The Overseas Division of the Department of Employment helped us to get reports from USA, Canada, Australia, South Africa, Germany and France. Two of our members visited North America, and another went to Bavaria to obtain first-hand information on the collapse at Kempten.

Part 1 of the report provides details of some of the collapses we studied. These included major disasters, but we must emphasise that we also obtained evidence on smaller jobs; indeed far more accidents occur on building sites than on major works of engineering construction.

Our studies showed that failures arise from many different causes. Each one has two elements: the technical cause which led to collapse; and the procedural errors which allowed the faults to occur and to go undetected and uncorrected. In Part 2 of the report we discuss the commonest technical faults. In hardly any case did we find that failure was the

result of a problem beyond the scope of current technology. In Part 3 we consider common inadequacies in procedure. Some of the latter are the result of the particular organisation of the construction industry in Britain, by which the design of permanent works is often largely divorced from that of temporary works: we discuss this aspect at the end of Part 3. We also mention briefly practice in other countries.

In Part 4 we suggest ways in which the technical faults can be avoided and make specific recommendations about research. Our objective here is not to lay down specific codes of practice; this is the duty of the British Standards Institution Committee. We have been fortunate to have as a member of our committee the Chairman of the British Standard Committee preparing the code of practice on falsework. This has ensured that our line of thinking has been made known to that committee so that it has not been delayed in its work by the necessity for awaiting the publication of our final report. We have, therefore, confined ourselves to discussing the philosophy behind the code and to listing factors which we believe are essential to consider in the code.

In Part 5 we propose certain procedures which should help to correct the inadequacies discussed in Part 3. We recommend the appointment of a Temporary Works Co-ordinator with the duties of ensuring that necessary procedures have been followed and of co-ordinating the activities of the different specialists. We also discuss the relationship of the designer of permanent works to the falsework and this leads to a consideration of responsibility, liability and insurance.

None of the improvements we consider necessary can be achieved unless a determined effort is made to improve the training of all concerned. Designers must be helped to master the technology of falsework. Managers must be helped to appreciate the special problems of falsework, and to be convinced of their duty to promote safe practices. Site workers, particularly first line supervision, must be trained to work accurately and safety. The committee visited the CITB Training Centre at Bircham Newton to study the facilities available there and also received evidence from safety organisations. In Part 6 we discuss how and where the required training can be carried out. We recommend that certain activities should be carried out only by properly qualified people and that contractors should be encouraged to institute proper schemes for training their work force.

We end with a summary of the actions already taken since we started work and the further actions which we believe are necessary. In making our recommendations we have tried to be practical and not to suggest measures which would put an unnecessary economic burden upon the industry. The reactions which we have received to our interim report and the adoption of the recommendations in it by a number of contractors in the industry, who have assured us of their practicality and benefit, encourage us to continue on the lines which we initially adopted.

Since the report is rather long we can hardly expect that it will be read by everyone involved in the design and construction of falsework and permanent works. On the other hand we believe that much of what it contains is worthy of a wide audience. We therefore consider that a version which includes the most important points of our final report ought to be produced.

We hope that, in setting out so much of the fact and argument presented to us, our readers will be helped to understand our lines of thought. We make no claim to have covered every detail of the use of falsework and its associated problems though we hope that we have considered all the major issues. We wish to acknowledge that this work would not have been possible without the enormous fund of goodwill and support which has been shown to us by all concerned.

Principal Recommendations

1 Any collapse of falsework whether it leads to injury or not should be made reportable by statute.

2 Regulations relating to falsework should be harmonised with those relating to periodic examination of scaffolding so that the same administrative rules apply whether or not the falsework is used for access.

3 Designers must consider the lateral and longitudinal stability of falsework. Unless and until an authoritative body, backed by appropriate research and field testing, recommends a different figure we reiterate the recommendation in the Interim Report. That is, all falsework should be designed to withstand a total horizontal load in any direction equal to the sum of the calculated loads plus 1% of the vertical load or 3% of the vertical load whichever is the greater.

4 Although individual components in a falsework may have their own accepted factors of safety we nevertheless recommend that the overall factor of safety for the falsework as a whole should not be less than two. Particular elements may require the adoption of a higher figure.

5 In his calculations the designer should allow for possible variations in positioning and alignment which are inevitable even with good workmanship. The drawings should state the tolerance within which the falsework must be constructed.

6 All falsework must be *designed*, even if on a small job the design is only a simple sketch. The designer, especially if he is not on site, must have a proper written brief which must include all the factors which have to be allowed for.

7 Special attention must be paid to the design of grillages. The designer must ensure that tendencies for beams to overturn or webs to buckle under load (particularly eccentric or lateral loads) are resisted and that allowable bearing stresses are not exceeded.

8 Work on the measurement of loads on actual falsework in the field should be extended.

9 Theoretical and laboratory work on falsework elements and systems should be extended and correlated with the measurements made under the previous recommendation.

10 Suppliers of proprietary materials should be required to specify the conditions of test, the failure loads and the mode of failure of each item of equipment in addition to any recommendations about safe working load.

11 Tests should be carried out on new materials to check the validity of claims made for them and on used materials to check the deterioration which occurs in service.

12 The designer should assume that previously used material will be incorporated in falsework and must use appropriate stresses. If there are critical areas where he has assumed the use of new material these must be clearly indicated on the drawings.

13 The initial design of any falsework other than minor and any subsequent significant alterations must be approved by a fully qualified engineer.

14 If a design contains novel features the contractor should arrange for the design to be checked by an independent assessor.

15 The falsework design and, if he requests them, the calculations which were made must be submitted to the designer of the permanent works for comment. If the person responsible for the permanent works is an architect without engineering qualifications he must submit them to his consulting engineer unless the building method is traditional in all respects.

16 The philosophy of preparing and checking the design, of not modifying it without assessing the resulting effects and of having any doubtful points checked must apply in all cases major and minor.

17 On all sites the contractor or construction organisation must appoint a properly qualified Temporary Works Co-ordinator whose duties are to ensure that all procedures have been followed, that all checks and inspections have been carried out and that any modifications or changes have been properly authorised. Falsework may not be loaded or struck without the written permission of the Temporary Works Co-ordinator.

18 Communication between designers and others on and off site must be improved. Drawings must be clear and loading diagrams must be provided.

19 Training in safe working procedures must be an integral part of all courses in falsework technology and practice, whether for skilled operatives or professional engineers.

20 Instruction in the special features of falsework should be included in all education courses in civil engineering and architecture.

21 Professional institutions should require the design of the relevant falsework to be included with any permanent works design submitted as evidence of professional competence. They should also commission case histories and suitable data for instructional purposes.

22 Short professional courses in falsework should be provided for practising engineers and architects.

23 Practical training courses in falsework should be provided for skilled operatives and first line supervision. The performance of everyone attending such courses should be assessed and a certificate awarded to those reaching an acceptable standard. Courses should be on such a scale that the proportion of certificated operatives in the industry should be 10% at the end of the year in which courses started and should continue at this rate.

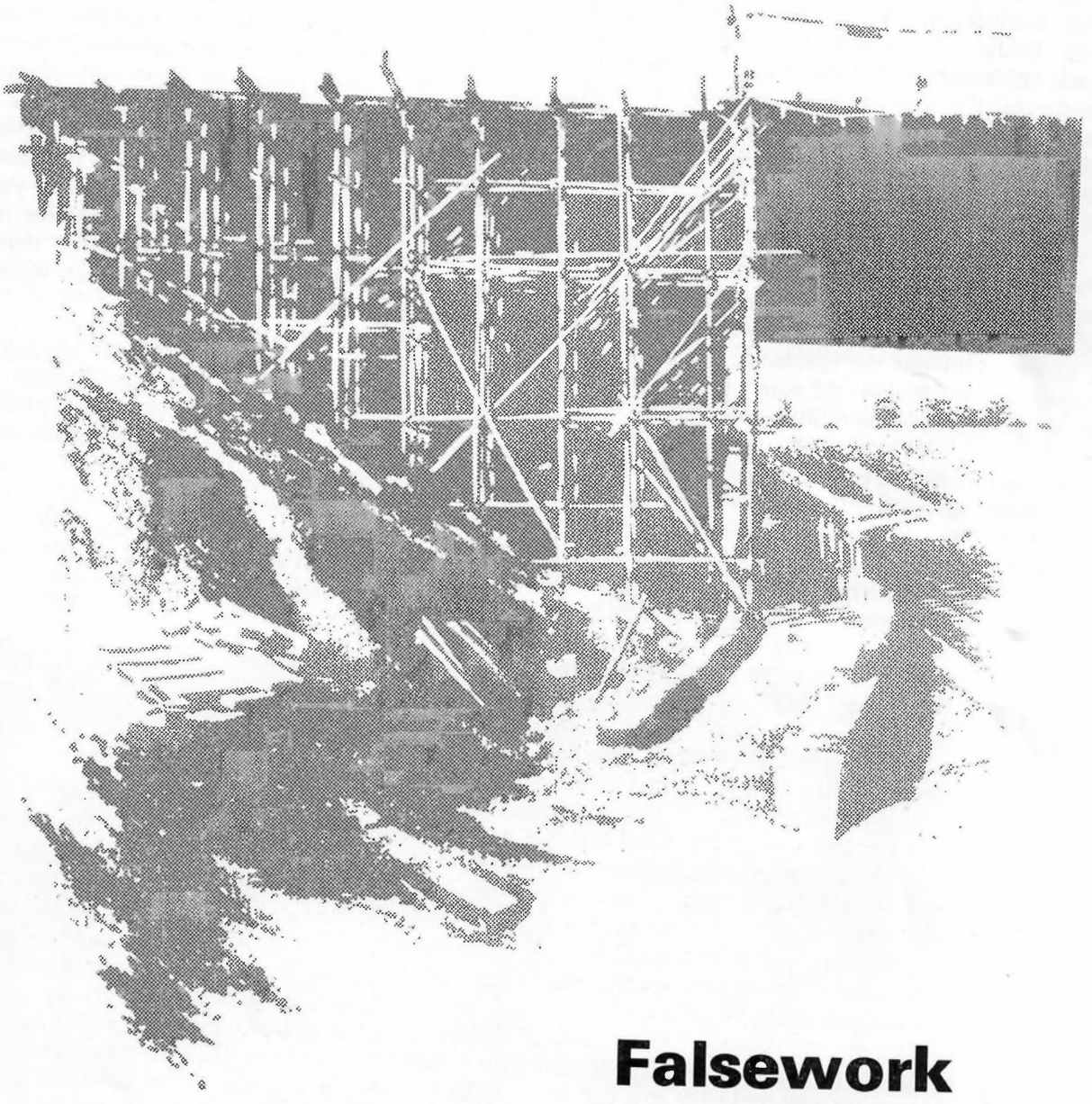
24 The standard of the courses should be controlled by the Health and Safety Executive and reviewed regularly. Resources for such courses are already available from the Construction Industry Training Board. The Training Services Agency should regard falsework as a key training area.

25 Contractors, sub-contractors and other construction organisations who are directly responsible for falsework must keep a register of the number of certificated operators they employ on each site.

26 The Government should insist that contractors carrying out work for the public sector in which falsework is a feature, provide a training record and programme which will ensure that properly trained operatives will be employed on that work.

27 A handbook on falsework and simple data sheets for use by personnel on site should be commissioned by the Government. A textbook on falsework should also be commissioned.

1



Falsework collapses

1 Falsework Collapses

Historical perspective

The collapse of a major falsework such as that supporting a bridge or a tall building is invariably given wide publicity and often provides spectacular pictures. Interest is aroused, not only in those having a professional or personal involvement but in members of the public at large. The collapses of falsework for the Loddon Viaduct, the Birling Road Overbridge, the Danube Bridge at Vienna, the Rhine Bridge at Koblenz, the bridges in Pasadena and San Bernadino in California, the Skyline Plaza building in Fairfax County, Virginia, the Kuwait multi-storey car park and the Leubas River Bridge at Kempten, Bavaria all suggested a continuous series of disasters which required urgent action to prevent a recurrence.

To these major incidents one must add a large number of smaller ones, many of which did not result in death or injury though they might have done so. It is, however, necessary to put the spectacular events in perspective by relating them to the number of construction works which proceeded without accident.

Finding accurate figures poses many difficult questions which are at present largely unanswered. We would like to know the number of falsework collapses occurring in the United Kingdom, preferably over a period of years, in order that a comparative study may be made. We need to know the numbers of falseworks in existence at any one time and the number of persons employed on such projects as well as the number who are killed and injured during collapse. Such information is hard to come by. Figures of the number of reported accidents, including fatal accidents, in the construction industry generally are available through the reports of HM Chief Inspectors of Factories. However, while total figures are given and certain subsidiary classifications are available, it is not possible to determine with any degree of accuracy the number of persons whose injury was received working with falsework. Furthermore unless there is actual injury to persons employed there is no legal requirement to report a falsework failure, however serious or potentially dangerous. Even then, it is possible that only some 50% of such accidents in the construction industry are actually reported to the Factory Inspectorate.

The statistics of persons employed, published by the Department of the Environment, while covering a large number of classes in the construction industry, do not enable the numbers employed on falsework to be assessed. No statistics are available on the number of construction operations involving falsework – including buildings – at any one time. However, it has been estimated that some 12,000 jobs involving falsework are in existence at any one moment. It has been possible to obtain an estimate from the Department of the Environment of the number of bridges under construction during the year. These figures are given below but it should be noted that they neither include bridges built under Government auspices in Scotland, nor bridges commissioned by local authorities. Nor do they collectively give an indication of the total number of bridges built for the Department of the Environment in England and Wales because any bridge which takes more than a calendar year to construct will be included more than once in the table position. We are however informed that it is exceptional for a bridge to be included in the return for more than two years.

Year ending March	Approximate number of bridges under construction during the year
1956	70
1966	600
1967	600
1968	500
1969	900
1970	1100
1971	800
1972	900 estd
1973	800 estd

Reporting of failures

It is thus clear that reliable information has not so far been recorded and made available. Estimates of falsework failure vary widely. Some authorities believe that spectacular collapses reveal only the tip of an iceberg and that the total number of all classes of failure is substantial. Records have been kept by HM Inspectors of Factories of every failure in Great Britain where death or injury has been reported since the inception of this committee. During 1974 no less than twenty such falsework failures were recorded. The failures covered a wide range of construction including commercial and industrial premises, silos, towers, hotels and reinforced concrete structures as well as the smaller type of building operation.

Any failure which could have caused injury is important since it indicates an error or weakness which must be avoided in future. Failures which do not cause

injury are of as much interest, but at the present time these need not be reported. Thus, under present statutes, collapse of a falsework supporting a substantial volume of concrete may well escape recording and investigation, the concrete being hosed away and the debris removed without the incident receiving publicity or being recorded. We recommend that *all* failure of falsework should be made reportable under statute in a manner similar to the procedure for recording dangerous occurrences under S 81 of the Factories Act 1961 and that such events shall be reportable whether injury occurs or not. In this way a more reliable body of evidence will be available for analysis and improvement of practice.

Case studies

We examined reports on a wide range of falsework collapses. Most British reports covered cases where failure had caused injury or death or where evidence had been collected by HM Factory Inspectors because of a breach of statutory regulations. The experience of HM Inspectors, who provided edited summaries of reports covering a wide variety of situations, was most valuable. In addition we drew on our members' own experience. Through the co-operation of other bodies we received reports of collapses overseas, often in the form of official inquiries. Some of the information was given us in confidence because actions or claims for damage were pending. Several contractors willingly provided such information on the understanding that our object was not to apportion blame but to study possible causes of collapse.

We paid special attention to four particular groups of failures.

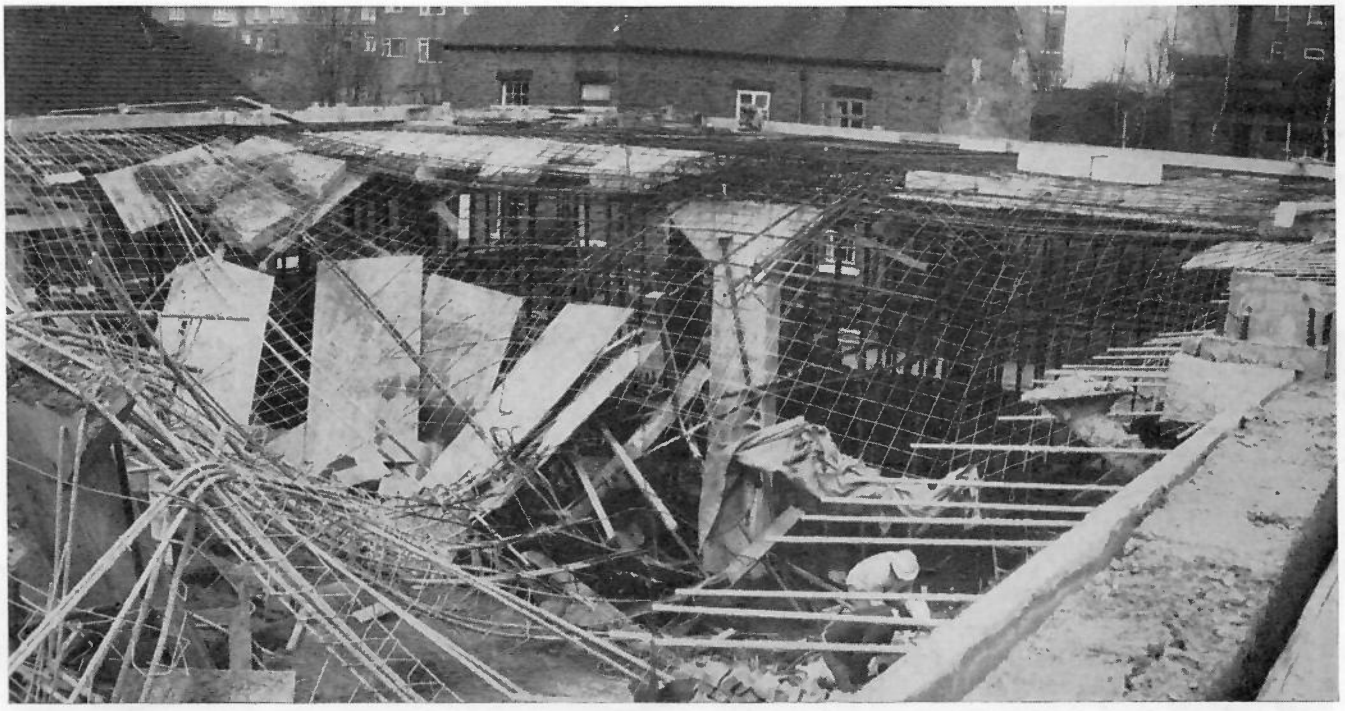
(1) The recent collapse of the Loddon Viaduct on 23 October 1972 and of the Birling Road Overbridge on 23 March 1971. In both cases the contractors provided information.

(2) A sample of 25 falsework collapses investigated by HM Construction Engineering Inspectors of Factories. The inspectors who gave evidence also gave us the benefit of their wide practical experience of falsework problems over the whole of the United Kingdom.

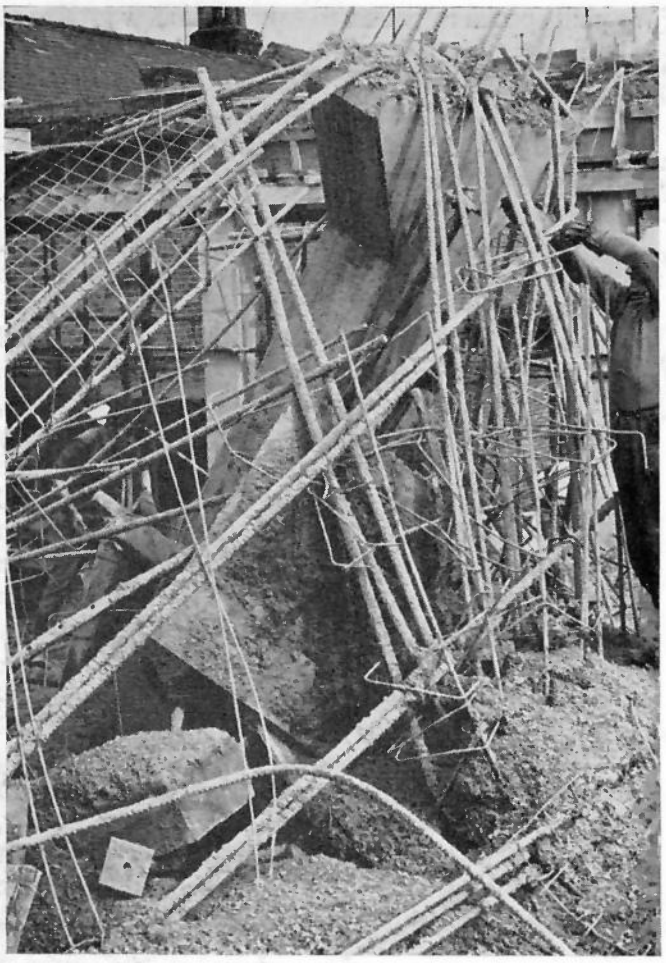
(3) Failures in countries abroad including Canada, the United States of America, Australia, Germany and France. The very thorough reports on the Heron Road Bridge failure in Ontario, the Second Narrows Bridge collapse in Vancouver, the Arroyo Seco collapse in Pasadena, California and the Welshpool Road Overpass in Western Australia were of great help to us.

(4) Failures which have occurred since the committee was set up such as the collapse of the Skyline Plaza in Fairfax County, Virginia, the Kuwait multi-storey car park collapse, the falsework failure at Kempten while bridging the River Leubas in Bavaria and the silo collapse at South Ferriby, Lincs. There have also been a number of recent failures during the construction of buildings, large or small.

The committee considered that it would be of value to include in its report summaries of some of the



Typical failure of a prop-supported medium sized floor slab



papers which it has examined. These show the range of falsework problems which arise in construction projects. These summaries with photographs are given in Appendix 1.

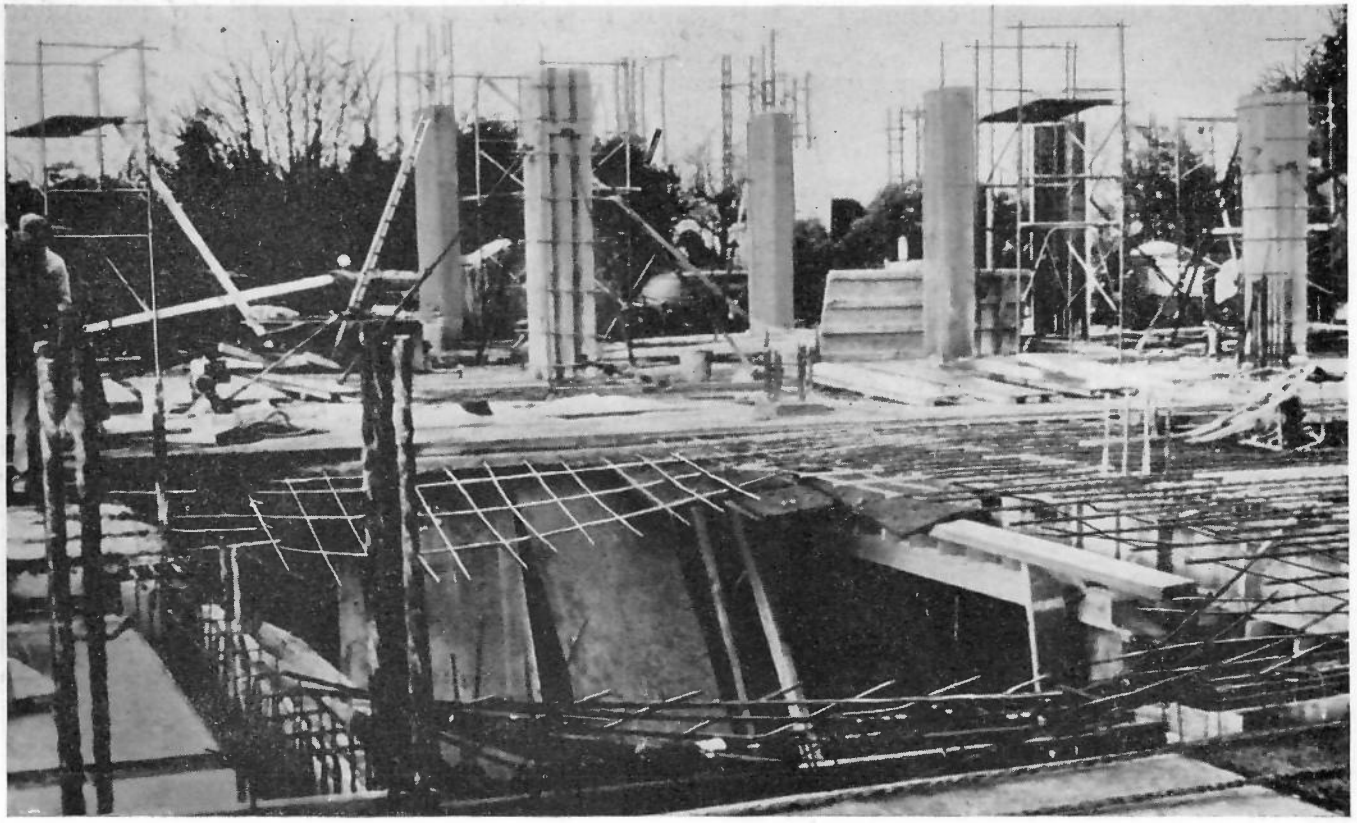
These reports and studies provided much of the material upon which we have based our deductions and conclusions. We have also benefited greatly by sharing the professional experience of our members.

Thus we have based our discussions on practice rather than on hypothesis and have tried to provide solutions that are realistic rather than utopian.

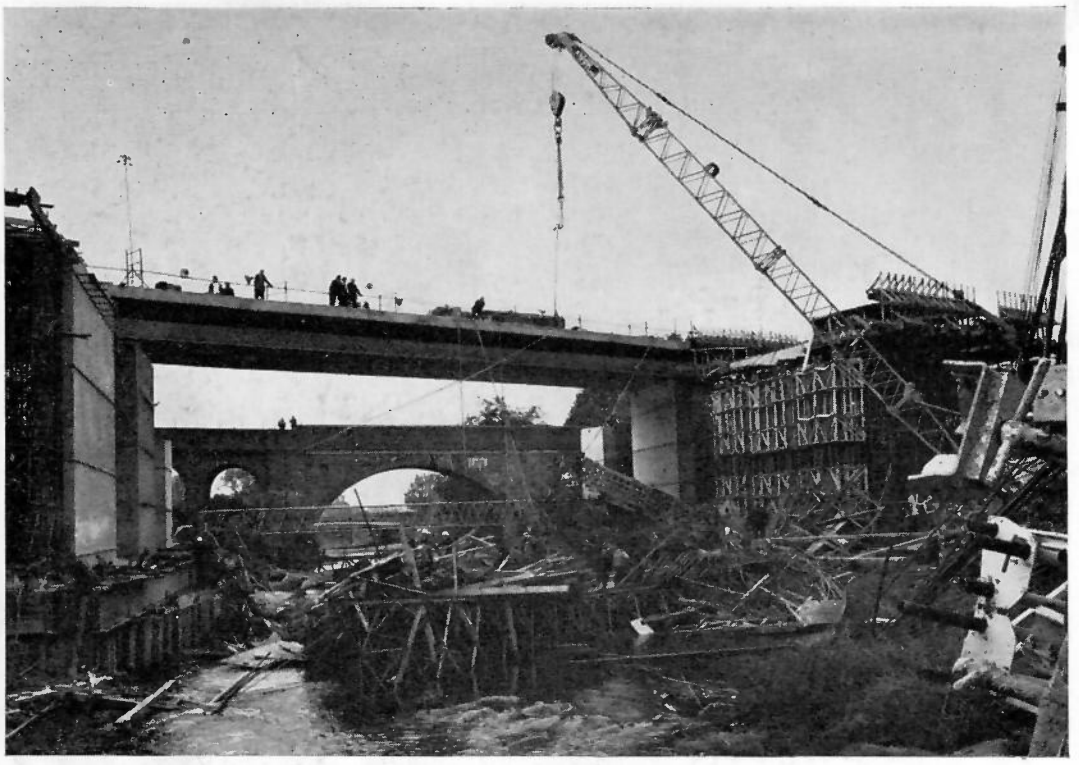
We shall consider in the following chapter the causes of falsework failures.

Aftermath of collapse showing damage caused to existing construction and loss of materials

Example of collapse due to failure of row of props supported on unconsolidated backfill



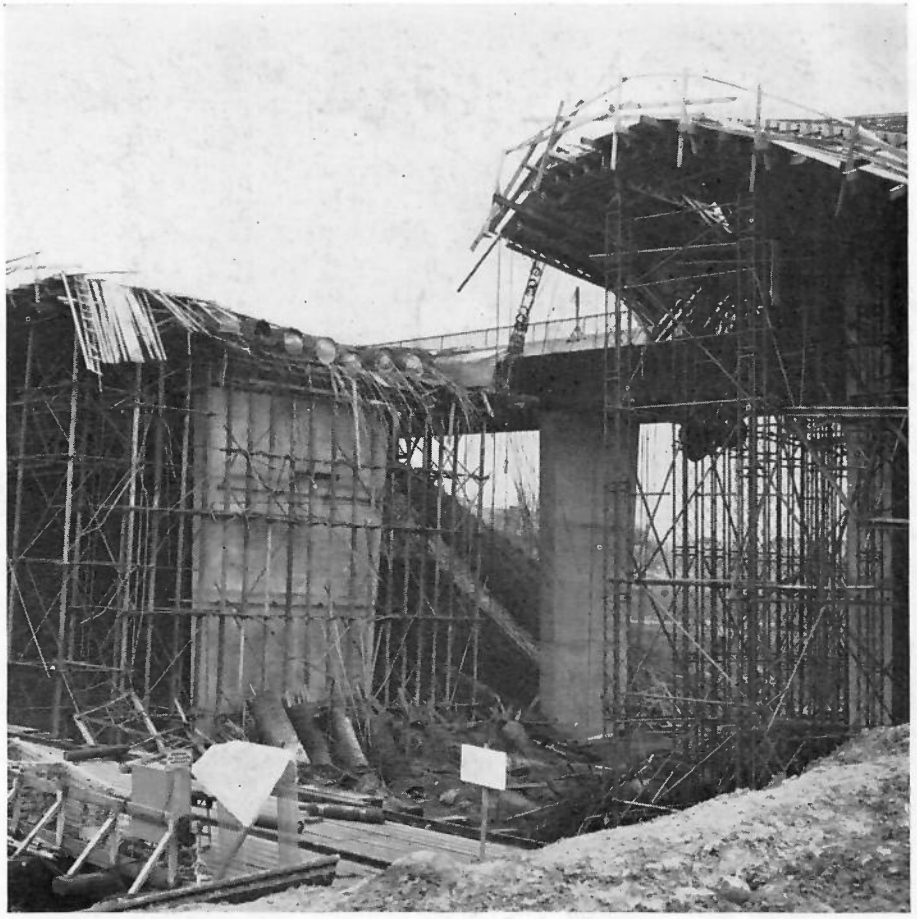
Progressive collapse of multi-storey column and slab structure caused by premature removal of the support props



General view of collapsed falsework at Loddon Viaduct, October 1972

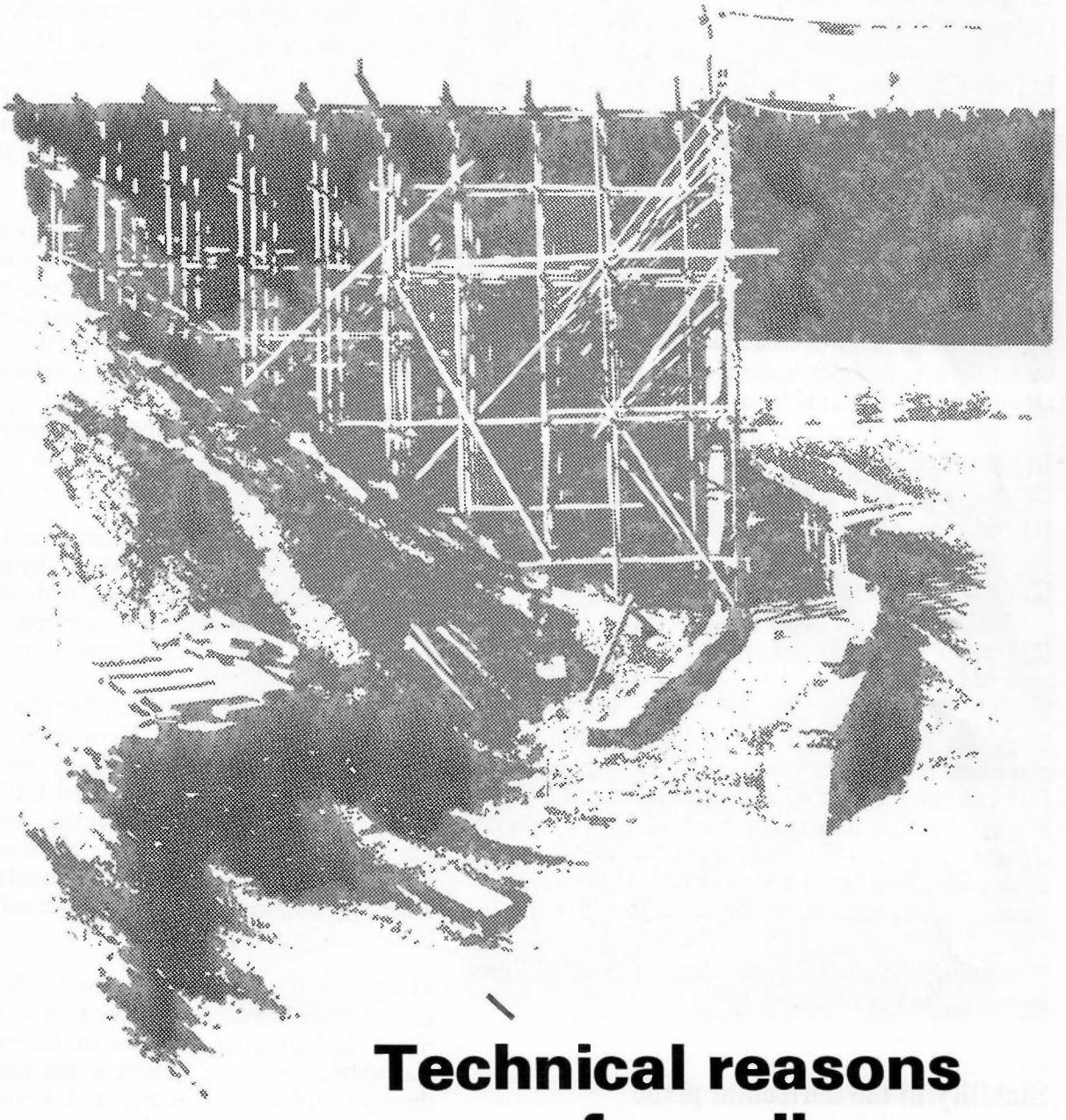
Large-scale falsework collapse on approach spans to Rhine bridge at Koblenz, September 1972

Collapse of truss-supported span of Kempton bridge over the river Leubas, Bavaria, April 1974



Aerial view of the devastation at Birling Road Overbridge, Ditton, Kent, March 1971

2



Technical reasons for collapse

2 Technical Reasons for Collapse

An analysis of all the falsework failures brought to our notice indicates that there is no single cause of collapse. Indeed the examples already given show that the causes are varied and widespread. In each case, however, one may discern the direct technical reasons for failure and also the contributory procedural failures which allowed the technical faults to go undetected. In this section we will discuss what appears to be the commonest technical faults.

In providing this catalogue of errors we must make it clear that it has been derived from a selective study. The great majority of falseworks do stand up to the loads imposed on them. In relatively few will any of the errors occur and remain uncorrected to an extent which would lead to failure.

In surprisingly few cases have we found weaknesses which could not have been recognised and dealt with by well established procedures. However, there are evidently areas of particular difficulty, where special attention is required, guidance is offered these in Part 4.

In general one may divide technical failures into three categories:

(1) where the loads on which the design was based are different from those actually applied

(2) where the design itself was inadequate for the specified loads

(3) where the works were not constructed according to the design.

Thus faults of understanding, interpretation and execution all occur the design and construction stages. For example, a lack of sufficient stiffness in a pin-jointed structure may result from a failure by the designer to recognise the need for it or from the absence of clear detailing in a drawing or from the omission of bracing due to carelessness or shortage of materials.

The principal technical causes known to us will now be considered in detail.

Stability in the horizontal plane

The primary purpose of most falsework is to support loads or to take reactions which are vertical. In contrast the forces in the horizontal plane are relatively small and difficult to quantify so they tend to be inadequately allowed for. Several of the investigation reports which we have studied and much of the evidence before us both from the United Kingdom and overseas emphasised lateral instability, and to a lesser extent longitudinal instability, as one of the prime causes of failure. In fact the most commonly occurring fault in falsework design seems to be a neglect of horizontal forces and a failure to make provision for adequate lateral and longitudinal stability. Horizontal forces may be introduced by wind, vehicle braking, impact of skips or vehicles, attempts to free stressing cables, guys, concrete pouring methods, vibrators and a multitude of other causes. In at least two collapses of bridge falsework shutter vibrators were being used; these transmitted compressive waves to the outermost members of the falsework. Poker vibrators, which have a direct effect on the concrete impose fewer stresses on the sub-structure.

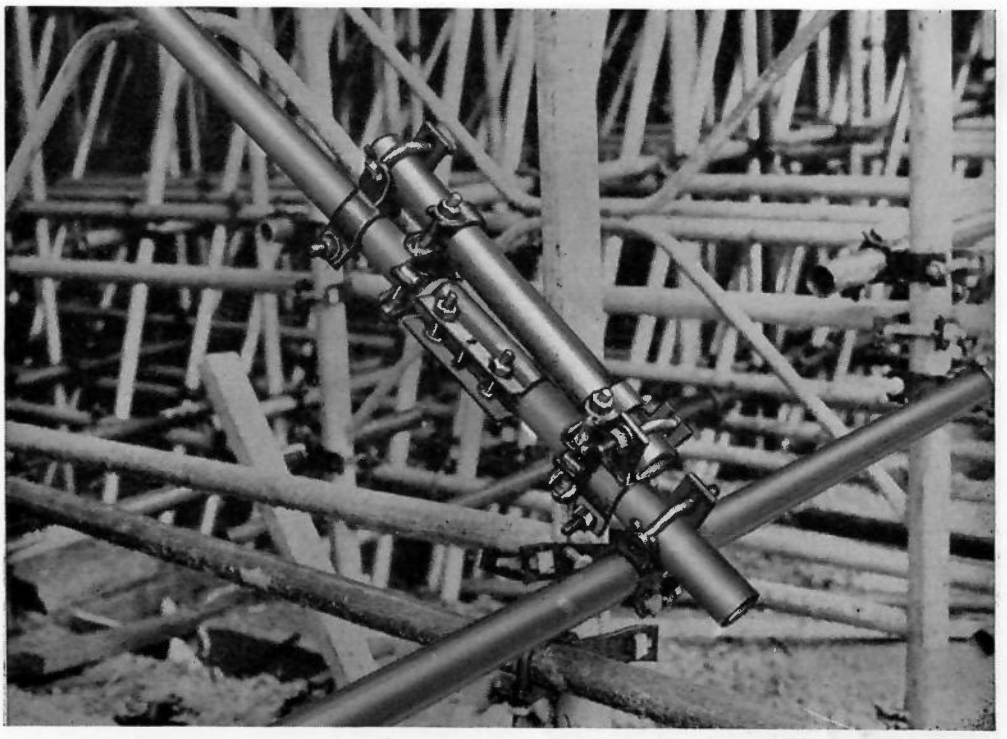
It is by no means always possible to anticipate the commencement or duration of every component of the horizontal force which has to be catered for as in the case of forces induced by accident. Adequate measures need to be taken to forestall the effects of such occurrences. Numerous accidents have been recorded where there was no efficient signalling system between the person controlling the pouring operations and such operatives as crane drivers and the drivers of concrete delivery lorries.

Local horizontal forces at interconnecting points in the structure can also be introduced by such factors as the non-verticality of members, hydrostatic pressure on formwork, inclined soffit members or inclination or uneven deflection of the foundation surface.

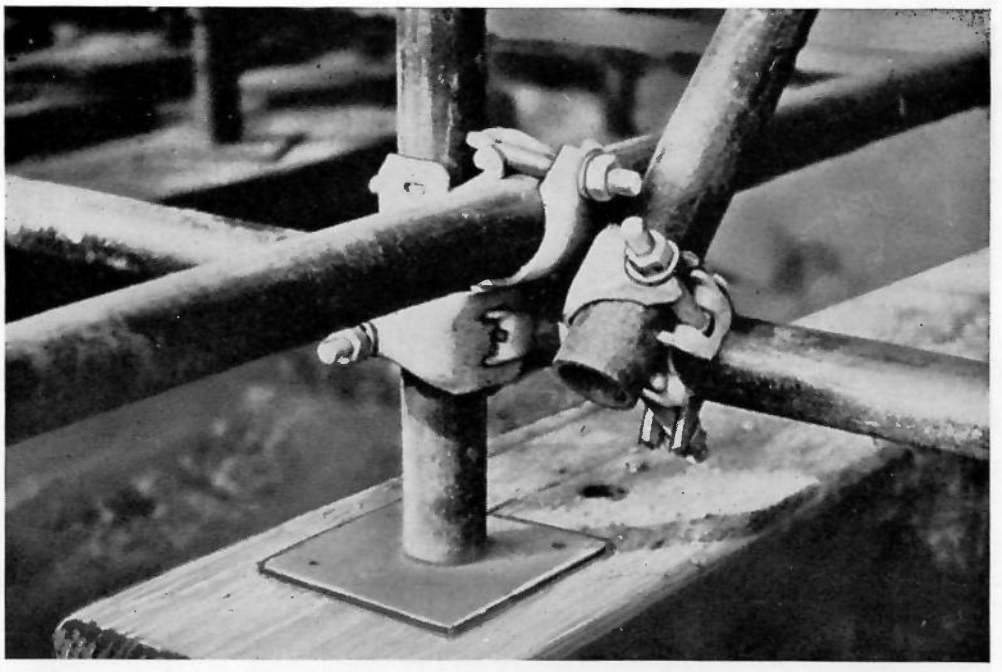
The effects of cross fall of the foundations are particularly important. The downwards slope causes drainage towards the lower level with consequent ground weakening and differential settlement. Taller struts must be used on the lower side, and these, when weaker, deflect more causing relative movement. There may be a deeper filling of foundation material which allows more movement of the sole plate if it is inadequately compacted.

The probability of local horizontal forces makes it essential to consider interconnection in the horizontal plane. It frequently happens in falsework that the assembly of separate timbers is not bolted or nailed through joining plates, nor spliced, joined or otherwise formed into a coherent structure. The reason is that the members have to be easily dismantled and are usually required for re-use.

This lack of structural connection prevents one portion of the whole helping another to withstand lateral forces. For example we studied a case where the



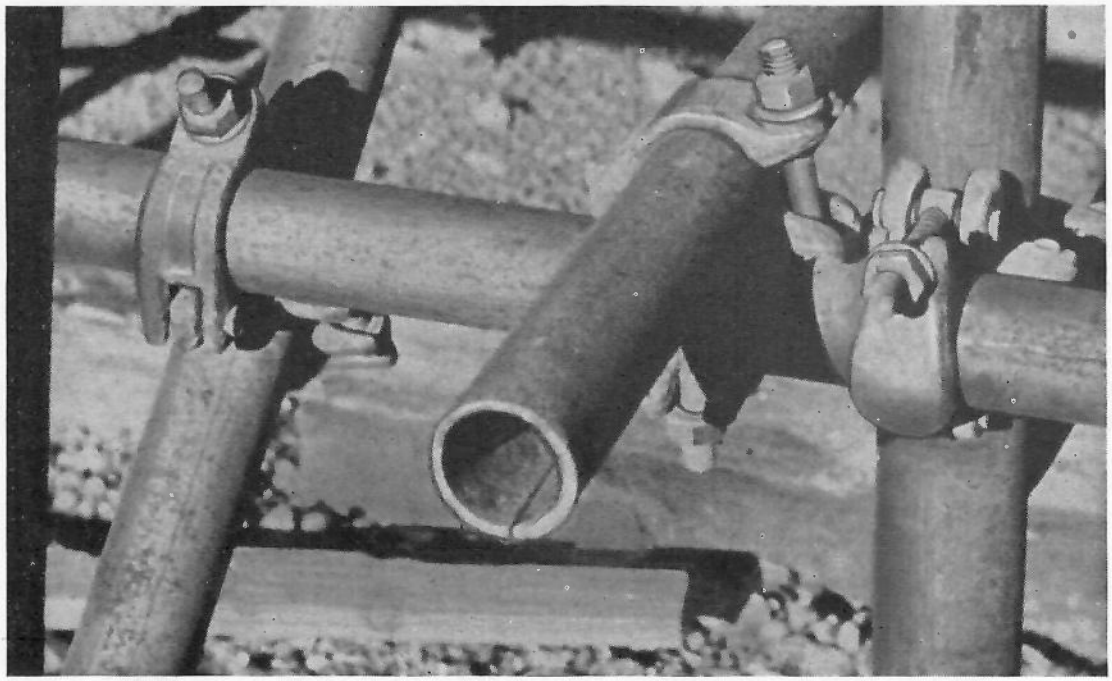
Over-elaborate lengthwise joint in diagonal. Brace connected too far from node



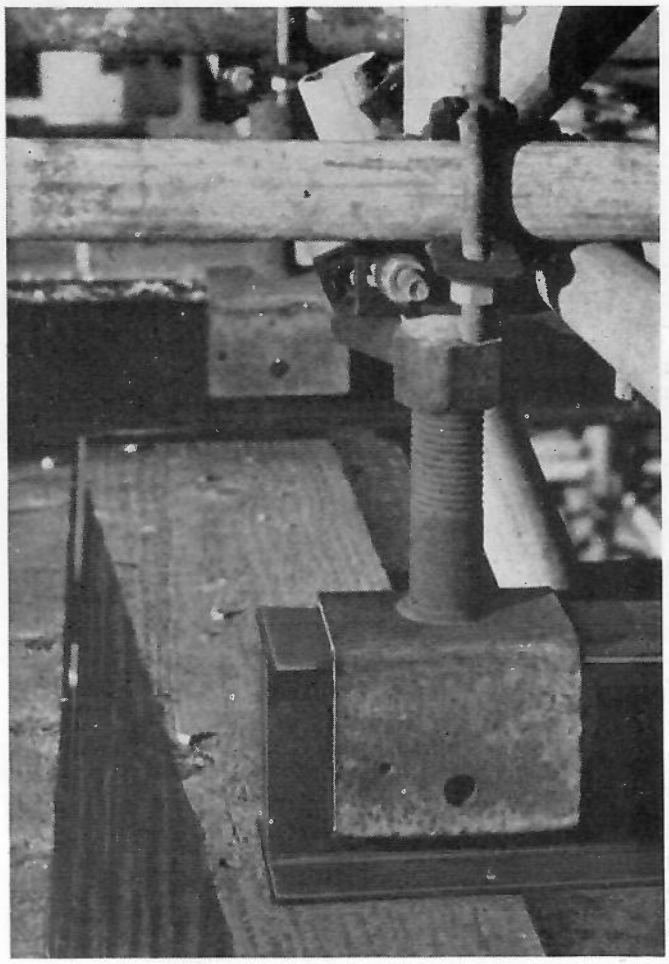
Good example of concentricity of connections at a node

breakage of through ties resulted in the hydrostatic forces on vertical formwork members being transferred to the falsework: because the falsework elements were only resting on each other and were not interconnected they moved sideways. This caused disruption and consequential failure of the whole structure.

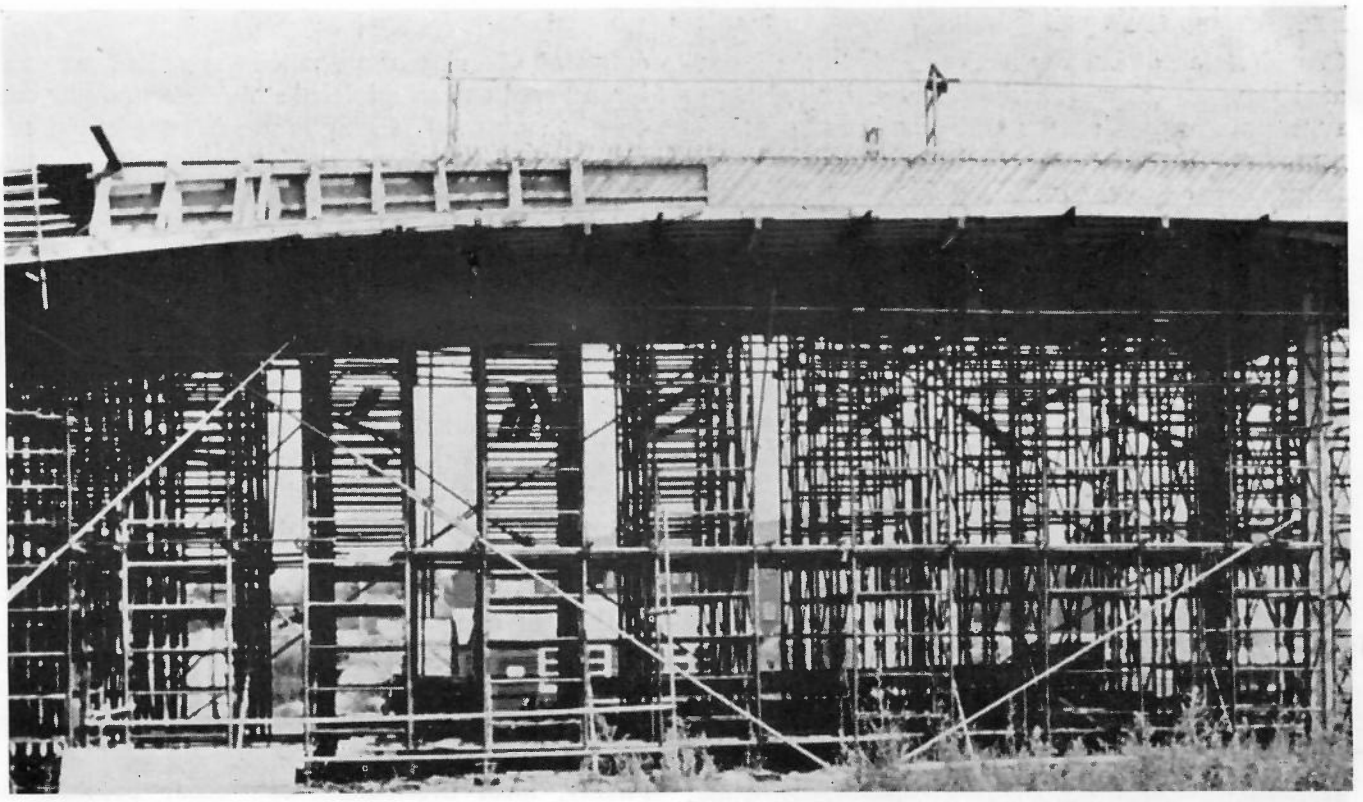
This highlights the danger of using a multiplicity of unconnected elements on top of each other, relying only on friction for structural integrity. We consider that this commonly receives too little consideration by both designers and erectors.



In contrast with figure on page 21, this shows undesirable separation of members at a node



Good use of inverted forkhead to ensure stability of base support on steel beam



Example of prefabricated system falsework, horizontal and diagonal interconnections, and regularity of construction

Poor practice in small-scale construction work, showing mixture of prefabricated support frame, beamhead and plain props. The props are buckled, out of vertical, not laced and have no forkheads

Progressive collapse

Consideration of interconnection leads to the associated problem of progressive collapse. United States authorities responsible for bridge and road construction were emphatic about the risks of collapses *seriatim* of the elements in long falsework structures. In the United Kingdom we have examples of progressive collapse initiated by the failure of an intermediate section due in one case to river scour, in another to the giving way of a bricked culvert used as a foundation, in others to road traffic damage or failure of an arch upon which reliance had been placed. This disastrous form of collapse may be averted by designing the several sections of the falsework to be independent self-supporting structures, using lacing, bracing and diagonal support in longitudinal and transverse planes. A similar philosophy was applied in the case of the Tasman Bridge at Hobart so that it did not collapse completely when two piers were knocked down by a ship in January 1975.

Overloads

We can distinguish three specific categories of overstress. In the first category the falsework is inadequate for the design load. This seems the commonest type of failure in small jobs. Often no proper design has been done. For example we mentioned in our interim report a case where a 5in × 2in timber beam, part of the falsework enabling an opening in a factory floor to be filled, failed and a man underneath was killed. Once again we must emphasize that many accidents occur on small sites on apparently simple jobs where the standard of skill of those involved may be insufficient to enable them to produce an adequate design.

We have also seen instances where a genuine mistake was made in calculation or where no check was made on the ability of a particular member to withstand a particular stress. In both cases the design was inadequate for the loads specified in the design brief.

In the second category the design is adequate to support the loads assumed, but the loads actually applied are different. For example, the plant in use may be heavier than was catered for. Another example concerns the support work for materials of unknown density such as rubble-filled walls, brickwork or masonry, where special allowances should be made for possible inaccuracies of load assessment.

In the third category the way the load is actually applied may not have been properly allowed for in the design, or alternatively the load was not applied in the way the designer specified. For example the emptying of a skip of concrete in one place causes an impact load and a high local static load until the concrete is spread. If placing is started at one end of a bridge the deflections and possibly the torsions applied to the falsework are quite different from those obtaining when placing is started in the centre.

The designer may have assumed that loading would produce progressive stressing whereas the method actually employed may be conditioned by the jib length of the crane handling the skips of concrete, so producing maximum deflection at an early stage.

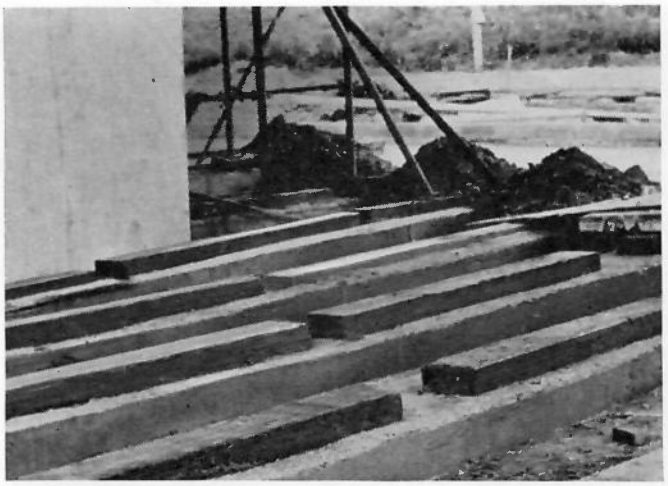
In one instance we suspected that the deflection of a supporting beam in the early stages of a pour produced a buckling torsion on a supporting trestle leading to a serious collapse. There are many ways in which the method of applying the load imposes a temporary local overload which cannot immediately be shared by other elements. The same effect may be produced by local displacement of base supports during loading.

Finally, local overloading can occur because the designer, perhaps ignorant of actual site practice, assumed a perfection in construction which was impossible to realise. This whole subject of tolerances and eccentricities is, however contained in a separate section in our report.

Inadequate foundations

The evidence we received indicated that it was very important to establish beforehand the true nature of the foundations on which the falsework is to be constructed. The client does not always pass on full details of the nature of the ground on which the falsework is to be founded, or even the soil analyses on which the permanent works were based. We heard of a case where a falsework designer was not told that there was to be a deep excavation for a project carried out by another contractor immediately alongside the foundation of his falsework: when the information was belatedly passed on a complete redesign was required. It is not always appreciated that the soil sampling and testing which were carried out for the supports of the permanent structure may not be reliable guides to the nature of the ground which will support the falsework. Empirical tests may be quite inadequate for falsework foundations which may be on or near the surface of disturbed or prepared ground. Practical load bearing test may be required.

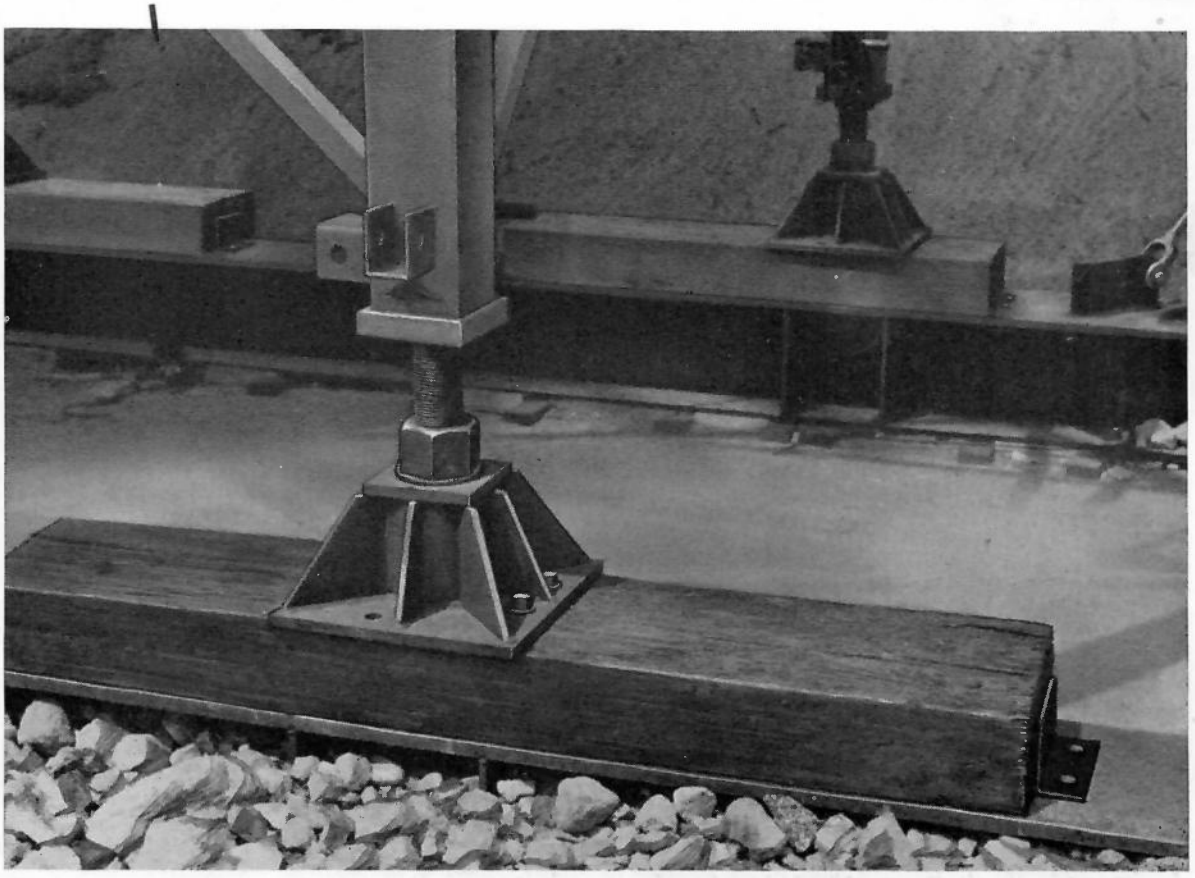
We were also shown cases where conditions had changed after the design had been done, due to diver-



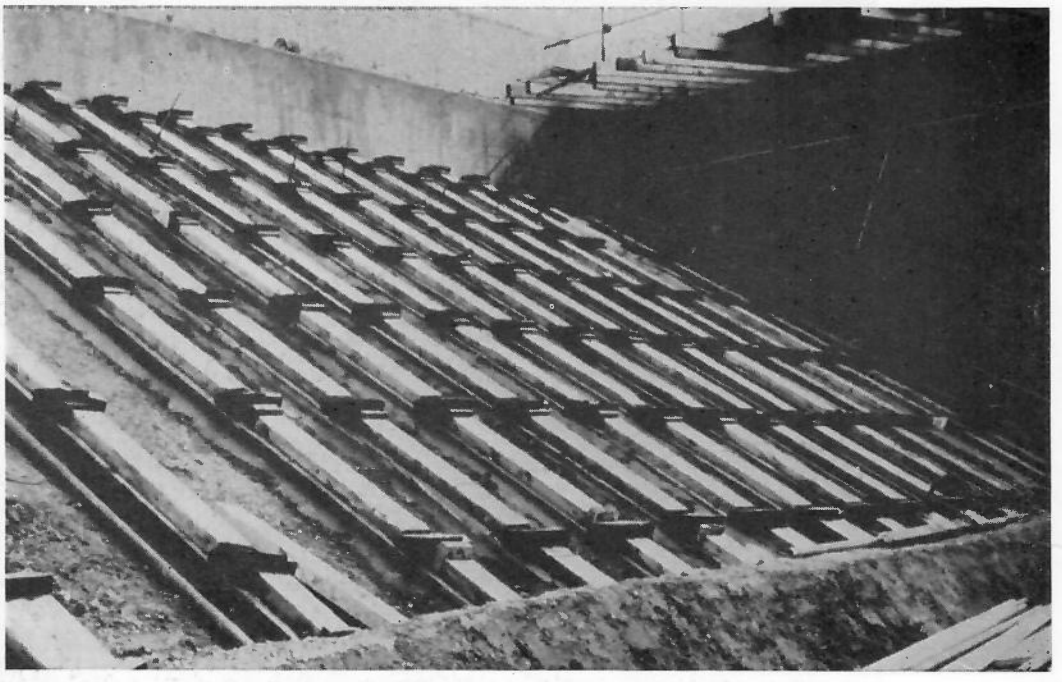
Excellent preparation of base supports, using heavy timber on concrete ribs

Falsework undermined by scour due to failure to provide site drainage

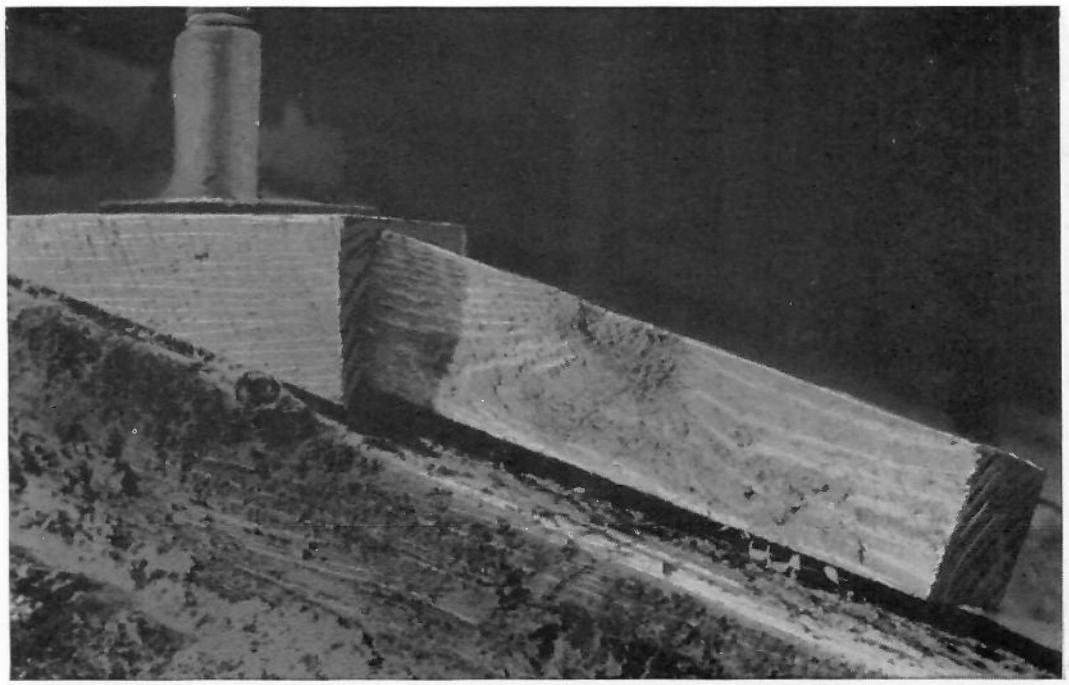
Excellent detailing of main jack bases, showing chair bolted to substantial timber pad, cleated to web-stiffened bearer beams



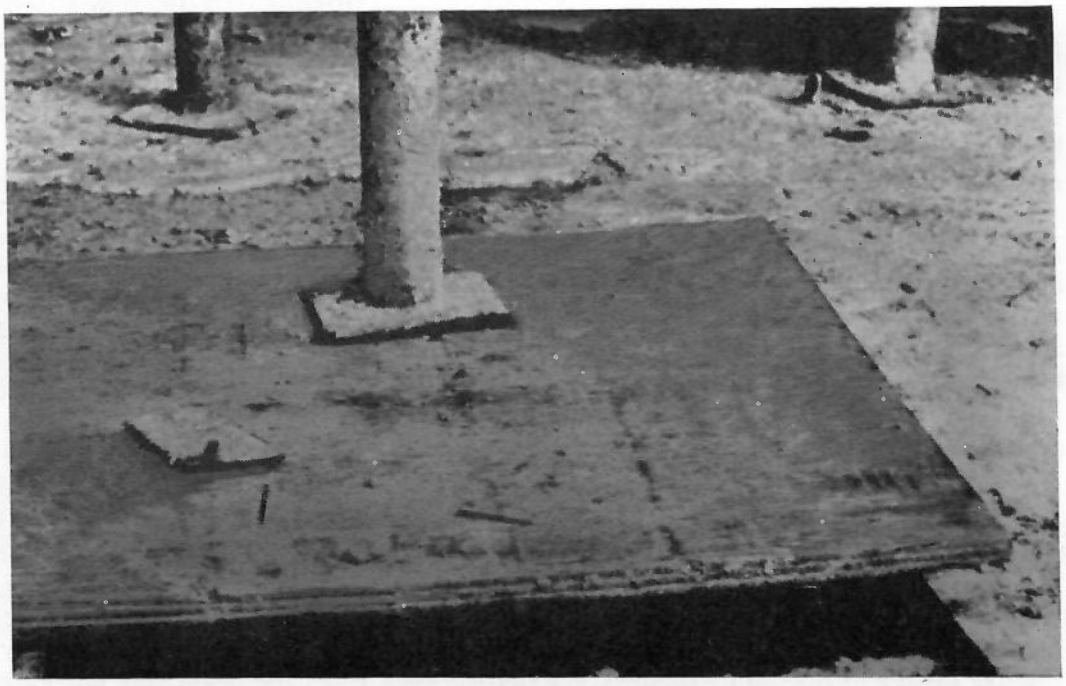
Attempt to provide adequate support on sloping base marred by incorrectly cut wedge with the load taken on the end-grain. The diagonal foot tie should have been lowered and a transverse lacing added



Careful preparation of sloping surface, with over-site concrete and timber bearers, carrying accurately located wedge pieces



Detail showing excellent use of wedge piece, and cleat bolted to bearer with timber connector



Dangerous practice: use of plywood sheet to bridge a floor opening under a prop base

sion of surface water, freezing and thawing, or the provision of an access road.

Founding falsework on an inclined surface such as the side of an embankment raises particular problems. We were shown examples where the restraints against the base plates slipping down the slope were clearly inadequate. Even minor settlement can produce disruption in a load bearing falsework.

Timbers, often old railway sleepers, which are used to spread the loads from the bases of scaffold columns or proprietary struts, may be short and worn. If the soleplates are resting on the edges and ends of the sleepers, the load will not be properly spread. We were shown examples of standards which were not adequately supported – in an extreme case one was resting on the edge of a pile of bricks. Any base material containing silt or fine sand which may permit movement after wetting is potentially unreliable, and any badly compacted material will cause trouble.

It is difficult to stabilise sleepers against some overturning movement – grillages which have intermittent lower beams improperly dug into the ground may introduce bending stresses in the upper layer of cross sleepers. Close boarded grillage mats with sleepers in both directions are costly. Crawler mats with close sleepers in one direction must be stiffened by cross timbers and very evenly founded or prepared.

It is evident that the same care should be taken over the base supports as over all other parts of the falsework, but that this is not always done.

In some cases timber foundations should not be used. Concrete into which timber can be intimately bedded results in a better spreading of the load because it can be cast wider and thicker and be dug into the formation to make perfect contact with it.

Although very few of the collapses studied could be attributed directly to a foundation failure, emergency action was needed in some instances to prevent an accident. The evidence received indicated a definite need for greater thought to avoid a number of pitfalls, including:

(a) not taking the trouble to find out the true nature of the ground or the formation on which the falsework is to be constructed

(b) not informing the designer of pertinent data and conditions, e.g, proximity of deep excavations, need for site access lanes between the falsework supports and nature of traffic to be expected thereon; ground water table and possibility of surface water during construction

(c) not realising that the results of ground investigations done for the permanent structure may not be reliable guides to the nature of the ground on which the falsework will rely for support

(d) not allowing for the changing conditions caused by weather, diversion of surface water, or flooding and effects of flood water, erosion, freezing and thawing, or the effects of site traffic etc

(e) not providing adequate restraints for bases to falsework founded on inclined surfaces such as bridge embankments

(f) not anticipating effects of differential movement and settlement

(g) using materials of unsatisfactory quality, e.g, in the foundations, scaffold boards, etc

(h) not placing sole plates horizontally or otherwise bedding them properly

(i) placing structural supports at the edges of timber sole plates, or in some instances not even providing sole plates

(j) not providing adequate base supports above ground.

(k) not resisting the temptation to use at random the material on site, for example soft wood under the falsework legs

(l) making modifications on site to the falsework foundations to cater for changed conditions without prior consultation with the designer or supervisor to ensure that the modifications are sound.

In contrast the trouble-free results achieved in other jobs on which the falsework foundations were treated throughout with exemplary care, highlight the wisdom of foreseeing and avoiding such pitfalls.

We appreciate that it would be impracticable to expect all these items to receive full treatment on every construction project. But items such as (g) to (k) should always be considered even on the smallest of building jobs to avoid unnecessary risk to life and limb. Our impression is that the primary reason for the bad cases is ignorance of the possible consequences of failure and not deliberate skimping.

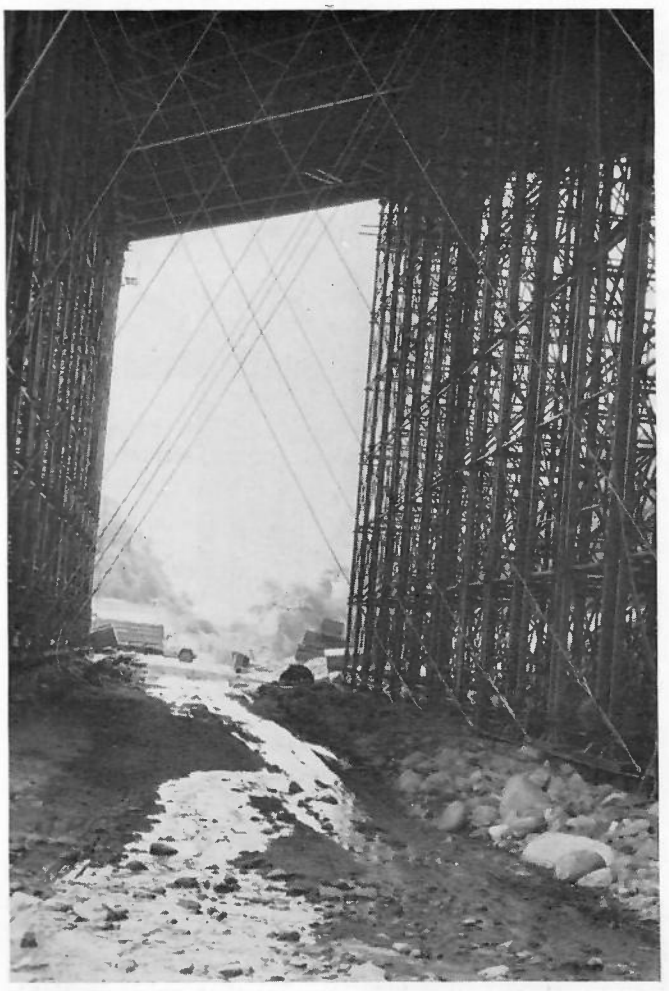
Support of beams

Many of the examples we studied suggested that the behaviour of beams under load had not been properly understood and allowed for.

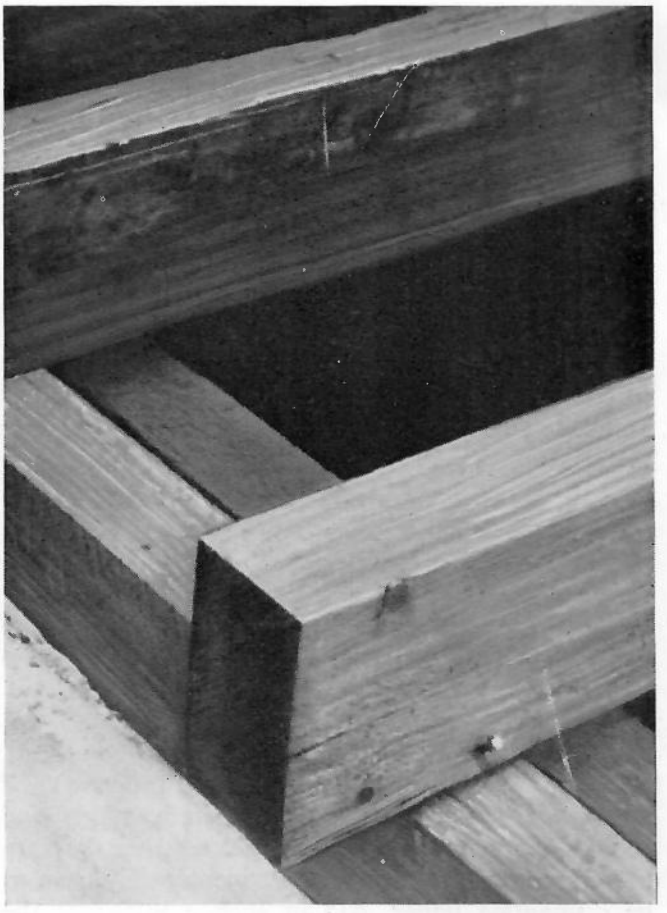
One common fault in smaller jobs was the inadequate bearing surface provided for the supports. In some cases the beam was not long enough to extend over the full length of the forkhead. In some the forkhead

was inclined to the beam so that there was a high local pressure and indentation. In others, perhaps due to previous misuse, the ends of timber bearers were so crushed or split or rotten that failure in shear was almost inevitable. Similarly there were cases where insufficient extension of telescopic beams had reduced the length of the beam bearing on the end supports.

Another common fault was the disregard of the effects of deflection. One effect is to redistribute the load. If, for example a relatively rigid beam is supported on three relatively elastic supports the two end columns will each carry one quarter the weight, and the centre one half. But if the supports are rigid the end columns only carry 3/16 of the load, and the centre one 5/8. Thus if the designer makes unjustified assumptions the end or centre columns can be under designed by 25%. If beams are crossed as in a grillage this increase in reaction may be compounded.



Good use of heavy duty proprietary system falsework supporting decking of a bridge spanning a deep canyon in California, USA



Doubling of timbers to distribute load rendered ineffective by their unequal size

Another effect of deflection is to introduce axial forces unless the supports are free to move horizontally. This effect may be most important in skew spans and the differential movement in any beam arrangement may have serious consequences.

Differential movement may produce a twist on the supports and in one instance this may have contributed critically to the overload.

The third common fault is failure to restrain beams against twisting. Any beam under load will tend to twist, the tendency increasing with the difference between the section moduli about vertical and horizontal axes. We studied one case where the only restraint was in the form of wooden cross struts between neighbouring beams: these fell out when the beams moved away from each other, allowing overturning. The effect could be particularly important on cambered spans where the loads produce twisting moments if the beams are not exactly in the vertical plane.

Similarly special three-dimensional effects arise when the supports are not themselves parallel – for example the piers supporting a curved roadway.

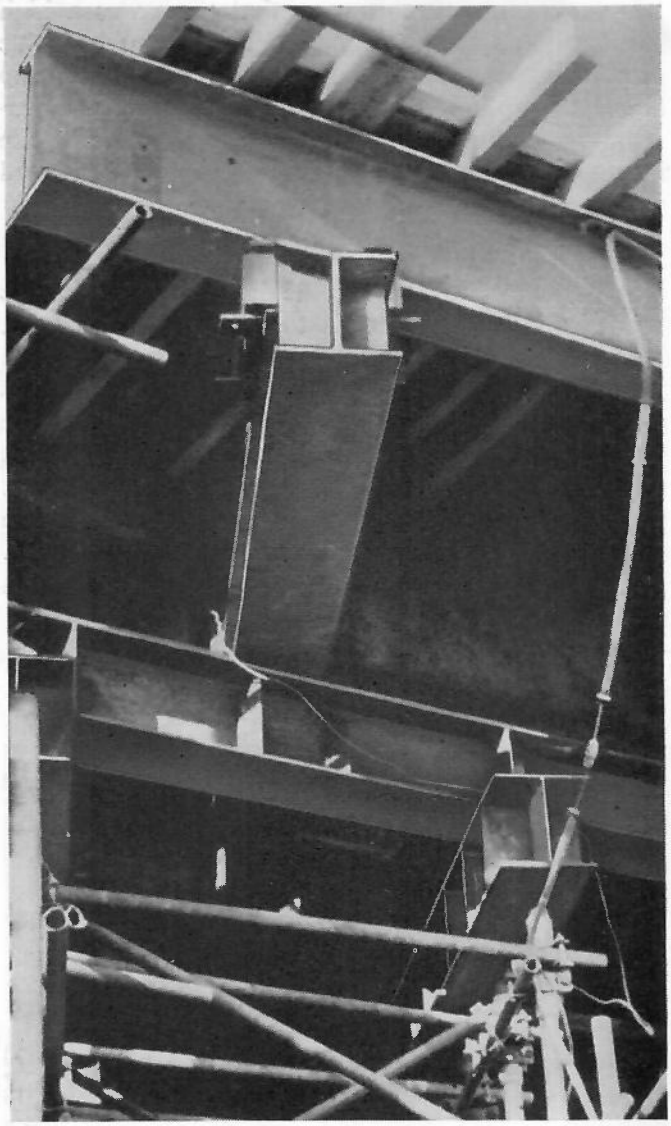
Grillages

Universal beams are often used in falsework as packing pieces in order to cater for differences in level between falsework units. An example would be the making up of height between the top of a unit construction and the support beams. They may also be used to spread the load from a number of beams to a different number of supports, as at Loddon. Improvement in the stability of grillages, particularly for foundations, may be made by packing concrete round the crossed joists to obviate crippling. When this is undesirable the crossed members of the grillages may be prevented from crippling by the use of sleeved bolts between the webs, or in the case of timber beam grillages placing them close together to enhance their stability. Such precautions are not often taken in temporary works.

In temporary works the materials have to be re-used on the job and frequently have to be preserved for future works – perhaps of a different type. The components have to be dismantled whether they are to be used again or not, and frequently they have to be dismantled under load in such a way that the permanent structure supported by them during construction can deflect and carry the load itself.

Most grillages, therefore are constructed without actually fixing one member to another and so suffer the disadvantages discussed earlier with regard to interconnection. A particular hazard arises where the height to base ratio of the component beams is high, because this increases the possibility of overturning under lateral forces.

Another special difficulty arises when steel beams are used to form grillages. It must be remembered that the section of such beams is chosen to provide stiffness against bending: the thick flanges and thin web produce a suitable section to resist bending, but one which is not ideal for supporting and distributing concentrated loads. Nor is the section well adapted to taking eccentric loads which can easily lead to buckling of the web. The difficulties are exacerbated by variations in the accuracy of rolling, the thinness of the web, and sharpness of the fillet radii of modern sections. At least two of the collapses studied were attributed to overstressing of the web of universal beams used as load spreaders: and cases have also been reported where the essential checks on the strength of the grillages had never been done.

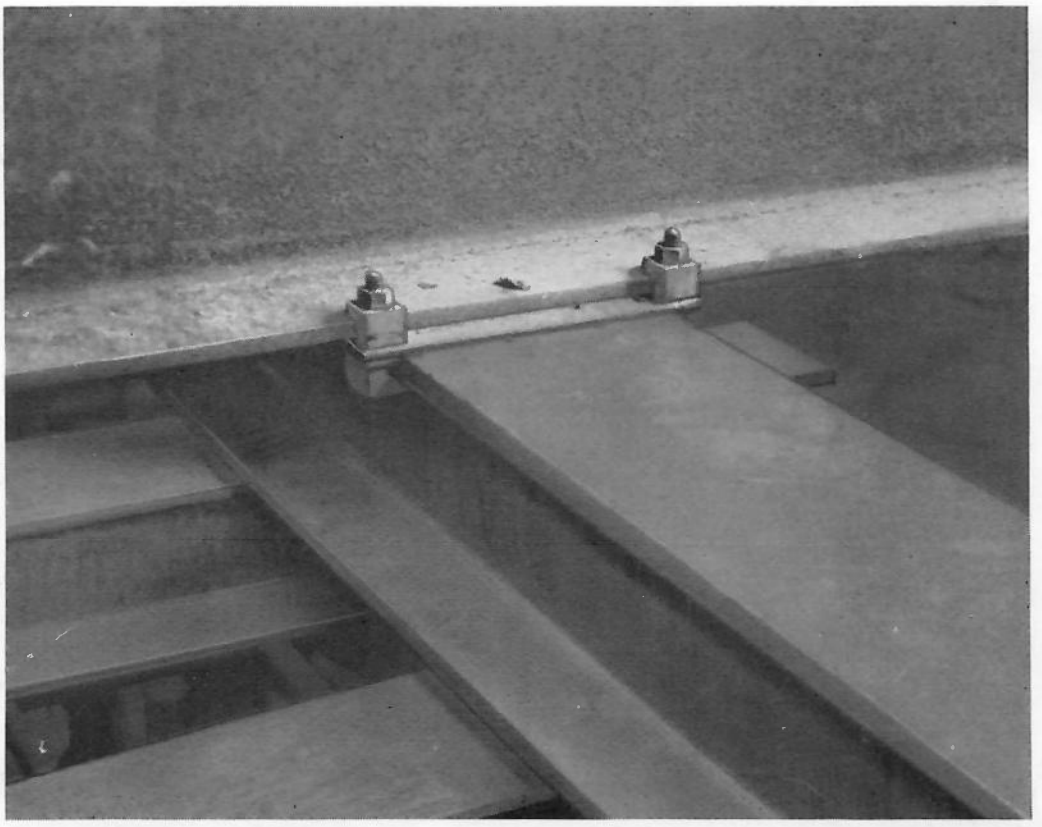


Heavy duty grillage beams provided with web stiffeners at load transfer points with separate components securely interconnected

This does appear to be one of the areas where technical knowledge is not entirely adequate. We would therefore recommend as an important subject for continued research the behaviour of standard section rolled steel beams under concentrated loads, applied eccentrically to the web.

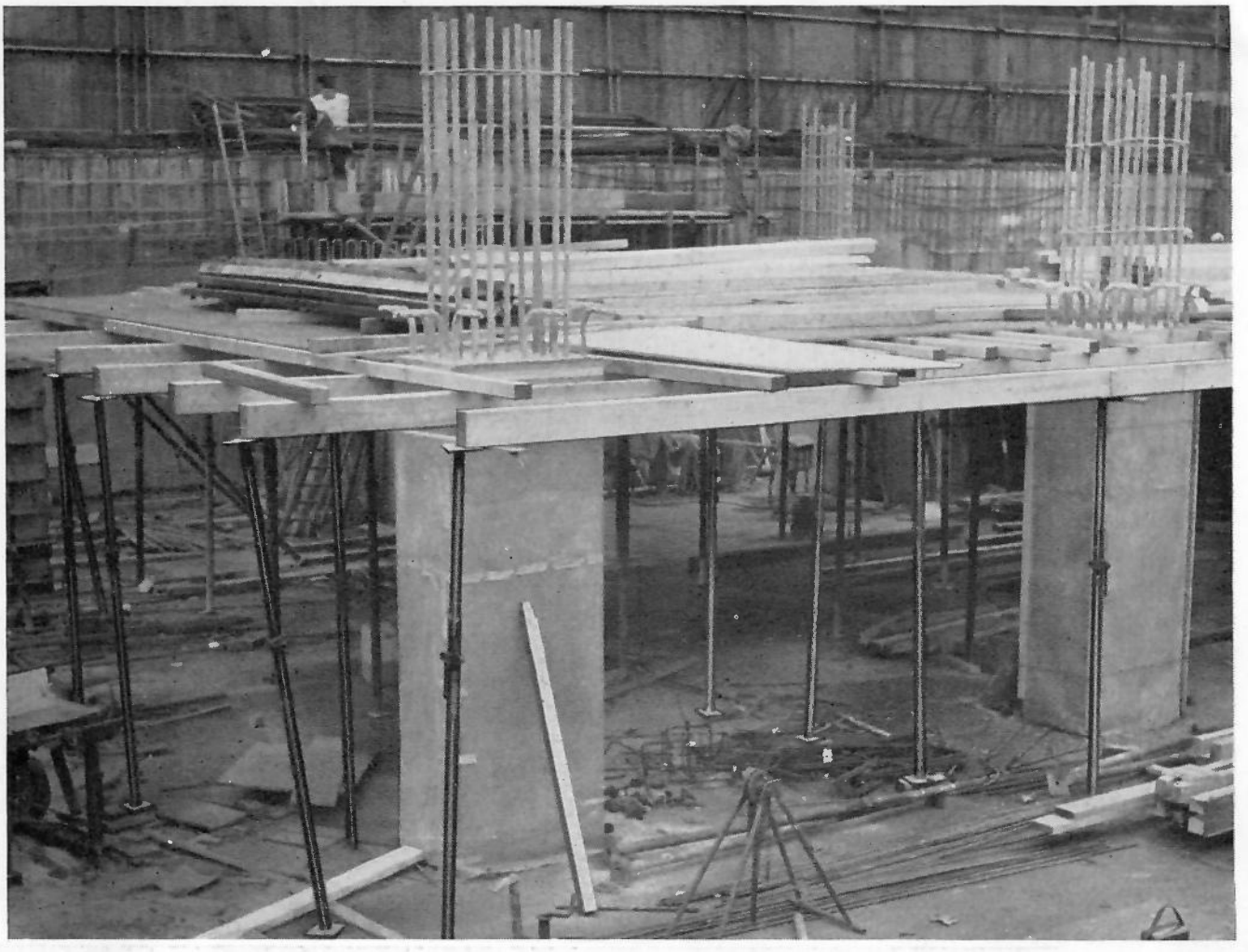
Tolerances and eccentricities

The Report No 27 produced by the Construction Industry Research and Information Association (CIRIA) gives the results of a survey, made on a number of sites, of the accuracy of construction that is currently accepted. It appears that an appreciable number of props are inclined at $1\frac{1}{2}°$ or more to the vertical and others are displaced by an inch or more



Detail of proprietary connector for use with steel beam grillages

Buckling of unstiffened webs, and flange distortion of grillage beams in major falsework collapse



Example of insufficient attention paid to stability during intermediate stages of erection of propped shuttering. There is a risk of collapse of the incomplete and unloaded falsework by the failure to provide enough well-lined, plumbed and laced props from the outset

from their correct position. Our own observations and the reports of others confirm that these figures are not exaggerated. These deviations could result in a significant reduction in load carrying capacity: for example the capacity of a prop 2·59 metres long inclined at $1\frac{1}{2}°$ to the vertical may in certain circumstances be reduced by 27%.

We were also shown pictures of bearers placed eccentrically in forkheads, and of base plates eccentrically positioned on sleeper supports. In one extreme case, illustrated in our interim report, a vertical support was mounted on the cantilevered end of a timber beam some four feet away from the lower standard to which its load was to be transferred. The overturning moment exerted by the imposed load would have been sufficient to cause the collapse of a whole line of falsework had not the defect been corrected under threat of legal sanctions.

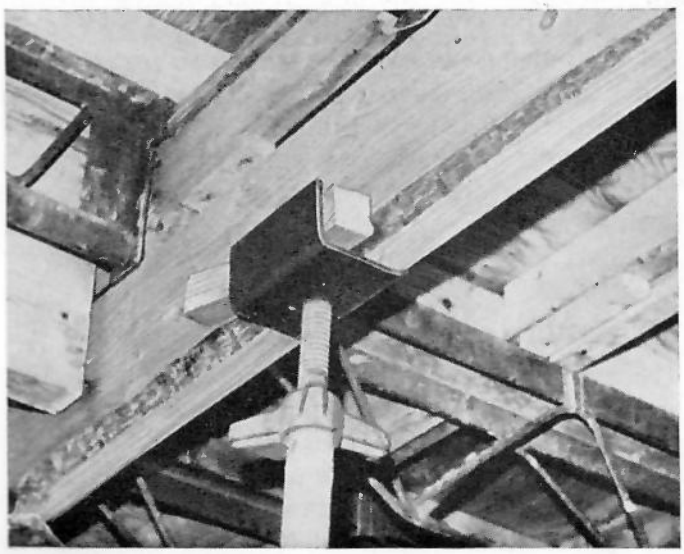
Similarly the inevitable variability of large trusses and the difficulty of positioning supporting trestles in exactly the right place lead to slight discrepancies and the need for local matching arrangements.

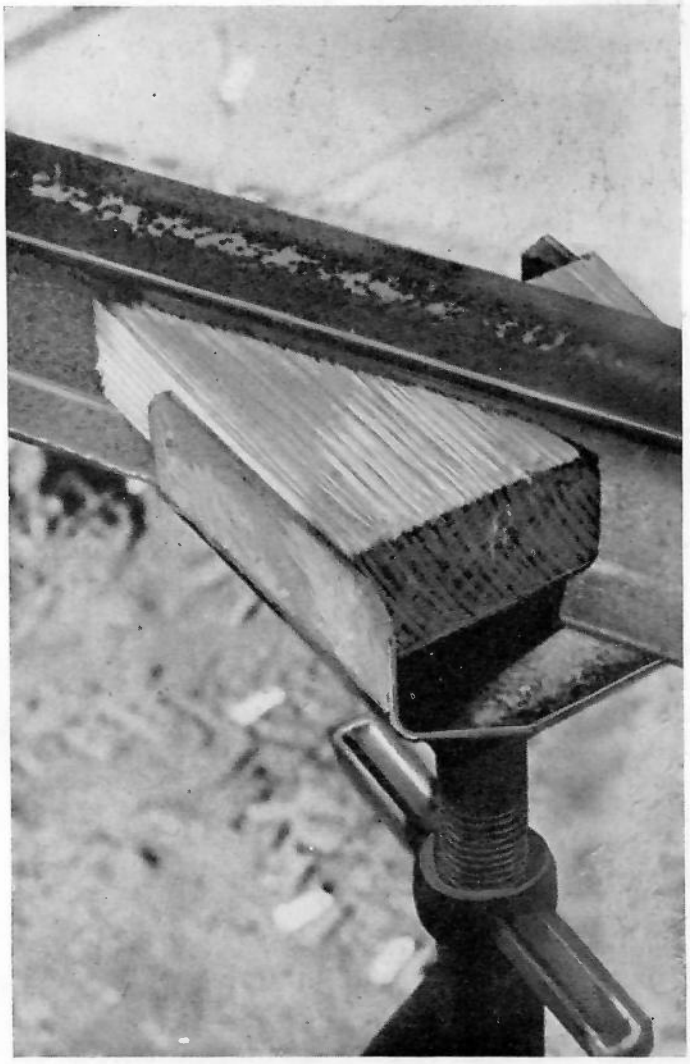
All these effects lead to eccentricity of loading which could have critical results on the strength of struts or grillages. The large number of points at which the load is applied multiplies the possible sources of failure. We found no evidence, however, that designers made any specific allowance for possible inaccuracies in construction other than that incorporated in their standard loading tables. They have in fact generally and implicitly assumed that all loads would be applied concentrically or used factors of safety which presumed deviations less than those which might actually occur in practice.

Nor were we told that construction drawings always specified realistic tolerances or drew attention to areas where accuracy was essential.

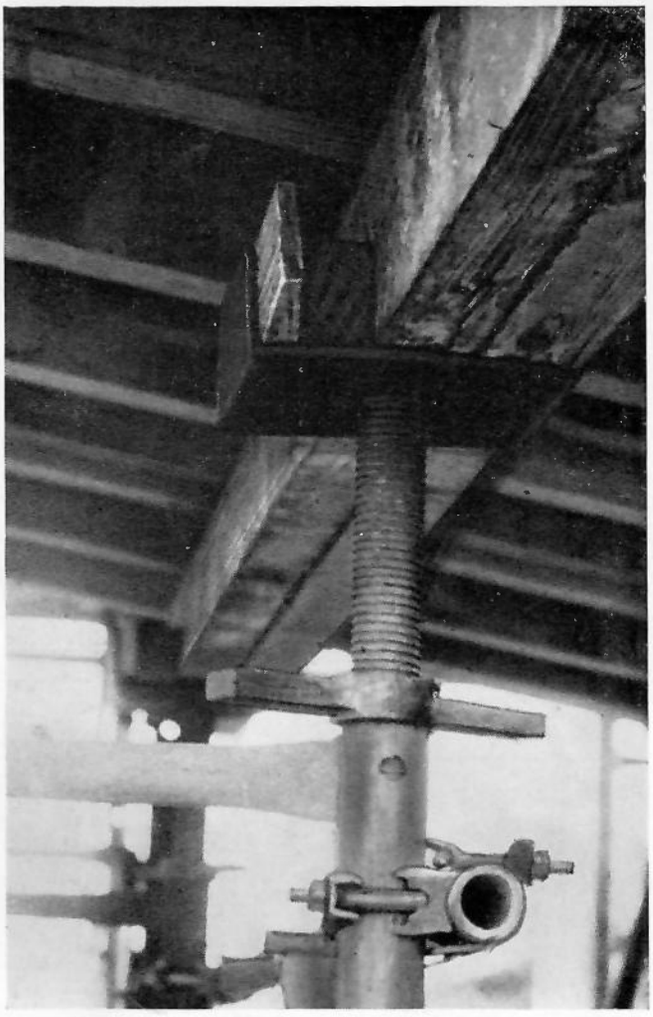
This damaged forkhead is being used in an attempt to support two timber members, only one of which lies within the forkhead

Eccentric loading caused by wedging of timber on one side only. Use of waney edged timber will reduce load-bearing area





Concentric loading ensured by use of opposed pair of folding wedges



Oversize forkhead and incorrect use of folding wedges will produce eccentric loading

Faulty setting-out

It is an undeniable pre-requisite of satisfactory falsework construction that the ground plan for the falsework supports should be in accordance with the drawings. We have even been informed of an extreme case where the pegging out for a falsework had been carried out in entirely the wrong place. Other examples of inaccurate planning have been given to us, particularly on skewed structures where elements of the falsework have been placed significantly away from the intended position. It is, therefore most important for the contractor to arrange for surveyors to be involved in the initial setting-out, and for a check to be made of the pegged-out location marks upon completion of the setting-out.

Defective or inadequate materials

A review of the major technical causes of falsework collapse would not be complete without reference to the contribution made by sub-standard or wrongly chosen materials; corroded and damaged steel components; inadequately repaired materials; cracked, knotted and rotten timber.

Most of the falsework components are used over and over again. Without an efficient inspection system there is always the likelihood of defective pieces finding their way into a structure.

There is also a danger that designers may be misled by claims made on behalf of proprietary materials. Working loads may be quoted which are not applicable under the conditions of practical construction. Special recommendations are made on this point in a later section.

Finally, there are the cases of unauthorised changes in materials. The design of a structure clearly involves stipulation of the materials to be used. It is therefore of fundamental importance for erectors of falsework to appreciate that the capacity of the falsework to support the anticipated load rests upon a preconceived understanding of the load-bearing properties of the specified components. To alter one of these components and to substitue another could endanger the concept upon which the design was based.

With the methods and organisation which exist on civil engineering and building sites it is unlikely that all the materials necessary for the falsework arrive ready for the start of the job. Erection often begins as soon as the first load of essential materials arrives. Unless this load is quickly supplemented by further deliveries there will be a temptation to improvise in order to avoid delays in construction and unprofitable waiting time. It is at such a stage that unauthorised substitutions of material can easily occur though the blame rests more on managerial failures than the positive acts of the erection team.

Dismantling

The specification of the order in which falsework should be dismantled is of considerable importance both in ensuring that stresses are safely relieved and that the permanent structure takes up the support of its own self weight without imposing extra stresses on the falsework. It is essential to follow the specified order to ensure that there is no member under stress which could produce springing or dislodgment and put at risk other parts of the structure or those working on it. We have received evidence of the partial collapse of falsework being dismantled due to instability of separate sections.

We have also heard of cases of inadequate re-shoring or re-propping of parts of the permanent structure

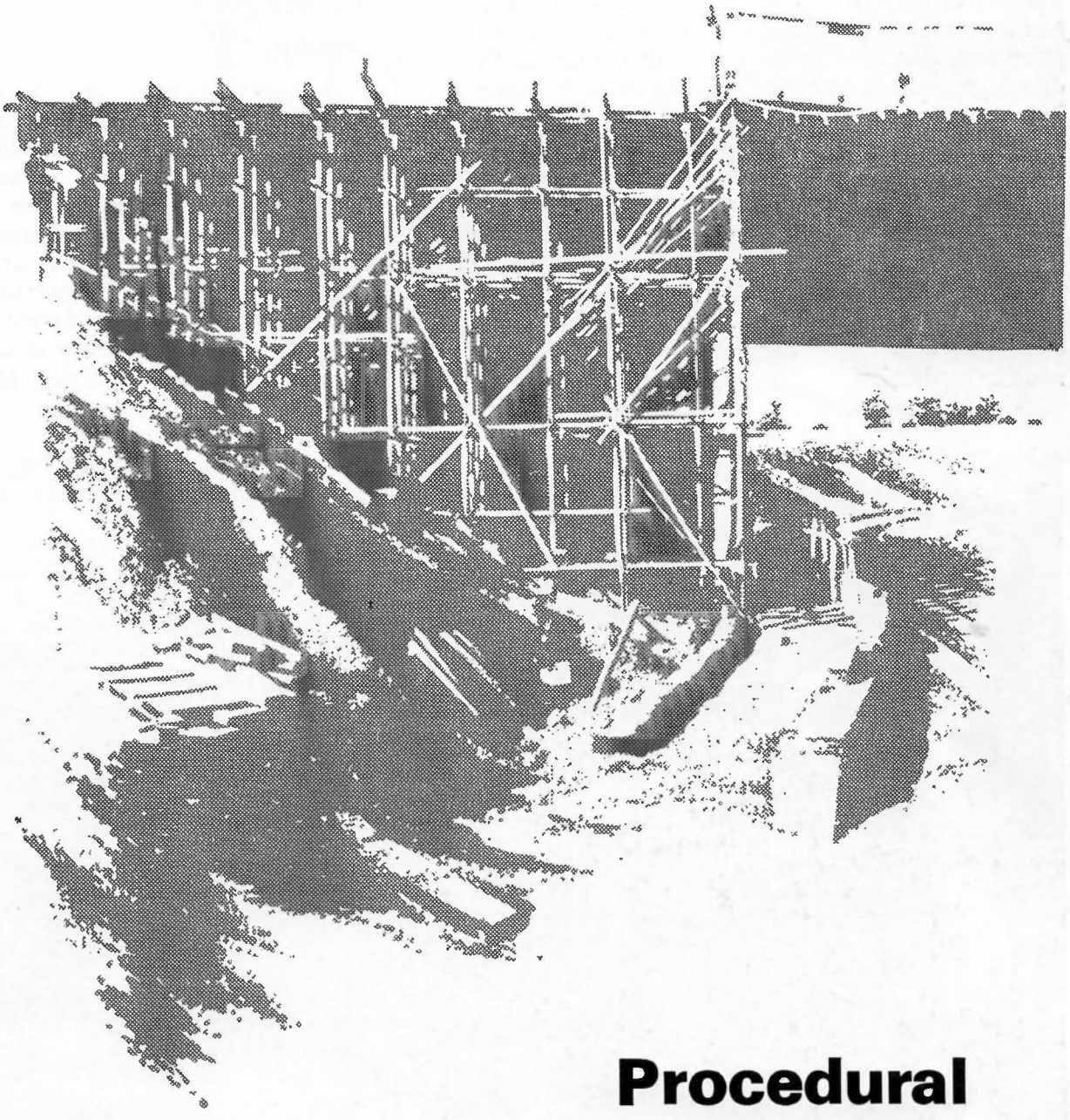
which were to support other falsework. The collapse of the slab floors of the Skyline Plaza in Fairfax County, Virginia in March 1973 was one such case.

Conclusions

A falsework constructed from the most carefully manufactured, properly selected and well maintained materials can be no safer than is allowed by the expertise employed during its erection. Whereas we have been impressed in some instances by high standards of methodical workmanship, the results of training and experience, we have also seen examples, particularly on the medium and small building operations, of deplorable standards. The working there appeared to lack the method, system, orderliness and tidiness which are essential for good working conditions and good workmanship.

Indeed it would not be a great exaggeration to say that we have seen examples of errors in almost every element where errors can occur. Some common features are: absence of effective bracing and lacing; inadequate ties; lack of verticality; inadequate base plates for standards; defective sole plates; props pinned by pins of the wrong type, size and grade of steel; eccentric loading in forkheads; failure to use centralising wedges; failure to secure wedges; failure to ensure a safe angle for cut wedges; over-extension of screw heads without additional bracing; inadequate bearings for the ends of telescopic centres; failure to brace together the individual towers of a multi-tower support system; failure to tie back to a fixed structure; failure to use temporary props and stays to counter instability during the construction of the falsework; failure to reinforce around vehicular openings; failure to provide traffic fenders or, in their absence, to provide sufficient redundancy in vehicular openings liable to dislodgment; lack of connection between units in vertical tiers; the mounting of rolled steel sections in grillage-type forms without the interconnections, web stiffeners or plan and cross-bracing which were called for in the design; and many others. Some of these unsatisfactory features are illustrated in this report, as are examples of the high quality workmanship also found.

3



Procedural inadequacies

3 Procedural Inadequacies

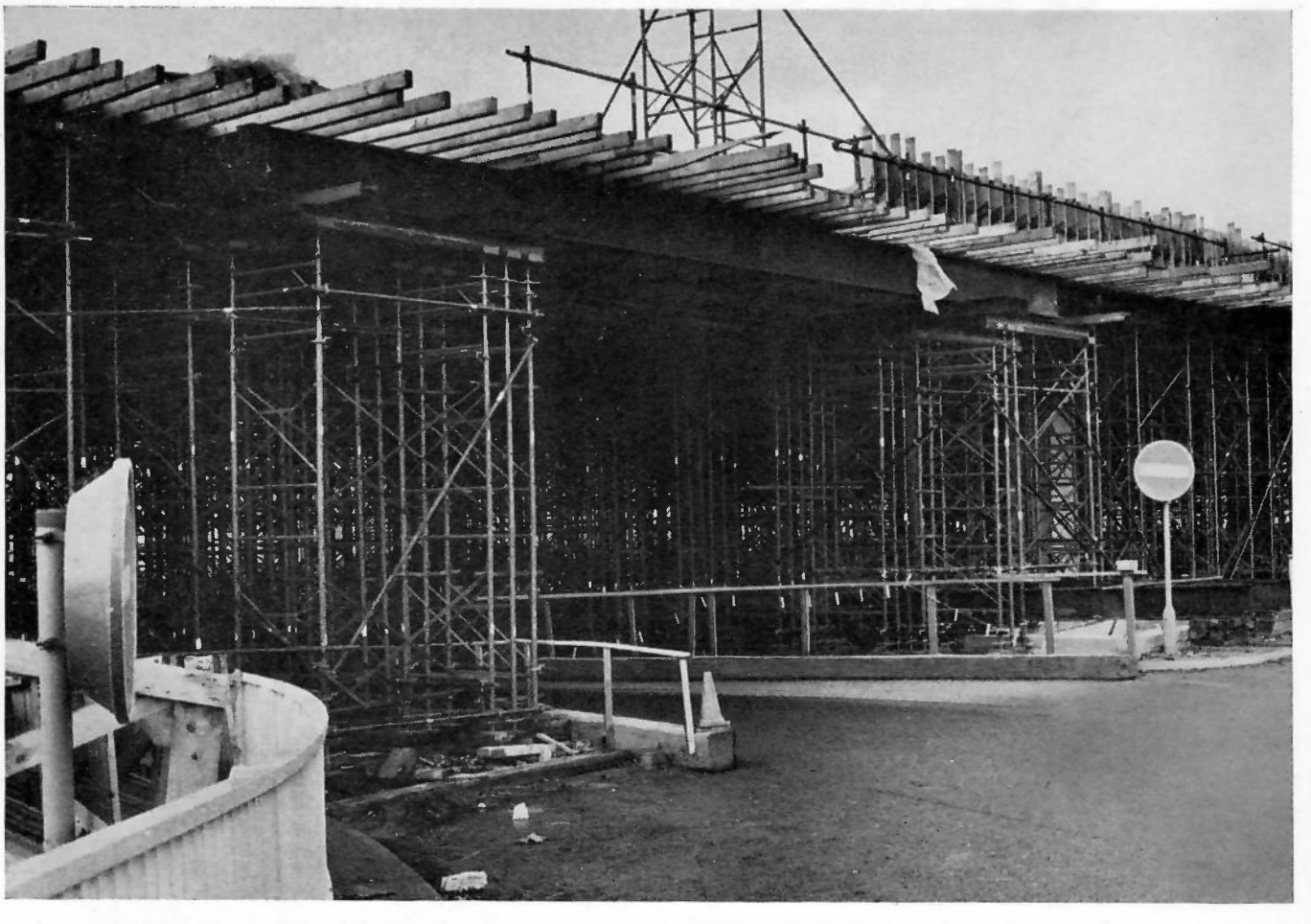
In the previous chapter we described various technical features of falsework which contributed to failure or collapse. In the following sections we consider why these technical faults occurred – what were the failures in procedure or communications or inspection that allowed them to happen.

The failures may be considered from two aspects. *The first is failure of communication:* the designer was not given a proper brief by the client; or the designer's drawings were inadequate or liable to misunderstanding; or there was no feed-back to the designer when conditions on site were found to be different from those assumed. *The second is failure of inspection:* the design was not checked by a competent authority; or the structure was not inspected after erection.

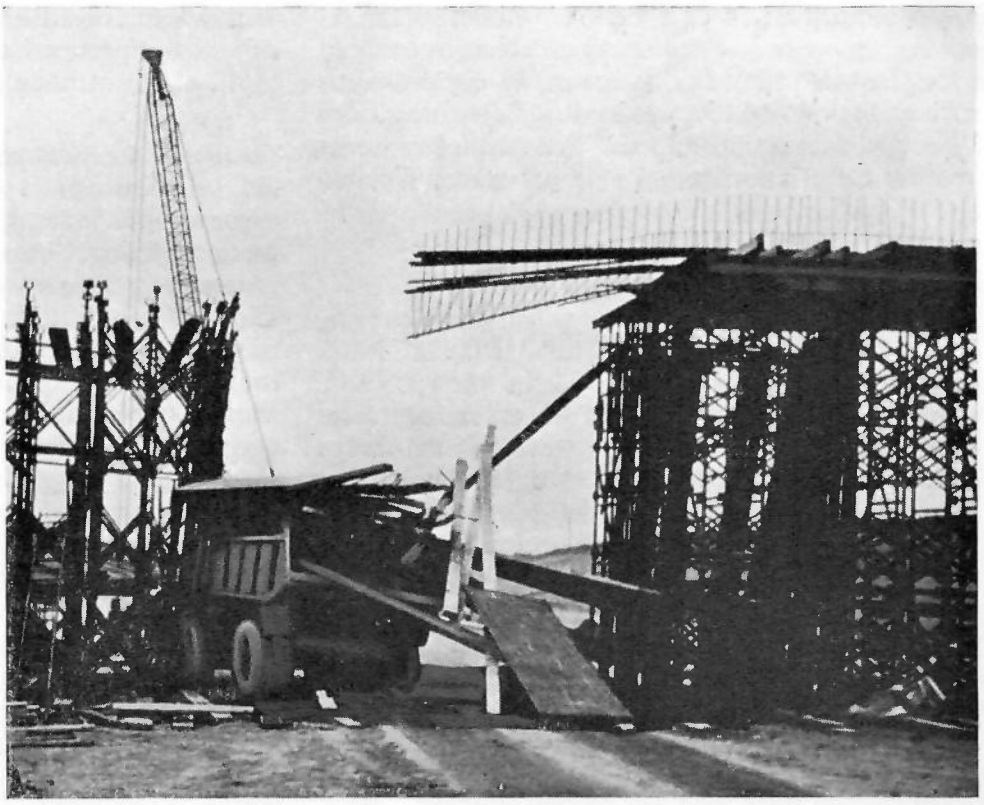
From the evidence we received it is clear that failures of communication are some of the most important contributors to falsework inadequacy. Good communication is vital in the proper control of a substantial falsework in view of the range of disciplines involved, the number of organisations involved and the diversity of procedures and practices which exist. We are of the opinion that if adequate and proper attention were paid to communication of information which is already available somewhere, this could possibly be the greatest single contribution to improved standards of falsework construction.

Design Brief

It is of fundamental importance that the client indicates in his brief any special features or constraints to which the falsework is subject. We have examples where of underground cables, sewers, pipe-runs or gas mains, whose existence was not known to the designer, have necessitated alterations to falsework. In some cases the alterations were undertaken without reference back to the designer resulting in the remaining props becoming an incoherent system: what had been a deliberate redundancy at certain points was eliminated and the remaining props became



Protection provided at an access opening in falsework to prevent accidental damage by traffic



The effect of impact between a road vehicle and an unprotected access opening through falsework

incapable of supporting the main load. Similarly, we have heard of examples where access openings for contractors' plant were introduced after the initial design was completed, and this led to unnecessary weakness. The particular problems of spanning roadways, rivers and railway lines are examples of constraints which which must be considered before design is started.

It is clearly necessary that such bodies as the river authorities should have a primary regard for river drainage or navigation. Similarly the Railway Board must have the safety of the travelling public and rolling stock as its primary concern. It was, however suggested to us that in some cases discussions between the authorities and the contractors might have allowed a relaxation of arbitrary constraints and so led to simpler and safer falsework without compromising safety elsewhere. Better communications should ensure that such conditions as are imposed do not make the construction of the falsework unnecessarily difficult, particularly by the imposition of blanket rules which could well be the subject of discussion in individual cases. For example, a rule which prohibits the erection in midstream of falsework supports for a bridge spanning a river may be sensible in prohibiting a forest of falsework in the river bed which could trap debris and vegetation and alter the normal flow of the river whose discharge could spread on to adjoining land. Similarly, as we have heard from overseas countries that river bed props may be prohibited because large tree trunks or blocks of ice or rivers in spate could dislodge a vital member. But to interpret these rules as an overall embargo preventing the placing of a central row of props under any bridge is too authoritarian when there may be other ways of avoiding interference with the flow.

Similarly we have been told of cases where a dialogue between the designer of falsework and permanent works before the latter were finalised could have allowed the inclusion of features that would have considerably simplified the falsework problems. A major problem which has been drawn to our attention several times is that the preliminary design of falsework is undertaken at the tendering stage when only preliminary documents are available. Instances were given where the designer had no information on how the falsework was to be located, no information whatsoever on the ground conditions nor of adjacent and even contiguous structures which could have influenced the design. Once the contract has been placed however, and fuller details are available, there is tremendous pressure to produce the final designs at high speed. One of our enquiries revealed a period

of no more than 14 days between a constructor receiving an order and the starting date of a contract which included sixty bridge spans. In circumstances such as these it is little wonder that falsework design is sometimes skimped, and that mistakes occur because there is no time for proper communication and discussion.

Design Modifications

Another line of communication which needs clearing is that between the people on site and the falsework designer. We have heard of many cases where, because of non-availability of material or unforeseen local conditions, it was not possible to follow the design details exactly. Sometimes the need for changes was not communicated back to the designer and modifications were made on site which seriously weakened the structure.

Errors in Design

There can be no doubt that some failures of falsework are the result of errors in design. We have studied reports which indicate beyond doubt that the primary cause of the failure arose through a fundamental design error which was either not detected or not rectified before loading took place. It is of considerable significance that the design errors could have been avoided by using existing technology. That is, they could have been discovered had an adequate checking procedure existed. One would expect such a check to be made internally, that is in the office where the design was done.

Unfortunately the evidence we have received shows considerable variation in opinion as to what the engineer is required to do under contract, what he ought to do to discharge his professional responsibilities, and what he might do to enhance the safety of temporary works.

The most significant divergence of view in this area was the polarisation of opinion on the action which should be taken if, for example, the engineer discovers a defect in the erection of a falsework. One school of thought stated that even if a serious fault be observed, he should in no circumstances draw the contractor's attention to it for fear of incurring some responsibility in the event of his fears being realised. Some design engineers went as far as to express unease about even visiting a site where permanent works of their design were being constructed. Separate witnesses said that they believed absence of body was better than presence of mind. At the other extreme, many professionally qualified witnesses stated that if they observed material defects which, in their view could lead to unsatisfactory completion of the falsework, they would, regardless of any legal consequences, inform the parties having direct responsibility. We consider this attitude furthers the interests of safety.

The scope for differences of viewpoint is shown by the standard contractual forms used in the civil engineering and building industries as well as by more specialised forms of document entered into by government departments and nationalised industries. The revised contract of the Institution of Civil Engineers, 5th edition, has been amended in an endeavour to clarify the duties of the respective parties and, in particular, to clarify the status, and consequently power, of the engineer. Not everyone seems to agree, however, on the true interpretation of parts of this document.

Construction Industry in Britain

This leads in practice to diametrically opposite actions being taken on the field which does not advance the cause of falsework safety. The areas of doubt include the powers of the engineer to call for the contractor's falsework proposals in cases where the permanent works are not directly affected; whether the engineer is entitled to ask for calculations as well as drawings of the contractor's proposals; the exact position of the engineer when, in examining proposals, he believes he has found a design error. The standard form of contract of the Royal Institute of British Architects (RIBA), which has been under discussion from many points of view, makes no mention of the consulting engineer who thus appears to have no status under the contract. The building contract of the Institute of Registered Architects and the British Railways forms seem clearer than many of the others. The recently revised government form of contract GC/Works/1 has not made the inroad which it could have done in setting out a categoric statement of duties and we shall have comment on this when dealing with contracts.

Site Organisation

It is all too easy to focus attention upon the erection stage of the falsework construction. It is at this point that errors, omissions and deviations from design are most apparent. However, on poorly managed sites, the deficiencies which are made apparent at the erection stage largely result from a failure to provide the erection team with the properly prepared preliminary instructions which are essential for the success of their work, and the materials required for its execution. It is not sufficient merely to prepare a sound design. This must be translated into adequately

detailed site working drawings, and accompanied by the delivery to the site of the correct quantities of materials in a sound condition.

Many of the particular procedural difficulties encountered in Britain are associated with the way the construction industry is organised. We therefore consider it useful at this stage to comment on this matter. We must however accept that the situation cannot easily be changed, and must make it clear that the recommendations which we make elsewhere are applicable to the system as we find it.

In the construction industry, as opposed for example to some types of manufacturing industry, each job is different. Each project calls for different resources of men, materials and equipment. Only the very largest organisation could maintain all the facilities it needed for such a wide range of jobs. There has thus developed a variety of individual units, each with its own special contribution to make. This situation produces major problems of both organisation and supervision for the main contractor. These are discussed at length in the Report of the National Economic Development Office Working Party on Large Industrial Construction Sites.

The actual work of construction is carried out on a site which may be anywhere in the country – or indeed in the world. Not all employees are prepared to move from area to area so contractors tend to recruit local labour for a particular job. This lack of continuity of employment makes it difficult to prepare proper training schemes and career patterns. The situation is made worse by the fitful investment in capital projects which is accelerated in boom times and drastically cut in times of recession. It has also been worsened by the use of "the lump", which brings on to site free-lance operatives over whose qualifications and practice the contractor has little control. The net result is that the labour force on any particular project is heterogeneous and the standards of discipline, co-operation and workmanship which are essential to safety become difficult to achieve.

The same process of development of specialist groups with particular expertise has occurred among professionals such as architects and civil and structural engineers. At the same time there is a continuing tradition that these professional men should be retained directly by the client both to provide him with designs of permanent works and to advise him that they are being built to specification.

This introduces a confusion of responsibility. If a structure is found to be inadequate, it is not always clear whether the fault was in the design and thus the responsibility of the designer, or in the construction and thus the responsibility of the contractor. The history of the industry is full of lawsuits and arbitrations, which the forms of contract used by the different professional groups have done little to reduce.

Construction Industry Abroad

Having considered some particular technical faults and inadequacies of procedure, it would be helpful to review briefly the position in three other countries – West Germany, the United States of America, and Canada before making specific recommendations.

West Germany

Germany is a Federal State, with a central government, and 14 Lande, or states. Whilst the federal government legislates in general terms, each state adopts and works out these requirements in its own way. Technical matters are now dealt with at federal level, local variation being comparatively small.

Building Law

Compared with the UK, the official control of construction is more thorough. It is carried out by codifying the requirements and by using sufficient competent staff to do the necessary work – the various control organisations employ relatively more of the highly qualified people available than in the UK.

Federal government enacts general requirements: there is a set of 'master building regulations'. These are adopted into 'state building regulations' and cover most aspects of construction, with brief references to construction problems. In Bavaria the regulations fill a large book, but the requirements for falsework are brief and general: basically falsework is the contractor's responsibility.

All construction work comes under the Ministry of the Interior. One section deals with approvals and supervision of privately generated work. Another deals with road design and construction, partly on an agency basis from the federal government. There are local offices as necessary.

There are some technical data embodied in standards, and a type approval system is involved for falsework equipment.

The client must, *inter alia*, designate an individual to act as a 'responsible building supervisor'. His duties include seeing that all the regulations and agreed designs are followed, and supervising the general safety of the work on site. It is desirable on legal grounds to have one person clearly responsible. In a bridge building context he will be employed by the Roads Department, but he could be employed by the contractor in other cases.

Responsibility

The 'responsible building supervisor' should only permit work to proceed when he is satisfied. How much this requirement is side stepped, or what real knowledge or experience he must have, is conjectural. But where an engineer is brought in to check a design ("Prufingenieur"), the responsibility rests jointly with him and the contractor. In the event of the falsework design being faulty, it appears that the contractor would be primarily liable at contract law. The Prufingenieur's penalty would be his loss of reputation and doubtless difficulty in renewing his licence. However he is required to carry insurance up to £50,000.

To become a Prufingenieur it is necessary to:

(i) have had appropriate education

(ii) have had at least 10 years' experience in structural design

(iii) be between 35 and 60

(iv) submit oneself to a jury which includes government representatives and university professors

(v) request a licence in a particular field – such as prestressed concrete or steelwork.

A licence is granted for 5 years, and it is issued to a named Prufingenieur. The licence cannot be given to a firm.

Because of the clear cut allocation of responsibility, the road authority does not consider itself involved. They have been given a Prufingenieur's certificate, which they neither assess nor override.

While the main contractor is clearly liable in the case of falsework failure he will have little difficulty in passing this on to his falsework contractor, unless it can be shown that the main contractor was negligent. The Prufingenieur is merely a check and does not relieve the falsework contractor by his approval.

The situation in practice will be a little more complex, especially if no clear cut cause of failure is discovered.

"Bau Berufsgenossenschaft"

This national body is in effect the insurance organisation, one of whose main duties is to ensure good safety on site. It decides the level of insurance premiums so its recommendations on site practice are treated seriously. Members visit sites and attempt to improve practices. The organisation has power to impose fines where its regulations are broken. In some cases it will examine a method or a piece of equipment and approve it in principle.

Technical information

The main document is DIN 4220, currently under revision. It is effectively a Code of Practice for the design of scaffolds and falsework. Supplements have been issued and it will be split into two main sections in the revision, one for access and one for falsework.

Type testing

Individual proprietary components are assessed and approved. This is sometimes done at state level, sometimes nationally. A previously agreed set of tests are carried out and these are vetted by the Bautechnic in Berlin, a national organisation set up for this purpose.

A final approval from a committee which includes representatives of competing forms is normally required. The equipment can then be used within the scope of the approval without further investigation.

USA

Falsework collapses have occurred in the USA during the construction of bridges and tall buildings. The various States have developed their own regulatory procedures, those in California being particularly comprehensive. The advent of the Occupational Safety and Health Act of 1970 which is part of the codification of public law and therefore applicable federally, contains requirements "to assure safe and healthful working conditions for working men and women by authorising enforcement of the standards developed under the Act: by assisting and encouraging the States in their efforts to assure safe and healthy working conditions by providing for research, information, education and training in the field of occupational safety and health and for other purposes". As far as California is concerned the steps already taken have been summarised in a much-quoted article by Arthur L Elliot, Bridge Engineer, California Division of Highways, Sacramento. Mr Elliott considers that the State's interest has been accentuated because the spans of bridges are becoming progressively longer

and the risks of fast-moving traffic hitting falsework are becoming more acute. These longer spans have resulted in more complex systems of falsework. Such systems require considerable experience and skill to erect. By requiring the work to be supervised by a licensed engineer the contractors are being forced to recognise the level of professional skill required.

Mr Elliott made these points:
"From a design standpoint, insofar as possible and especially over traffic, designs are avoided that would leave heavy loads on falsework for any extended period – for instance supporting precast beams until they can be cast into caps. Now enough of the cap is cast to support the beams adequately, then an additional pour is made to grout in the ends of the beams. Where possible, falsework is avoided over traffic, railroad or highway. Precast members can be used to achieve this – up to spans of 120ft (37 m). The highway division is also designing bolster hinges into some post-tensioned concrete box girder overpasses that will eliminate heavy falsework bents (that is supports) at hinge points. In post-tensioning spans, bolsters bear against the opposing hinge diaphragms to carry stressing loads directly into the bridge structure. This also allows the contractor to use lighter weight steel scaffolding.
The contractor is required to have his falsework designed by a licensed engineer. If possible, the engineer's responsibility should also be extended to the erection of the falsework. Of course, the falsework built must correspond with the design.
The falsework plans are carefully checked by the State engineers.
The constructed falsework is carefully checked for joint fits, bracing, stiffness, overturning possibilities, foundation settlement and general adequacy. These checks must continue immediately prior to and during the concrete placing.
Requirements are set up for the top and bottom anchorage and the protection of falsework posts which are adjacent to traffic. Generous traffic openings are required. Warning devices, collision walls and guard rails are required.

The above view is that of a highly regarded highway engineer in the United States and the practices of his administration are reinforced by legal sanction. An engineer is required to satisfy the requirements of "The Professional Engineers' Act" before he can be granted the certificate which allows him to practise professionally. A certificate to practise in one State does not confer the automatic right to practise in another. It is further enacted that "it is unlawful for anyone other than a professional engineer registered under this Act to stamp or seal any plans, specifications etc with the seal or stamp of a professional engineer or consulting engineer unless registered under that Act".

Subsidiary legislation promulgated by the Division of Industrial Safety in the State of California lays down its own requirements on falsework and vertical shoring. Amongst other requirements under Article 1717 of the appropriate Order it is laid down that an engineer who is registered as a civil engineer in the State of California must approve and sign for the detailed design calculations and working drawings for all falsework where the height of the falsework (as measured from the top of the sill to the soffit of the superstructure) exceeds 14 feet, or where the length of an individual span exceeds 60 feet, or where provision is made for vehicular or railroad traffic through the falsework.

Further, such falsework is required to be inspected prior to the placement of concrete by an engineer registered as a civil engineer in the State of California who shall certify in writing that the falsework substantially conforms to the working drawings and that the material and workmanship are satisfactory for the purpose intended. A copy of this certificate is required to be available at the site of the work at all times.

Canada

The regularisation of falsework procedures in Canada was stimulated by the collapse of the Second Narrows Bridge in 1958, and again by the Heron Road Bridge falsework failure in 1966. The Canadian falsework procedures vary from province to province. In Ontario for example the relevant legislation is the Construction Safety Act, 1973 and in British Columbia the legislation was made under the Workmen's Compensation Board of British Columbia and became effective on 1 May 1972. In essence the legislation requires that all design drawings of falsework in specified categories shall be checked and sealed by a professional engineer and additionally sealed by an independent professional engineer. The latter must satisfy the terms of the province registration authority and is referred to as the proof engineer.

In Ontario S. 142(4) lays down that if falsework includes any of the following features:
(a) tubular metal frames;
(b) columns where the effective length is dependent upon the provision of lateral restraints between the ends of the columns;
(c) shores placed one upon another to form a supporting system that is more than one tier in height;

(d) trusses;
(e) members so connected to one another that a load applied to one member of it may alter or induce stresses in the other members; or
(f) shores more than 10 feet in height,

the falsework shall be designed by a professional engineer in accordance with good engineering practice to withstand all loads likely to be applied to the falsework before, during and after the placing of the concrete and it shall be constructed in accordance with the design of the professional engineer.

The following sub-section states that the drawings of the falsework shall:

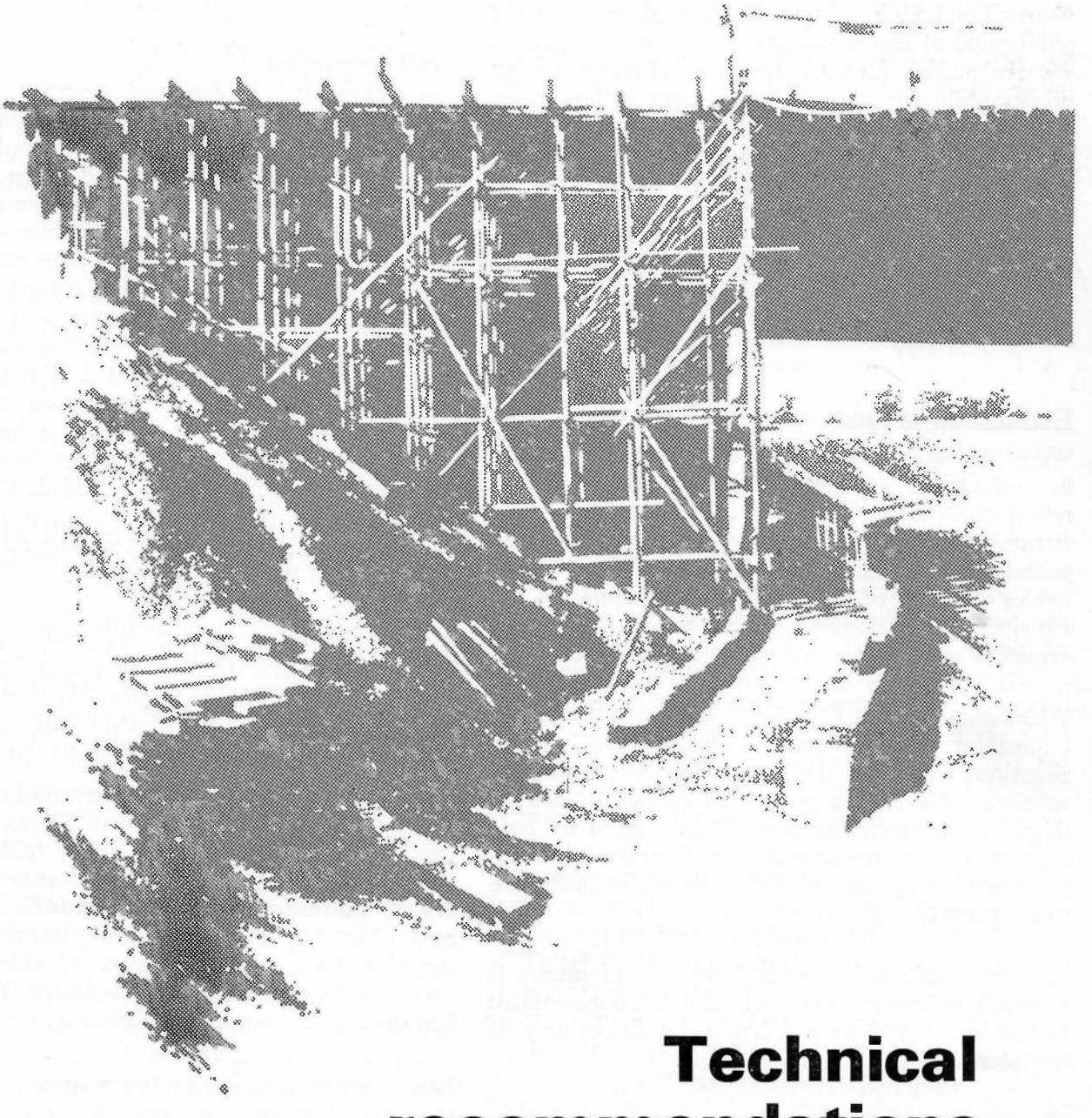
(a) show the size and specifications of the falsework including the type and grade of all materials to be used in the construction of the falsework;
(b) bear the signature and seal of the professional engineer referred to in sub-section 4; and
(c) be kept at the project at all times.

The corresponding requirement under the Accident Prevention Regulations for British Columbia require under S 34.28 that designs for falsework etc. shall:

(a) specify the size, type, grade and location of all components and the loads which the structure is intended to withstand;
(b) bear the signature of a registered professional engineer or other person acceptable to the Board, when the concrete structure is ten feet or more in height;
(c) be kept on the job site while the temporary supporting structure is under construction or use.

We believe that these various regulations include elements that might with advantage be imported and have kept them in mind when framing our own recommendations.

4



Technical recommendations

4 Technical Recommendations

In this section we make a number of suggestions aimed at avoiding the faults discussed in Part 2. We should make it clear that we are not here concerned with laying down detailed codes of practice: that is the responsibility of the British Standards Institution. The Falsework Report of the Concrete Society and the Institution of Structural Engineers has already laid a most useful foundation for the work of the BSI Committee and has been widely used prior to the publication of the British Standard Code of Practice. We are putting forward what we believe to be the proper philosphy and the guide lines within which detailed codes should be formulated. While many of the points we make have derived from the evidence presented to us we have also drawn liberally from the experience of individual members in compiling this section. Although we have not always been able to consider every point exhaustively in committee we consider it important that all the information we have received or discussed should be included.

Estimation of loads

When the load applied to a falsework structure cannot be calculated accurately – for example when a relieving structure is being built under an older structure or where a masonry wall has to be supported – the designer should consider all possible modes of failure of the structure being supported and anticipate the consequential loads rather than assume empirical rules such as 45° cracking in panels.

When concrete is cast in situ concrete densities of 2·7 tonnes per cubic metre are sometimes achieved in situations where the designer has assumed the conventional 2·4 tonnes per cubic metre. In heavily reinforced structures an even distribution of the concrete may be temporarily prevented by the reinforcement producing concentrated loads where such were not expected.

The effect of sloping soffit formwork in arches is particularly important as the load is first concentrated in the lower sections and horizontal forces may be considerable.

The process of building the permanent structure may prevent an even load distribution. The deformation of structural members as they are stressed or loaded during construction may radically alter the distribution of load on the supports. A typical case is the effect of the change in shape of a concrete bridge deck during stressing while it is still supported by the formwork.

The effects of snowfall, drifting, and of ice formation should also be anticipated and catered for where necessary.

An extensive list of potential errors in load assessment is given in the Falsework Report of the Joint Committee of the Concrete Society and the Institution of Structural Engineers.

Loading procedure

The critical loads on falsework occur while the concrete is being placed and it is essential that the procedure should be carefully controlled. Concrete can now be delivered at rates and in quantities that were unthinkable ten years ago. As a result the load on the falsework reaches its design value very quickly. The concrete which is placed first does not have time to set and provide some support for the later batches as was the case in limited batch and strip pouring. It is common practice in the United States and Canada and on some sites in the United Kingdom for the bottom slab of a box section in such structures as elevated roadways to be cast first. A period for curing is then allowed during which further form work and the additional reinforcement is added. Concrete for the webs of the beams and the top slab can then be poured upon a stiffened and strengthened base which takes some of the total load.

It is important to adhere to the loading programme both in place, time and rate of loading. Any proposed alteration of the loading programme may change the loads on the falsework and should be referred back to the designer so that the design or the programme can be modified.

Identifiable horizontal forces

We have already discussed the contribution of horizontal forces to falsework failures. In this section we consider some specific sources of sideways force which must be allowed for in the design. They include hydrostatic pressure from concrete and wind loads.

Lateral forces due to concrete pressures

Single sided shutters, i.e, those which are not bolted together in pairs, exert unbalanced horizontal forces which have to be resisted by the beams of a falsework structure passing at right angles under the concrete being placed. If however these beams are discontinuous and insecurely fixed the horizontal forces may not be satisfactorily transferred to a firm point

and the shutter movement which may occur can be both sudden and disastrous.

If the horizontal forces from the lateral pressures of concrete are transferred by raking supports to the uprights, the additional vertical forces in the uprights should be taken into account.

A vertical shutter resisting horizontal pressure tends to rise despite the fact that superficially there is apparently no vertical force to cause this. Vertical shutters which are not firmly anchored down may rise and permit the sudden escape of the concrete which when once started may become dangerous on account of horizontal impact and vertical load redistribution. The shutters should be effectively anchored down.

Wind forces

In general wind forces may be calculated by the method described in BSCP 3, Chapter V, part 2. Although this document is not strictly applicable to temporary works, correction factors can be applied to take account of a number of special factors.

For example the effect of wind on the falsework support for an *in situ* concrete structure before pouring may be of greater consequence during construction than after the concrete has been placed.

It is obviously difficult to cater for wholly exceptional wind conditions nor would it be economic to design for them in normal circumstances. However, designers should pay special attention to two factors. One is the geographical location of the site, which may be in a specially windswept area or which may have a topographical configuration, which funnels the wind to produce particularly high velocities. The collapse of the cooling towers at Ferrybridge shows how adjacent structures can produce a devastating pattern of wind flow. The seasonal variation in wind should also be considered in relation to the likely life cycle of the falsework.

The cross section of the falsework plus formwork is also important in determining wind resistance. Clearly the denser the supporting falsework, the less streamlined the component, and the greater the area of formwork, the higher the resistance. The relationship of the whole assembly to the direction of the prevailing or funnelled wind is another special consideration to be taken into account. Wind forces can also act in an upward direction and we have on record instances of collapse where the support shuttering became temporarily airborne and was not relocated upon its supports.

Allowances for impact

(*i*) *Shock loading* In considering the loads applied to falsework an allowance should be made for shock loading: some shocks can be anticipated and evaluated but others are accidental and unpredictable in size or in location.

In the first category is the shock loading due to the normal delivery of concrete or loading of beams, the use of vibrators (particularly shutter vibrators), the braking of vehicles and concrete transportation systems.* It is important to differentiate the above from shock loading resulting from accident, such as the dropping of the contents of a bucket of concrete or the collision of a vehicle with the falsework members. Incidents of this nature can clearly introduce deformation of part of the structure and it is important that an inspection is carried out at the earliest possible moment particularly if the accident occurs while concrete is being poured.

Accidental damage should always be reported immediately in order that the full corrective procedures can be agreed by all parties concerned.

(*ii*) *Impacts during the application of the load* The generally accepted impact allowance of 25% and 10% for mechanical and manual operation respectively are satisfactory for ordinary crane loads. However, the weights of precast units may be considerable and the difficulty in handling them may necessitate greater allowances. In working in exposed positions the wind forces and swinging of the crane rope may cause serious lateral forces at the moment of landing the beams so that a horizontal resistance of, say, 10% of beam weight should also be built into the system.

For *in situ* concrete work a value of 240 Kg/m^2 is frequently used as an allowance for shutter weight and impact of concrete placing. Of this figure about 70 Kg/m^2 is the allowance for the shutter. For thin slabs every underestimation of the live load is of much greater significance as it comprises so much greater a proportion of the total load.

In fact we are generally doubtful about the value of expressing impact loads as a proportion of the static load. Whilst the impact from a precast beam is

*Machinery driving conveyors delivering concrete should be insulated to prevent the transmission of vibrations to the falsework structure.

related to its whole weight the impact in an *in situ* concrete construction is only related to the size of the skip and the construction plant. It may well be argued that there is then greater danger with a falsework designed for a relatively light duty than for one designed for a heavy load.

(*iii*) *Access openings* We have drawn attention elsewhere to the need for planning in advance the openings in falsework where access for vehicles will be required. We have mentioned the need for additional strengthening to accommodate loads resulting from impact by a vehicle or its load. In addition to this, where an access opening is to be used frequently or for public traffic, substantial fenders, bollards, crash barriers, etc, should be provided. These must be of sufficient strength and sufficiently embedded to prevent the effects of accidental impact being transmitted to the falsework proper. We have noted some examples of excellent protection in the United Kingdom where falsework has been constructed on either side and over an existing public highway. These recommendations are invariably adopted in the United States and form part of the codes of practice of several bodies concerned with falsework construction.

The 3% horizontal load rule

In paragraph 31 of our Interim Report we recommended that "all falsework structures should be designed to accommodate all identifiable horizontal forces plus an additional allowance of 1% of the vertical load in any horizontal direction to allow for the unknowns. But in no case should the allowance for the horizontal load in any direction be less than 3% of the vertical".

In writing the recommendations we were thinking of the structure as a whole. Certain horizontal forces are identifiable and can be calculated. There may be other forces which were not foreseen and to allow for these, and for any underestimation of identified forces, we added an amount equal to 1% of the total vertical load on the falsework.

If the summation of the estimated horizontal forces plus 1% of the vertical was greater than 3% of the vertical loads then the design was to be based on the summation. If the summation was less than 3% then the design was to be based on 3%.

Our object was to ensure that each falsework structure was properly braced, guyed or tied back so that it was stable against lateral and longitudinal forces. We were aware that previously the empirical value of 2½% was commonly used. As lateral instability has so frequently been shown to be the cause of collapse we considered it imperative to increase the figure by 20% resulting in the value of 3% we recommended in our Interim Report. The estimated value of the horizontal load applied to any particular point of the falsework, however, is not necessarily a fixed proportion of the vertical load. Wind forces, for example, will be greater on some members than on others.

Furthermore a vertical strut which is effectively pin jointed at its ends but which is not correctly aligned can introduce local horizontal reactions which are quite distinct from the external loads. For example if the strut is 1½° out of plumb it will produce a horizontal component of force at its ends equal to 2½% of the vertical load which it carries.

Thus when a falsework is loaded vertically at a multiplicity of points, each point must be interconnected with adjacent points by continuous formwork, lacing or other means so that the known and unknown horizontal forces can be collected together. The spacing of the collecting points should not be greater than about four times the average spacing of the points of vertical load application.

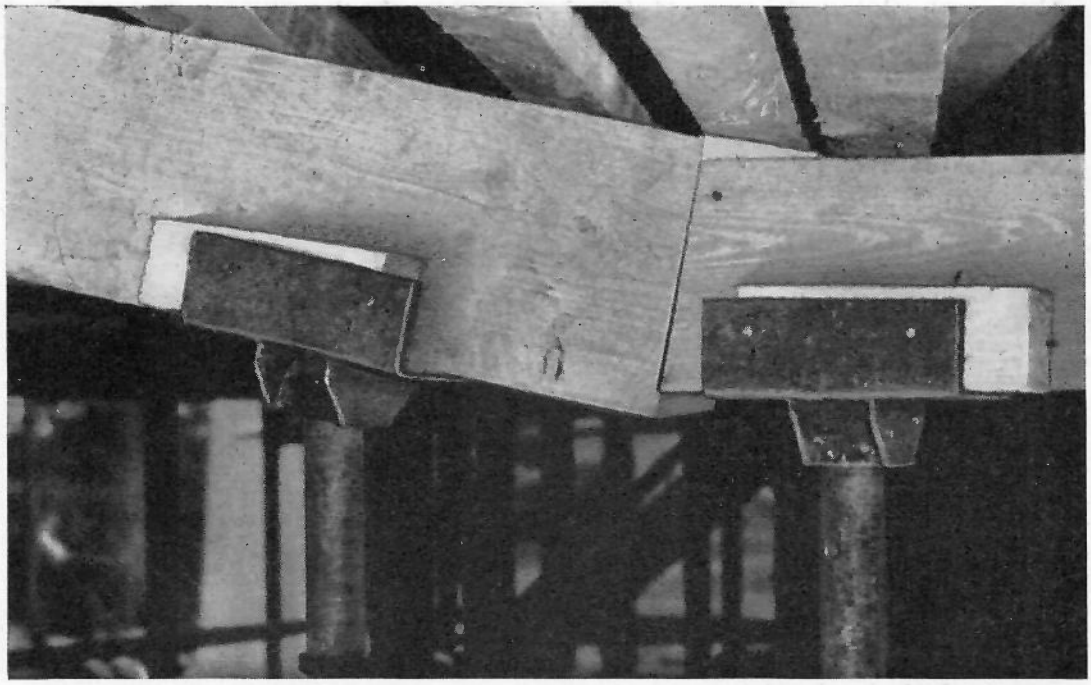
In any structure which consists of a large number of elements the internal reactions caused by misalignment will tend to cancel out. The net horizontal forces must be transferred from the collection points to the ground or other stable point. If struts are used for this purpose it may be necessary to make intermediate connections to control their effective length. Such connections may be made to other falsework members and so increase their resistance to buckling.

The relevance of the present BS 449 in this context is that it requires that at any point which is to be taken as a node when calculating the effective buckling length of a strut, the connections restraining sideways movement must be capable of carrying 2½% of the load of the strut.

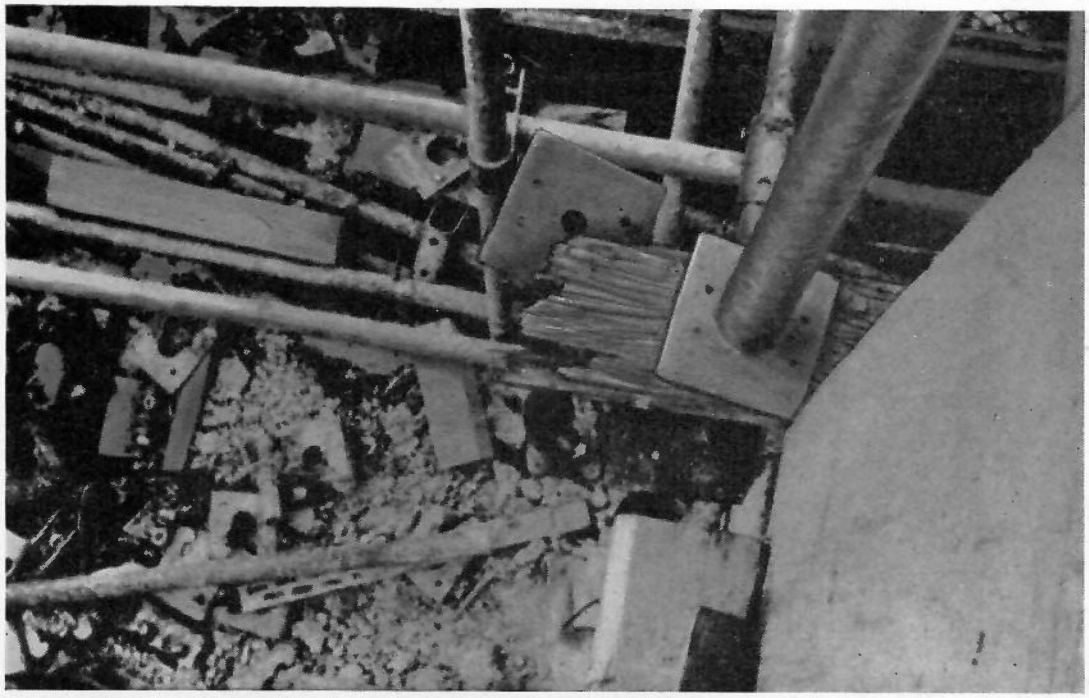
It is for the British Standards Institution Committee to codify these practices in detail. However we would confirm our recommendation that falsework structures must be capable of withstanding a net horizontal load in any direction of at least 3% of the design vertical load, or 1% of the vertical load plus the estimated horizontal loads if that sum is greater than 3%.

Lateral stability

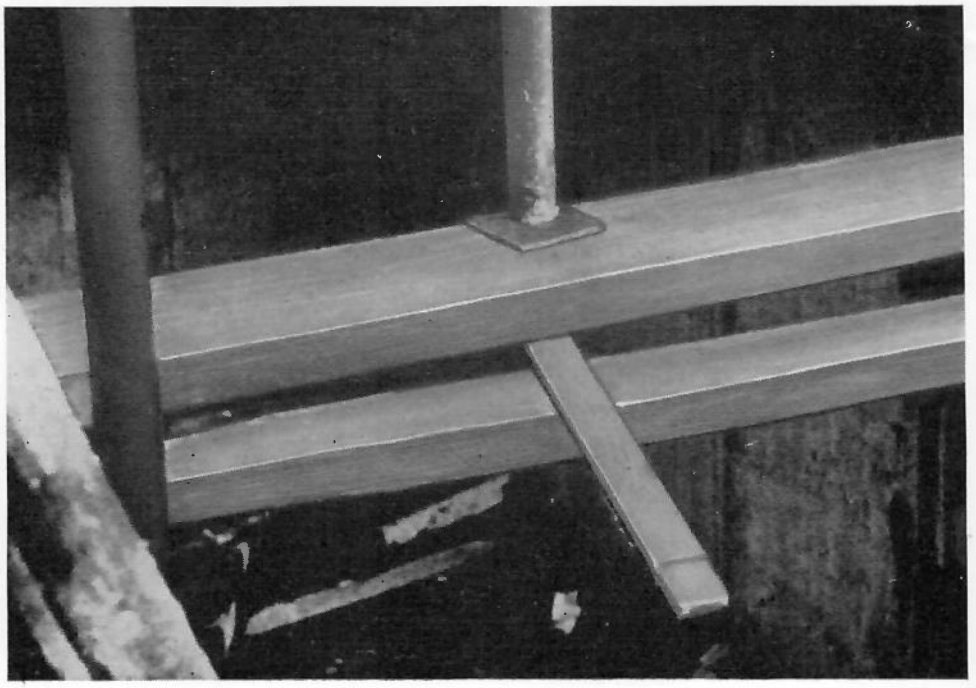
The basic problem of ensuring the lateral stability of falsework can be shown as a development from elementary propositions.



A good example of the care taken to absorb horizontal loads by butting the beams properly wedged in angled forkheads



An example of bad improvisation for the extension of vertical support members. The offset vertical and the use of unsuitable timber packing is clearly shown



Insufficient support provided for prop base on timber spanning large void in floor slab

This badly improvised edge beam support was being prepared for concreting at the same site where the collapse of the floor slab is shown on page 13 had recently occurred

If a single prop is used it is inherently laterally unstable, so is a small group of such props even when some formwork is being supported on top of them. We now consider some of the cases of support systems proceeding from the simpler to the more elaborate. Let us take as a starting point a flat and horizontal bridge soffit to be built on a flat and horizontal firm foundation roughly square in area. By exaggerating successive modifications to this ideal the rules for dealing with lateral instability will become apparent.

Firstly by modifying this ideal square falsework into a long thin structure supporting a bridge span we produce a structure which unbraced is weaker transversely than longitudinally. Such a structure must be given more transverse stability than total longitudinal stability because there is less chance of compensation for weaknesses of one section by another.

Secondly if we assume the ends of this long temporary structure to be locked into the columns of the permanent structure, there is a decreasing lateral stability towards the centre. The transverse stability must therefore be increased towards the middle of the structure. Stability at all transverse sections must be adequate. If no permanent columns are there to provide this, other measures will be required.

Thirdly if we now leave an access way through the long thin temporary structure we have a discontinuity at this point and the two "free" ends are in need of further stabilising. The vertically loaded units on each side will also need appropriate stabilisation.

As a fourth modification to the structure, imposed after its shape change, assume that the foundation is lower at one side and on weaker ground. Some rotation towards the lower side may take place. The lateral effects referred to above instead of being self-compensating become influenced in one direction. They may become further enlarged by moments induced in each foundation if they rotate separately as well as collectively. Consequent inaccuracies in verticality enhance the trend. This effect is due almost exclusively to the weaker ground.

A fifth modification would be to raise the soffit at one side, the higher side being supported on taller and hence weaker struts. Increased stability is then needed at that side, so that the strut strength is restored to the general level.

As a sixth modification the inclination of the soffit may cause moments in the struts. (Pin joints in laced struts do not ensure axial loading but only the absence of applied moment at the ends.) Rocking fork heads or their equivalent may be used to ensure axial loading with no applied moment.

Seventh, the raised side of the soffit will probably be on the outer side of a curved bridge which being slightly longer than the inner side may be less frequently supported and have greater applied loads in the struts. The design must be carefully checked for the wider spaced and taller support work, and this is likely to be the critical section controlling the design.

The possibility of the cumulative effect has to be considered. In addition, the superimposition of the other known lateral forces such as wind and plant surge, if acting in similar directions, can produce a disruptive and sometimes calamitous effect.

In two falseworks constructed from the same materials it must be acknowledged that the smaller will be less stable against disruptive forces and so account must be taken of the overall size of the job.

For all these reasons particular attention must be paid at the design stage to the provision of sufficient bracing in plan, transversely and longitudinally. Bracing between tower units, foot ties and head lacing are specially important. Buttresses, rakers and anchors may be all needed.

Bracing and lacing

In this section "lacing" refers to connections between one strut and another in the horizontal plane and "bracing" refers to diagonal members transferring the forces in the lacing from one level to another.

Small soffit supports

In the case of small soffits when there is not a multiplicity of supports the need for bracing and lacing is actually greater than when there are many interlaced supports and must be treated at least as seriously.

For example a telescopic prop without any lateral support will cater for a certain safe working load. If it is effectively held in position by lacing, this load can be increased. Stabilisation at two levels will increase it further (the limiting item may be the pin) but this is only true if the lacing is effective. Correspondingly if the lacing assumed by the designer is omitted the strength required will not be obtained.

It is usually easy to secure a line of bracing in one direction but frequently it is difficult in the direction at right angles. This difficulty must be overcome if a potential hazard is to be avoided.

Isolated struts in larger structures

Where isolated struts of larger dimensions are used these should preferably be pin jointed at their ends so that no moments can occur. The lateral stability of the strut must then be ensured either by the external bracing or by taking sideways loads to other elements of the structure being built.

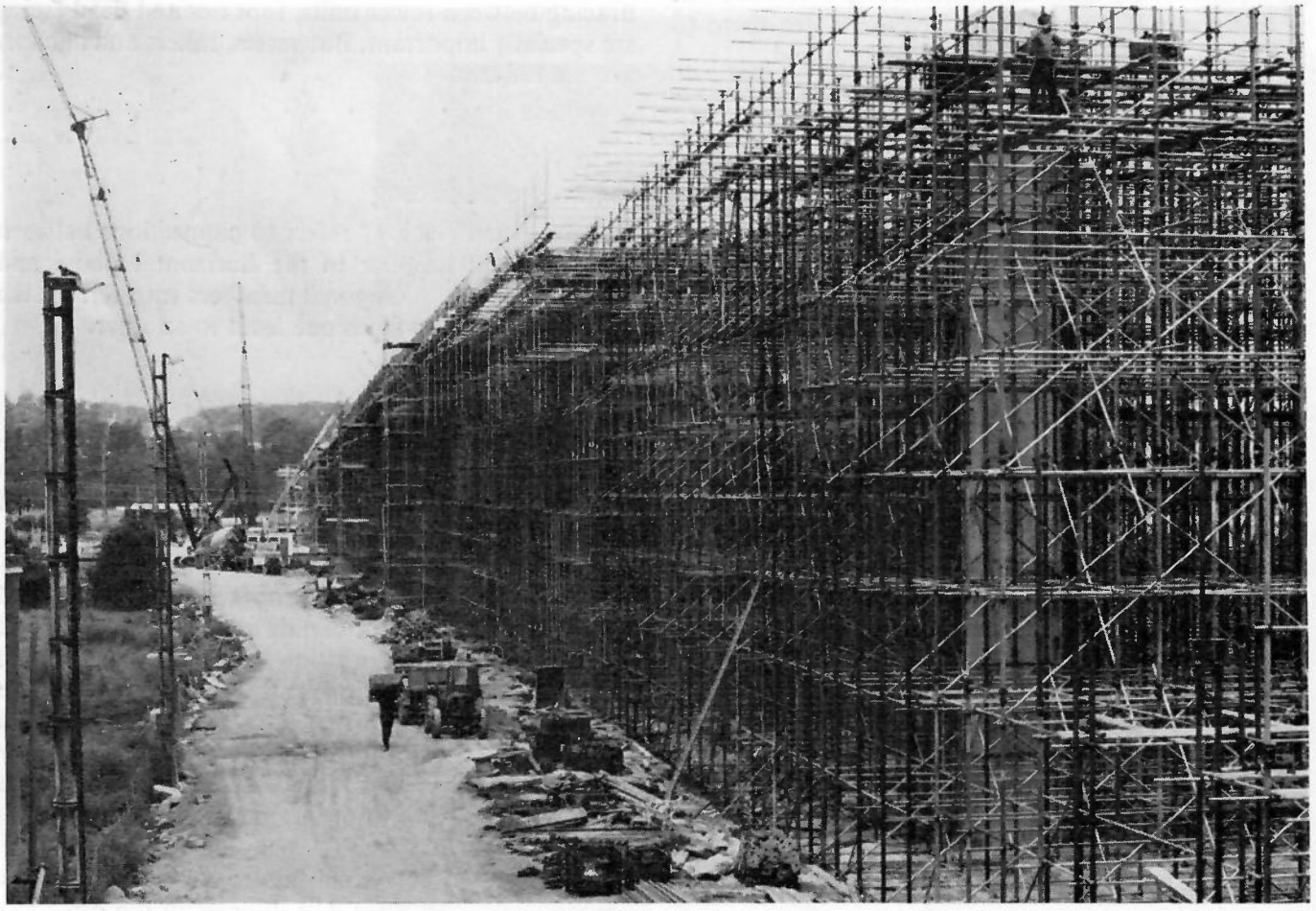
The bracing of lines of towers and bird cages

If the towers are independent they must each withstand the horizontal forces plus 1% of the vertical load or 3% of the vertical load – whichever is greater, and this may involve lateral support. If the towers are in connected lines one brace along the line may cater for several towers; for instance in a square arrangement of towers there may be one brace for each pair of towers in each direction. This means that intermediate towers may not be individually braced. With this situation the lacing must be strong enough in bending to give stability to the unbraced lines and strong enough to withstand the whole of the lateral force if required to do so.

Structural bracing

The bracing must resist all the horizontal loads. Some were discussed previously and there will be others in different cases. In addition to resisting all these, the bracing must also provide the lateral stability described above and ensure the stiffening of the strut to prevent its buckling.

In most cases wind and other major forces will be greater than 3% of the deadload, and the Interim Report proposed adding 1% as a safety factor over and above those conscientiously assessed. But the additional 1% is no substitute for exhaustive consideration of loads. The total should never be less than 3%.



An example of the benefits of careful setting-out and design is shown in this large-scale falsework, where excellent bracing and lacing is facilitated by the regular construction

To stabilise the top of an isolated strut, the two main directions should be considered and the 3% rule applied in both directions. The lacing and bracing members themselves should be stiff enough to carry this load. The classic example is the support of the mast of a scotch derrick by two inclined struts at right-angles which also act as ties.

To resist buckling, at intermediate points up the strut, a load capacity of 3% of the thrust should be provided unless the known external forces exceed the 3% value.

Isolated towers and lines of towers in larger structures

Towers with three or four legs present some difficulties in construction work because, being founded separately on each of their legs, they are not pin jointed at the bottom. They may be loaded at the top on individual legs or centrally through a grillage.

Where there is considerable internal bracing in support towers this can carry a certain fraction of the horizontal forces to the ground. The amount of this internal horizontal strength should be calculated for the system used and checked by tests wherever possible.

In many systems, however, this internal bracing does not transfer the forces directly to the ground because the adjustable legs at the bottom have much lower resistance to horizontal forces than the bracing within the tower. This must be taken into account by, for example, bracing from the top of the legs to a firm point.

The distance between the levels of lacing in either direction should generally not be spaced more than three times the dimension of the tower in the same direction. Thus a 2 m × 1 m tower should be laced at 6 metre levels in the long direction and 3 metre levels in the other. The forces in the lacing must be resisted by attaching the members to a firm point.

It is not usually possible to estimate the force which might come into the lacing system at any level and therefore empirical rules are used. The total lateral resistance, i.e, internal plus external, should be at least 3% of the load in the strut. From this value the internal resistance of the built-in bracing in the tower may be subtracted and the residual amount resisted by attachment to a firm point, provided the lateral resistance of the lowest leg element is adequate.

Where there is more than one level of lacing it need not be assumed that the several three per cents are to be added together and the total of them brought to the firm point. In collecting the forces together any one of the levels of lacing must be capable of transferring the 3% to the firm point. But it need not normally be assumed that the summation of all the forces in all of the levels is ever more than 3% unless there are special horizontal loads which must be catered for. In this way if the lacing forces are brought to the ground at the firm points the bracing need only be designed to transfer a total lacing force of 3%, provided that it can collect this force from any one of the lacing levels or components of it from several.

When isolated towers or lines of towers are surmounted by a grillage it must not be assumed that the grillage will apply only a vertical load to the towers. Whilst the grillage may be centred over the legs of the towers and thus apply its reactions at this centre, the load may not be vertical. It may have considerable inclination if there are substantial horizontal forces at the top. If the grillage is made of three levels of joists the reactions applied to the top of the grillage may be a metre above the top of the tower and may exert a considerable moment on the whole tower.

The inclination from the vertical of the force applied to the tower, or alternatively the inclination of the tower if the force results in a lateral movement at the top of the tower, may be sufficient to throw the line of the load towards, or even outside, the base of the tower. The loads in some of the legs of the tower will then be increased. The effect of lacing is to reduce the effective length of the tower, but it will not alter the inclination of the applied force, and thus the strength of the foundations and lower lifts of laced towers must be carefully assessed.

The lower end of bracing members

Generally the upper end or the intermediate connections to the brace are uncomplicated but the lower connection is sometimes difficult. It has to act in compression and tension and the brace force must be transferred to the ground.

This does not mean that braces must have separate foundations as in the case of the scotch derrick. But it does require that there is a foot tie joining the load bearing struts together near the ground level, and certainly at a level below which there are no adjustable or other units which have low lateral stability for the attachment of the bracing. The vertical weight of the structure being supported must normally provide the resistance against uplift of a brace under tension and the foundation of the load bearing struts will suffice for the thrusts of the braces under compression.

The connections of the braces to the foot ties must be adequate to accept the accumulated tensions or thrusts going down the braces and must not apply excessive lateral force on to the weak portions of these foot ties or to the uprights.

Use of guys

In general the use of guys is not advocated since they have a number of disadvantages.

The primary one is that the guy has a high extension under load and therefore permits increased movement. This effect is made worse when the guy is long so that its inherent elasticity is increased by the sag. Other disadvantages are summarised in the following paragraphs.

The guy tension produces extra vertical loads in the structure at one point.

Since the guys act only in tension two cannot supplement each other when situated on opposite sides of a falsework. Furthermore since the guys act in opposition they must be tightened simultaneously.

The increased flexibility can allow oscillations to build up. Indeed the wind forces on the guys may themselves introduce oscillation, particularly under icing conditions.

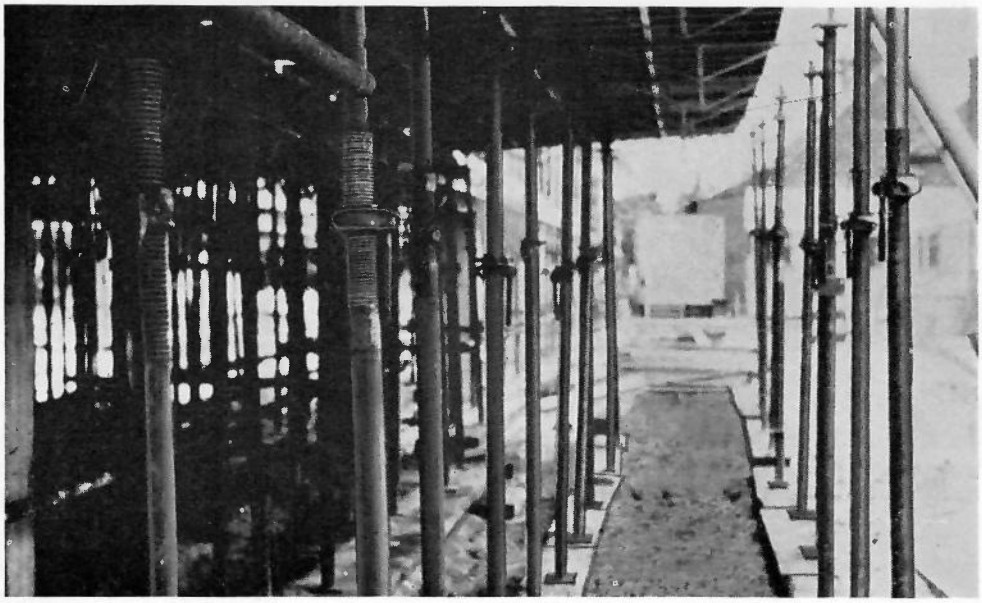
It is difficult to provide a firm anchorage which can withstand tension, particularly in weak ground. Although appearing firm the fixing may give way a little under load and allow unexpected movement.

Where two or more levels of guys are used tensions may be introduced in the falsework and these must be anticipated.

The lateral forces carried by intermediate laces cannot be transferred easily or effectively to the guys and must be resisted by internal bracing in any event.

In general therefore the use of guys is not advocated. However in the case of very high falsework structures in open countryside – for example bridge soffits over valleys – it may be impracticable to use extensive bracing to the falsework towers which are tall and slender. We have seen guys in use, particularly in California, for stabilising such structures. We recognise also the need for guys as temporary stabilisers of falsework under construction.

The problems already listed must be studied very carefully before a guyed system of stabilisation is selected. Wire attachments, however, to parts of a permanent structure at levels approximately the same as the lacing levels can be used successfully provided that a multiplicity of such connections can be made so that individually the forces are small.



Badly placed, irregular, non-vertical rows of props do not lend themselves to fixing of the necessary lacing tubes, which have been omitted at this site

When a single level guyed system is used it must be realised that the structure is not stabilised until it reaches the height where the guy is attached. Similarly on dismantling, the structure may not be stable when the guy is removed and may require intermediate stabilisation.

Longitudinal stability

In the longitudinal direction there is opportunity for more braces per line of struts. Errors in verticality may cancel one another out to a greater extent and gradients of the soffits may be less than in the transverse direction. However longitudinal ground gradients may be more severe and require special attention.

In bridges there may be sloping columns within the falsework which apply severe longitudinal forces. These must be dealt with separately. The known horizontal forces plus 1% of the vertical loads should be added algebraically and for the worst condition of time and place. If this sum is less than 3% of the vertical load then at least 3% must be assumed.

The designer should allow for the possibility of the 3% minimum lateral force being transferred from the top of the falsework to the ground directly by the braces and also for the possibility that it is transferred down the vertical struts to lower node points and thence down the diagonal bracing.

Butting on to and tying back to the permanent structure

It will have been apparent from the previous section that lateral stability in a falsework structure is achieved by the combination of a lacing system joining the load bearing struts and by the bracing system which carries the forces in the lacing to the ground or to an alternative firm point.

In certain circumstances the lateral forces in the lacing can be transferred directly to firm points on the permanent structure. For instance in the case of a concrete slab being cast on four walls of a building the soffit shutter is usually erected tightly up against the four walls and thus prevented from any lateral sway. The joinery work should be butted on to the walls and not left clear with a gap taped up to prevent leakage of concrete. This butting ensures the lateral stability of the top of the falsework but it does not assist the strength of the columns in the falsework by stiffening them at lower levels.

The stiffening of the falsework columns should be achieved by butting the horizontal lacing members up against the walls – if necessary with a protective cap. If scaffold tubes are used the butting end should be the start of the lace and at the other end a separate tube should be used to make up the gap. This procedure should be carried out on every lace on every level in both directions.

Where one of the walls has not been constructed the laces have nothing to butt up against at one end. Two methods are available to overcome this:

(i) Scaffold tie fittings may be bolted on to the existing wall to provide resistance to tension as well as thrust in the lace

(ii) Diagonal bracing can be used coupled to a foot tie to provide lateral stability in the direction away from the single wall.

If neither wall is complete then diagonal bracing is the only solution to the stability problem and it should be inserted according to the rules given earlier.

Bridge soffits

Bridge piers or abutments may provide stability in the longitudinal direction but give little support to transverse forces elsewhere.

Bridge falsework is long and narrow in plan which means that a high degree of transverse stability is required. The lacing in such falsework should always butt up against the abutments and if possible be tied to them. It should also be locked round the ends of the abutment so that transverse stability is achieved at the end of the falsework.

Lacing should butt up against intermediate piers and be locked round the sides of them or, if the piers are formed of separate columns, the falsework laces should be box tied round each column.

It must, however, be remembered that when falsework is properly anchored in this way it will not be free to accommodate any longitudinal movement introduced by the deflection of long loaded beams or trusses. This must be allowed for separately.

In certain circumstances the design of the piers is such that no lateral forces can be applied to them. For example they may be pin jointed and maintained in position by their own falsework. In this case the soffit falsework should be made self supporting against lateral forces by bracing to foot ties. These braces should preferably be locked into the angle between the columns and their foundations so that a firm point is achieved for the bottom end of the brace.

Permission to box tie round the columns and piers and to butt up against abutments should not be unreasonably withheld by the designer of the permanent structure. With fixed end columns they are usually designed to resist greater lateral forces from the completed permanent structure than will be applied to them by the falsework during construction.

Of course there is a limit to the horizontal force which may be applied to a part of the permanent structure, particularly when this has not yet been stabilised by the soffit under construction.

It is preferable to design and construct so that adequate lateral stability can be provided entirely through one route – that is entirely by bracing or entirely by tying to the existing structure. However even if the design has been made on the basis of bracing alone it is sensible to take the opportunity to butt the lacing up against the permanent structure.

Selection of materials and equipment

All falsework designs are influenced by the materials available to the contractor. He may have certain items in stock and may have arrangements for hiring proprietary equipment from a particular supplier. The choice of material may also be affected by the experience of the workforce in the erection of particular falsework systems. Such limitations are normally acceptable but must not be allowed to be paramount if particular features of a project in hand – for example a very large unsupported span or an exceptionally heavy loading imposed by the permanent works – make the use of the available materials inappropriate.

The selection of appropriate timber, tube and fittings, scaffolding and proprietary systems of steel beam assemblies is discussed in the various draft standards which we have seen. These include the Canadian Standards Association 4th Draft entitled "Falsework for Construction Purposes" and the Code published by the State of California Bridge Department, entitled "Bridge Falsework". We support the general lines followed in these documents and would expect them to be followed by the British Standards Institution where they are relevant to British practice.

Timber

North American standards deal extensively with timber. This includes consideration of compressive, shearing and flexural strength and the effect of duration of load. The moisture content is important and so are the defects typically found in timber. These include knots, "checks and shakes" (i.e, radial separation of wood fibres) annual growth, splits, cross and diagonal grain, warping, wane and decay. This detailed consideration emphasises the greater use and importance of this material in a heavily forested continent but the conclusions drawn are equally valid for the United Kingdom.

The Joint Committee recommended that "grade stresses listed for 50 grade material should be used for the calculation of basic permissible stresses . . . " and that certain commercial gradings will consist principally of timber as good as this (para 5.4.1). Where stress graded timber is used, CP 112 provides the necessary guidance. In both cases the appropriate factors given in the relevant Code should be applied. We would like, however, to emphasise that a competent person should inspect the timber on the job and reach a decision on its acceptance or rejection.

When timber members are used side by side and are intended to share the load, it is particularly important that the qualities and dimensions are the same to ensure that the load is shared.

Allowable bearing stresses require careful consideration. We agree with the Joint report that a 33% increase can be allowed if there is no wane, but we draw attention to the fact that if several timber members are laid one upon the other – e.g, wedges, followed by primary beams, followed by secondary beams, followed by packing or firing, the compression of all the pieces together is very much greater than that resulting from the load on one single piece. In such circumstances consideration should be given to a reduction in the allowable bearing stress to reduce the disruptive effects resulting from deformation of bearing areas.

Falsework is sometimes constructed in such a way that timber beams do not fully cover or overlap their supports but are butted with other timbers on the same support. This reduces the end bearing area, which is already small, and some modification in allowable stress may be needed if this arrangement cannot be avoided. The effects are more severe if the beams have been used before, and the ends are damaged.

Discontinuity of primary and secondary shutter beams

It is essential that the end to end joints in shutter beams are placed where the designer intended. If they occur at a place where he intended continuity, the full applied load may pass straight through the beam system into one strut without distribution and cause a failure.

The increased reactions under the centre supports of continuous beams can sometimes create a hazard in struts with very rigid foundations particularly if both the primary and secondary beams of a strutting system are continuous on the same support.

Steel components

The commonest falsework components in the United Kingdom are steel tubes and fittings, telescopic props, proprietary framed supports and various steel members.

The components actually used inevitably vary from piece to piece. Not every prop is produced with identical dimensions and the British Standards for new material allow certain tolerances. In addition the designer must allow for deterioration due to corrosion, damage in handling, re-straightening and repair. These may have different effects on materials of the same nominal capacity. For example, scaffold tubes of 3·2 mm wall thickness are much more liable to damage from mishandling, and the deterioration due to a given depth of corrosion may be greater than that with 4 mm wall tubes. This underlines the cardinal point that the material specified by the designer or an alternative acceptable to him must always be used.

The allowable stress for a falsework member is not always easily determined. First, the original specification of the metal may not be available; secondly, its characteristics may have been significantly modified by age, repeated use or straightening; thirdly corrosion may have a significant effect on failure loads and hence on the allowable stress.

When corrosion has reduced the cross section area of a member, the section properties of the reduced area are not readily available to the designer. He usually prefers to modify the allowable stress and use the nominal and tabulated section properties rather than to re-calculate the properties of the corroded section and retain the normal allowable stress. Unless the re-used steel is in 'as-new' condition, it is preferred for simplicity and the avoidance of errors to reduce the allowable stress by 15%. This reduction is from the original allowable stress or, when this is not known, the old BS 15 steel stresses. This 15% will generally be adequate to cover corrosion, distortion and re-straightening. In making such a recommendation, it is assumed that any element which would clearly be inadequate will be discarded. If there is more than a 10% loss of section anywhere the item should be rejected.

Defects in joints due to previous use cannot be tolerated. Cracked welds in components must be ground out and re-welded only under expert guidance and preferably not on site. The movement in bolted or pinned joints should not exceed the design specification.

Tolerances in straightness should be limited to an amount which depends upon the total unsupported length of the member and its cross-sectional dimensions.

Components which have defects of thickness and straightness should be given the most careful examination if they must be re-used.

The emphasis in the USA is towards fewer stouter members rather than a multiplicity of smaller members.

Rolled beams are frequently used in falsework, but it is not always realised that the smaller root radii of the universal beams may result in a lower web capacity than in the case of the older joists. Furthermore there is evidence that the 'as rolled' dimensions are sometimes different from the nominal.

Careful attention must be given to these points in design and in the use of published data and on-site inspection.

Jacks to extensions

In a typical scaffold falsework it is usual to have jacks at the bottom and top positions in the form of adjustable base plates and adjustable forkheads respectively. Where extendable jacks are used it must be remembered that the point between the extension and the prop is relatively weak in bending.

Instances occur where frequent re-use leads to slackness in the threads which makes the connection even weaker. The jack designer should ensure that his design does not permit excessive screw extension. Furthermore, if pin-jointed forkheads and end plates – designed to accommodate sloping soffits and foundations – are used there can be no moment applied at the jack ends tending to keep them axially aligned. It is therefore essential that particular attention be paid to the lacing and bracing of jacks in such circumstances. The next lift may also be affected by the reduced restraint at the junction points and require stabilisation.

It must never be forgotten that members of a grillage of beams may be subjected to an overturning effect which will itself produce a moment in a prop and increase its tendency to buckle unless adequately braced. Similar effects occur with sloping soffits or foundations which tilt. Unfortunately there is very little information available on the moments which may be transmitted and their effect on jack strength.

Composite beams

We have already made several points concerning the stability of beams such as the importance of allowing for the defelection of beam ends in the horizontal plane.

It is also essential to ensure that the main beams are tied together in plan which extends from one top chord to the next top chord as well as by bracing which connects the lower chords of the beams. In addition there should be ample transverse cross bracing holding the beams upright and preventing their rotation. We were particularly impressed that special attention was paid to these aspects of beam bracing on very large bridge and motorway projects in the United States and Canada. In addition to welded plan bracing in the form of flats fixed to the beam chords, purpose-made rectangular frames with two diagonal braces were used and welded to adjacent beams, not only at the end positions, but also at regular intervals along their length.

We consider this subject to be of such importance that it is worth recapitulating the main precepts which must be taken into account in the design and erection of falsework using composite beams.

1 When first positioned a beam must be restrained from rolling over on its supports, particularly if these are below the neutral axis.

2 Beams tend to twist under load for the reasons already discussed apropos of standard sections. They must therefore be restrained all along their length against these tendencies for the beam to roll over, and for the lower chord to move sideways and rise.

3 Beams may be hogged so that the soffit surface becomes level when the beam deflects under load. This hogging may produce an additional over-rolling effect.

4 The top chords may be adequately stiffened so as not to buckle under compression.

5 The most concentrated loads are most likely to occur at the supports. The end battens and braces must be capable of supporting the end reaction. The extensions of top and bottom chords beyond the last node point must not be overloaded.

6 The supports must be capable of accommodating the longitudinal deflections due to loading or to thermal effects. This is specially important in skew spans, and where joints are made to the permanent structure.

7 It is always important to ensure that falsework materials have not suffered from damage or deterioration. Welds in beam assemblies must be carefully inspected. It is also important to check that the way the beams are handled during transport, assembly and dismantling will not cause damage. For example, a spanning Warren type girder should not be lifted by attachments which could damage either chord of the beams under its self-load.

8 Beams which overlap and are coupled should be joined in a way that ensures that the compression, tension and torsion forces and moments are properly transferred where such transference is intended. Fishplates and bolts must be of the size and quality specified by the designer, particularly if high tensile material is called for.

9 Everything that has been said about single beams applies to the individual units in a multiple assembly of side by side beams. Particular attention must be paid to skew spans where it is sometimes difficult to stiffen the end lengths. Different types of beams which have different characteristics should not be mixed.

10 Beams are heavy and the self weight of the beam or assembly must be added to the design load. The designer must also check that the load is not increased by any redistribution of load resulting for example from the deflection of the beam. The deflection of a continuous beam affects the load distribution on its supports and this must be allowed for.

11 Where beams are not symmetrical about both main axes, care must be taken to ensure that they are used the intended way up.

12 When the design of the beam permits multiple chords to be attached for the purpose of increasing strength, the attachment of the extra chords must be such that they come fully into play. The improved load-carrying capacity of the beam with multiple chords must not overload the battens and braces.

13 When used on mobile towers or on end trolleys or skids, beams must be battened together in such a way that they will not be disrupted during movement.

Grillages

Our attention has been drawn, as a result of several failures, to the over-loading of universal beams which has resulted in tilting of the flanges and buckling of the webs. The whole question of web stiffness is one on which more information is required. We have observed how much attention is given to the subject in certain overseas countries including the USA where welded metal fillets and timber packing pieces are widely used in grillages. Where crossed beams are used in highly stressed grillages the flanges should be fixed together by means of beam clamps or equally effective devices. Particular attention should be paid to the effects of horizontal movement at all stages of construction and loading. Longitudinal movement of the ends of beams during loading can produce horizontal forces or moments sufficient to fail the webs or even to roll the grillage beams over if they are not properly supported.

We recommend that particular attention to these points is given in the proposed code of practice for falsework.

The weakness of webs is highlighted in reports of research at Aston University. Professor Holmes, Head of the Civil Engineering Department, has measured skin stresses at the junction of web and flange. The same loads applied to the new universal beams produce stresses twice or even four times as great as in traditional rolled steel joists. These differences all point to the need for a new tabulation of beam data and we recommend that the research work on which such tables could be based is put in hand.

We have found a lack of understanding among designers of the way to use the web capacity tables for universal beams. The calculation of the stiff bearing lengths of one joist supporting another is difficult and there are no tabulated values for each serial size.

When timber is used on or under steel beams there is no stiffening of the section because the timber deforms. The effect of this deformation on stresses at the web/flange junctions is another point that Professor Holmes found significant.

Proprietary equipment

Section 6 of the new Act states that it shall be the duty of any person who designs, manufactures, imports or supplies any article for use at work:

(a) to ensure, so far as is reasonably practicable, that the article is so designed and constructed as to be safe and without risks to health when properly used;

(b) to carry out or arrange for the carrying out of such testing and examination as may be necessary for the performance of the duty imposed on him by the preceding paragraph;

(c) to take such steps as are necessary to secure that there will be available in connection with the use of the article at work adequate information about the use for which it is designed and has been tested, and about any conditions necessary to ensure that, when put to that use, it will be safe and without risks to health.

The committee welcomes these requirements and the following points should be read in that context.

Design by manufacturer

Proprietary units should be designed and constructed such that the stresses set up from normal use and the abuse to be expected on construction sites will not cause damage detrimental to the strength and stability of the unit. Even if units are designed with this consideration in mind they should be handled with care at all times.

In order to reduce the risks of failure the units should be designed in a way which eliminates as far as possible all dangers of incorrect assembly. They must also be designed for extreme conditions of use, for example, manufacturers of forkheads should ensure that there is always a residual length of shank in the load bearing tube when the nut is set at the lower end.

It is important that items which are similar but which may have different properties and therefore different load-carrying capacities should be clearly identifiable by the man on the site.

Design by falsework designer

It is essential that the falsework designer has a proper understanding of the use of proprietary units. This can only be achieved by training, experience and adequate communication between manufacturer and user.

When designing for the use of different proprietary systems within the same falsework structure, the compatibility of the systems must be considered, particularly at the interfaces.

The designer must pay attention to the bracing of proprietary systems even if the relevant trade literature

does not indicate the need for it; this may be especially important in the partially erected condition. Safe working loads on proprietary equipment should take into account all relevant boundary conditions, i.e, loads on expanding floor centres should not be so high that the timber supports crush. The designer must consider and cater in his design for every use to which the equipment may be put so that those on site are not, through absence of relevant data, themselves tempted to design details for which they may not have the requisite skills.

The designer should bear in mind that the falsework will not be erected perfectly vertically and without eccentricities and that the design should cater for normal site tolerances. Such tolerances and limits should be clearly indicated on the drawings in order that the operatives and supervisors, having been made aware of these, can take suitable remedial measures should they be exceeded.

Use of proprietary equipment

All proprietary equipment as well as other falsework should be erected strictly in accordance with properly prepared drawings and with the manufacturer's instructions. Evidence submitted to the committee has indicated that where problems have arisen they are often the result of lack of attention to seemingly small details. Instances of these are inadequate end bearing of expanding floor centres which had not been opened out sufficiently, use of incorrect pins and wedges, etc, eccentricity of loadings and lack of verticality of props. CIRIA report No 27 investigates this last aspect and calls attention to the resulting loss of capacity.

Both operatives and supervisors should be made aware of the importance of attention to detail in the use of proprietary falsework equipment.

Operatives involved in erection of proprietary equipment should be experienced in the use of the type being erected. If they are not experienced they should be given training by a suitable instructor. Even if the training session is brief, it will save time and money in the long run and lead to safer practice.

Appendix H of the report of the Joint Committee of the Institution of Structural Engineers and the Concrete Society lists defects commonly found in the use of proprietary equipment.

Damaged equipment should not be used until it has been thoroughly inspected and where necessary reconditioned to meet the original load specification.

Testing

Proprietary equipment requires to be tested when first supplied and at various stages throughout its production life in order to ensure its fitness for use. Standard test methods should be devised for the more usual types of proprietary equipment so that the data produced are more reliable and more uniform. Such tests should simulate typical site usage, to reduce the risk of mis-application of test data.

At present no such tests have been agreed. BS 4074, Metal Props and Struts, has a test method appended to it: but as this bears no relation to site practice, it cannot be used as an example. BS Committee PEB/1 has a brief to standardise test methods and the first for telescopic floor centres, has been circulated to industry for comment.

The specification of test conditions should aim to reproduce site conditions as far as practicable. Such specification needs to be definitive in order to avoid variation between test houses.

Such particulars as the end fixing conditions, the materials to be used at support points and the method and rate of loading should be rigorously specified. In order to give repeatable results, natural materials such as timber should as far as possible be eliminated from test procedures.

The test programme laid down should establish the effect of variations in usage which occur on sites.

New proprietary equipment should be tested (a) prior to its introduction to users and (b) during its life on site. The latter could be achieved by sample testing of randomly selected units. This will enable a check to be made that the characteristics do not significantly differ from the original model tested. These procedures apply equally to major modifications of existing types of equipment.

For initial assessment, several samples of a new piece of equipment should be tested to destruction and the results assessed. Using appropriate factors of safety – see page 62 – safe working characteristics can be calculated. The test should be conducted by an independent test authority and the test certificate should be available to those actually using the equipment. The certificate should give all relative data of the test, including a full description of the test method, failure modes and yield and collapse values.

This test should be repeated where there is any change in design, and when the model has been in production for a few years.

For continuing assessment a proof test is needed. This should be included in the initial assessment test to form a reference for subsequent testing of production models and for equipment on site which is suspected of deteriorating or in some cases after repair or refettling.

It has been suggested that a body should be set up to investigate proprietary products and the relevant literature and to give a mark of approval to products which pass this body's examination.

Manufacturers' literature

Publications produced by manufacturers of proprietary equipment should not be confined to glossy sales literature giving few details and little information on permissible loadings.

The committee are convinced that adequate details and information should be freely available to users.

It is important that erection sketches and photographs should include all the necessary bracing and ties.

Data sheets should be available for all proprietary equipment and should give the safe working loads and the factors of safety. They should indicate whether the information given is based on the yield or on the collapse value of the unit, and whether the values given are based on calculations or actual tests. The mode and location of failure of units should be stated. Full information of section properties, specifications of materials used and boundary conditions of tests should be given by the manufacturer.

In the interest of safety, where there is a danger of wrong units being used, clear markings should be incorporated in the design and manufacture of proprietary units.

The committee endorse the information to be supplied by the manufacturer of proprietary equipment which is given in Appendix E of the report of the Joint Committee.

Tolerances

Tolerances in permanent structural steel work have not normally been specified since it is well known that unless a certain standard of fabrication and erection is maintained the components of the structure will not fit together. In falsework, however, there is a quite different set of circumstances. The joints are not usually bolted through preformed holes and the level and verticality have to be set out for each of many members rather than for only a few.

To mechanical engineers the lack of specified tolerances on many falsework drawings is surprising. It is readily agreed that the precise tolerances associated with refined engineering projects such as aero engines, machine tools or scientific instruments would be out of place in the realms of falsework. We do recommend however that the principle of indicating the acceptable tolerances, e.g, ± 20 mm should be followed on all dimensioned drawings.

We are not stating that all props must be exactly vertical, but we do see the need for a consistently good workmanship standard. The limits within which the structure must be erected should be specified on the design drawings and on the erector's detailed working drawings.

Various draft standards have given guidance on tolerances for verticality. For example, the Canadian Standards Association specify at para 7.2.6.i of their 3rd Draft that vertical load-carrying members shall be erected and maintained plumb within the following limits:

> Plumb lines through any two points on the centre line of the member, and less than 10 feet apart vertically, shall not be separated by more than $\frac{3}{4}$ inch.
>
> Plumb lines through any two points on the centre line of the member shall not be separated by more than $1\frac{1}{2}$ inches.

The California rules for bridge falsework specify that for steel shoring "the shoring shall be plumb in both directions. The maximum deviation from true vertical shall not exceed $\frac{1}{8}$ inch in 3 feet. If this deviation is exceeded the shoring shall not be loaded until it is readjusted within this limit". The first Draft British Standard Code of Practice states that "plumblines through any two points on the centre line of the vertical member shall not be separated by more than 25 mm except that, if the two points under consideration are less than 3 metres apart vertically, separation shall not exceed 18 mm".

One suggestion we received was that in fixing the location of a strut an error of not more than 30 mm in any direction is admissible provided this does not result in much greater eccentricity in load application. Similarly we would suggest that the offset from the vertical of any unsupported length of strut should not be more than 1/5th its width in that direction, e.g, 10 mm per lift height between lacing levels of ordinary scaffold tube. In circumstances where there are several such lifts the cumulative offset should not be more than three times this value at any point, and checks that the erectors have achieved this accuracy should be made. It is, however, for the British Standards Institution Committee rather than ourselves to recommend exact details of allowable tolerances.

Allied to a lack of specified tolerances is the uncertain eccentricity of the load applied to struts, on which we have already commented. Eccentricities of load on a strut may be due to misplacement, misalignment or lack of verticality: or to lack of suitable packing or wedging at either end. They may be avoided by good workmanship, which is ensured by proper training. For example, concentric loading on a forkhead can be achieved by turning the forkhead so that its sides impinge upon opposite sides of an undersized timber by using properly matched taper wedges driven in and nailed to the bearer to ensure that the central position is maintained. Known eccentricities must be allowed for in calculating bending, thrust or tension stresses. But in every case the designer should also allow in his calculation for eccentricities and non-axial effects up to the limit of the tolerances he specifies. Every effort should be made to ensure that eccentricities are as small as practicable.

Factors of safety

In the classic method of elastic design of structures sufficient members are put in to ensure that the stresses – calculated on the assumption of elastic behaviour – nowhere exceed the material strength divided by a factor of safety. This factor is often taken as about 1·65, and gives a safe working load which is about two-thirds of that which would cause failure.

The factor of safety covers a number of unknowns – material variability, load variability, errors in construction and so on. More sophisticated analyses, such as the limit state design, have suggested that these effects should be allowed for separately. Thus a characteristic strength, which is possessed by 95% of the elements of a given type, is determined and divided by a partial safety factor to obtain a working strength. Similarly a characteristic load, which is unlikely to be exceeded, is determined and multiplied by a partial safety factor to obtain a design load. A further ratio between strength and load can then be introduced to allow for particular circumstances – for example the seriousness of failure.

We believe that our knowledge of the variabilities encountered in temporary works does not yet make it possible to apply the individual factors required in the limit state design. Indeed the use of such a detailed analysis might introduce a feeling of confidence in the figures that was quite unjustified.

We therefore recommend that temporary structures should be designed to accommodate all calculable loads with a minimum safety factor of two, and that the calculations take full account of the tolerances adopted. Consideration should be given to increasing the factor of safety towards three if any of the following circumstances apply:

Design If the design itself or the equipment used has novel features. If there are special uncertainties about the loads to be encountered in practice. If some members of the design staff lack training and experience. Where tolerances are not explicit. Where the structure does not permit accurate satisfactory calculation.

Construction If novel methods of erection are to be used. If novel materials are to be used.

Situation If working conditions are poor. If the consequences of failure, either as regards injury or damage, are serious.

Use of an overall factor greater than two should produce a "fail–safe" structure in which there is a duplicate path for every load. Having produced such a design it is instructive for the designer to check the effect on the rest of the structure of severe distortion or failure of any one member. Such an exercise is valuable in drawing attention to critical areas and to possible weaknesses which had not previously been appreciated.

It is important to remember that safety factors are introduced to deal with the unknowns. They are *not* supposed to cover variables such as wind loads or vehicle loads which should have been foreseen and allowed for in the original design brief.

It is also important that suppliers of proprietary materials should recognise that the existence of safety factors does not give them a licence to neglect quality control. It is not sufficient merely to publish nominal or average ratings. Failure loads under particular conditions of test should be given. We recommended in an earlier section that suppliers state both their safe working loads and their failure loads.

The overall factor of safety which we recommend may well be greater than would have been asssumed for permanent works. This is because the uncertainty in loads, both static and dynamic, and the variability of material used are both likely to be greater in falseworks than in permanent structures. Our recommendation is consistent with recent recommendations of French structural engineers* as described in records of the Technical Institute of Building and Public Works of the National Union of Reinforced Concrete and Industrial Techniques and the Technical Institute of Building and Public Works. The work is entitled 'Recommendations for the execution of falsework'. This recommends a partial safety factor proper to the material equal to 2 and a second factor which can range from 1·0 to 1·5 depending on circumstances. The CIRIA report† recommends rather lower factors in limit state designs, but these are for permanent works.

Research and development

One of the terms of reference of the Advisory Committee on Falsework was that it should "recommend what research and development should be carried out in the short and long term". It was stated in paragraph 42 of the Interim Report of the committee that "nothing in the evidence we have received has suggested that there are major gaps in the understanding of temporary structures". Although the committee has received a large amount of evidence oral and written since the Interim Report was published, there has been no suggestion that this view should be changed. What has become apparent during the committee's deliberations is the fact that neither the existing knowledge nor the results of research are disseminated widely enough. It is the opinion of the committee that the results of investigation and research into failures of falsework are often not published for the benefit of the construction industry at large. Such results should reach as large an audience as possible.

In order that the committee should be aware of both completed research projects and current research projects, over 70 questionnaires were sent out to universities, colleges, polytechnics and other bodies concerned with research and development in the construction industry. The vast majority of replies received indicated that they had no information that would be of interest to this committee. The remaining replies received revealed a narrow spread of investigation and a number of peripheral enquiries which are mainly aimed either at formwork or at scaffolding, but which have a bearing on falsework.

Those research projects closely concerning falsework include:

(a) An investigation into the effect of site factors on the load capacities of adjustable steel props. (CIRIA Research Report 27.) This work is being continued
(b) Research into the pressure of concrete on formwork. This subject has been investigated by a number of organisations and information on it has been published by CIRIA. (Research Report 1.)
(c) Investigations into the loading of bridge falseworks under the control of the Transport and Road Research Laboratory
(d) A field investigation on behalf of the British Standard Code of Practice Committee on Falsework
(e) Many tests by or on behalf of manufacturers have been conducted on falsework components such as props, soldiers, telescopic beams and towers
(f) Investigations into the strength of military trestling.

There are several investigations and research projects either completed or currently in hand which although not directly falling under the heading falsework will produce information of value to designers. Examples of these are:

(a) Investigations into the strength and stability of scaffold structures, by Dr E Lightfoot, Department of Engineering Science, University of Oxford
(b) Tests on scaffold couplers, by Dr E Lightfoot, Department of Engineering Science, University of Oxford
(c) Investigation concerning the web buckling of I-beams, by Professor M Holmes, Department of Civil Engineering, University of Aston, Birmingham
(d) Structural overload due to impact, by Professor B Rawlings, Department of Civil and Structural Engineering, Sheffield University
(e) Rheological early stiffening and early strength of concrete, by Dr A G B Ritchie, Department of Civil Engineering, University of Strathclyde, Glasgow

Although as already stated there are no major gaps in falsework technology the committee feels that in the interests of increased safety, progress, and efficient use of materials and labour, research should commence in a number of fields. The subjects which warrant close investigation are:

(a) The horizontal stability of falsework structures (money has already been set aside by the

Department of the Environment for this purpose)

(b) Whether limit state design processes could be applied for falsework. Research into partial safety factor on loads and strengths of materials will be necessary prior to the introduction of this method. These investigations must consider factors such as the standard of workmanship and level of supervision, the frequency of re-use of components, the effect of time on falsework structures and the variability of materials

(c) The magnitude and effects of dynamic loads on falsework. Plant such as power-operated material transporters and concrete pumps apply unknown horizontal forces to falsework structures. Concrete skips and loads on cranes can apply dynamic vertical forces

(d) The effects of wind on falsework structures

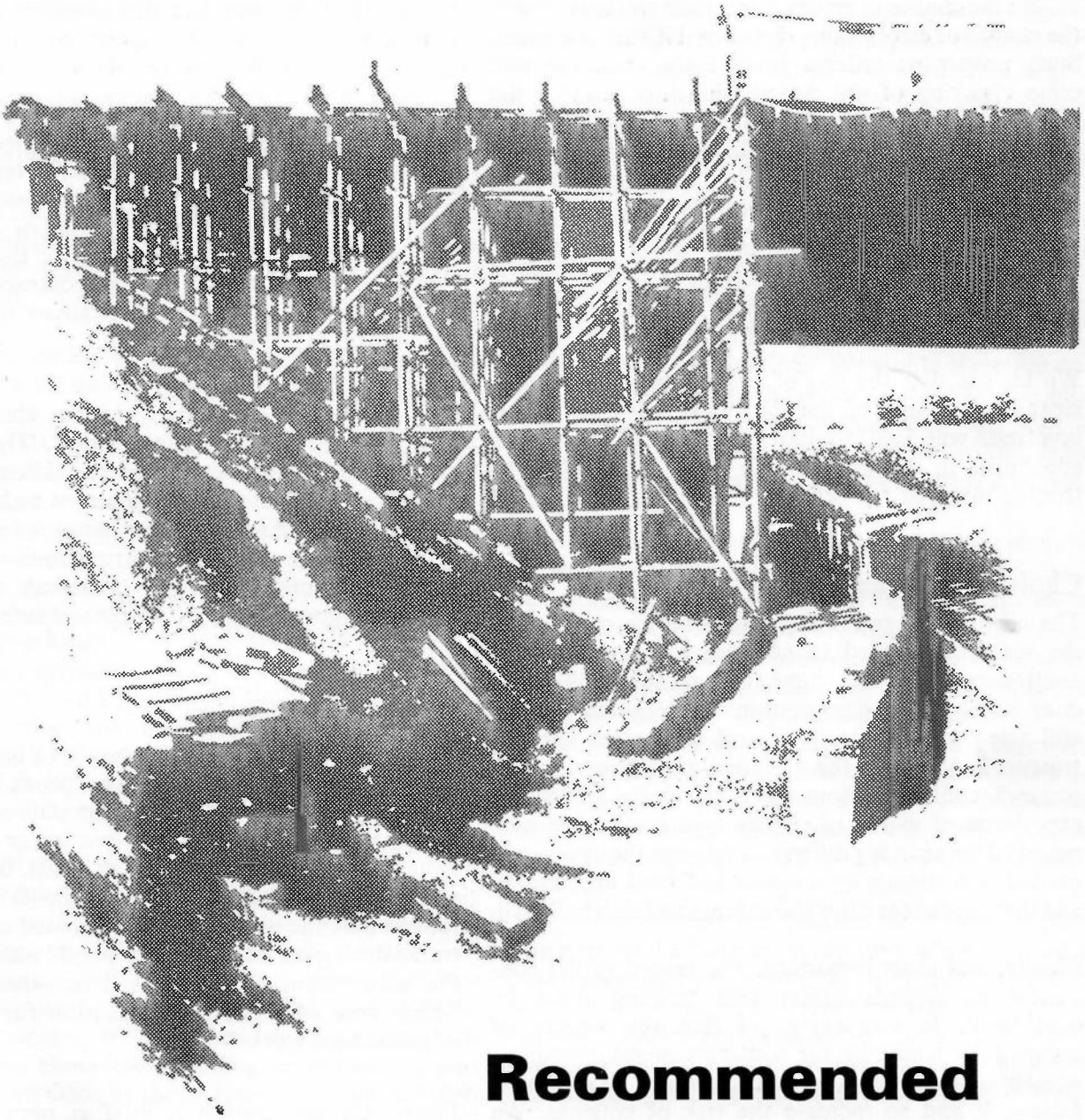
(e) The use of grillages as structural members

(f) Investigation into the production of an economic load indicating device for use in falsework and scaffold

(g) The establishment of criteria for tests on proprietary components and systems for falsework.

Although some work is progressing in the aforementioned fields, it is the Committee's recommendation that the pace of this work should be increased.

5



Recommended procedures

5 Recommended Procedures

In the earlier parts of this report we discussed the technical faults which are sometimes found on construction sites. We also discussed the factors that should be considered by designers and erectors so that they can avoid these faults. It is, however, inevitable that mistakes will occur, through ignorance or misunderstanding or carelessness. In this part of the report we recommend procedures which are aimed at minimising the chance of errors being made and maximising the chance of errors being discovered if they are made. Such proper procedures include the checking and cross checking of the design, the inspection of the falsework and, above all, the maintenance of good communications between all parties. This leads on to the questions of responsibility and professional indemnity. Finally, we confirm the proposal, made in our Interim Report, that a Temporary Works Co-ordinator should be nominated for all construction involving falsework: we outline his duties and consider how they might be carried out.

We believe that the use of proper procedures, with clear descriptions of the duties of every individual involved, will lead to improvements in safety and economies in operation which more than repay the trouble involved in their establishment.

Choice of parties

The client must select a contractor who can deploy the resources needed to complete the project. If a contractor does not have the resources himself, does he have the organisation that ensures that he will select and properly control competent subcontractors? Allowing for the fact that every job is somewhat different from the last, has the contractor experience of works of similar type to the one proposed? There is a big difference between the experience needed in constructing a clover leaf road intersection and that needed for a low rise column and slab buildin g.

Finally, and most important, the record of the contractor as regards safety and training must be considered. It was suggested that the system of competitive tendering for contracts might encourage unscrupulous contractors to cut corners, to skimp on falsework and so increase the risk of collapse. We have no direct evidence that this has happened and we believe that the loss and delay arising from collapse are such that market forces act on contractors to preserve their reputations in this respect. Nevertheless it is essential that a client should be free to prevent a contractor from tendering when he believes him to have too little regard for safety. By this we do not imply that clients should make indiscriminate comparisons of injury rates per hours worked, for example, which may be a reflection on the relative difficulty of the sites worked or jobs undertaken. However, we would expect tenderers to be required to support their claims for relevant experience by reference to low failure rates. We would also expect them to support these claims by reference to their training programmes and this aspect is discussed in Part 6.

We debated whether opportunities to tender for certain types of jobs should be restricted to certain approved contractors, as is the case for reservoirs. We think however that this would unnecessarily restrict the flexibility and growth potential of the existing system. So we are content to advise that the client should seek to establish that the contractor is likely to have the experience and resources to undertake the job in question.

The same rules must apply to the choice of subcontractors by the main contractor. They will also apply to the choice of Engineer or Architect for the permanent works: but this only concerns us here in so far as Engineers or Architects who have proved in the past that they were capable of harmonious relationships with contractors are likely to contribute to the maintenance of good communications and safe procedures.

The design brief

It is the duty of the client to specify to the contractor the exact details of the permanent work he requires. He must provide an outline of the philosophy of the design and give details of any particular methods or sequence of construction which must be used. He must specify any particular environmental constraints, for example the need to allow continued movement of traffic during construction. He should also provide all the information he has on soil or other conditions which were obtained in preparation for the design of permanent works.

From this information a brief is prepared by the contractor for the falsework designer. The brief must refer to materials and equipment that are or are not available and should provide all the information needed to devise a complete plan of the method of construction of the permanent and temporary works. This may include extra information on site conditions as already discussed in Part 2.

It is obviously essential that good communications are established as quickly as possible between the designers of the permanent works and those designing the temporary works. This will ensure that time is not wasted in devising a method of construction that is subsequently found unacceptable. It may also make possible slight modifications to the permanent works which will, without affecting their performance, ease the falsework design and construction.

Similarly it is essential that the falsework designer knows about the actual methods of working on site so that he can make reasonable allowances for live loads, can choose realistic tolerances and so on.

It is unfortunate that many designs must be done twice, once in a preliminary way for estimating purposes and then in final detail. Once the contract has been awarded it is essential that the design brief is updated to take account of the latest available information.

It is convenient for design offices to maintain a simple check list of all the information required. This would include:

- foundations and soil conditions
- local restrictions
- restrictions on method of construction
- philosophy of permanent works design
- dead loading
- available materials
- available equipment
- special live loads
- accepted tolerances

The designer could then check immediately what information was not available. This would allow estimates to be appropriately factored or would set in train a request for the information.

Checking of designs

Any major falsework design may involve the assembly of several parts which were designed independently. Not all the designers will be equally experienced; indeed some may still be under training. It is therefore essential to institute checks to ensure first that the overall structure is integrated and that different assumptions about cross loading or mutual support have not been made by the designers working on different parts; second that there are not basic errors in arithmetic, or unwarranted assumptions about capacity of materials; and finally that all foreseeable contingencies have been allowed for. These checks are particularly important if any of the components, or any of the design principles, are novel. Particular care must be paid to the interface and inter-relationships between different sections of falsework structures.

In some countries a well recognised standard has been set and only those who possess the necessary qualifications are allowed to design or approve falseworks. For example the enquiry into the Heron Road falsework collapse in Canada gave rise to a system of procedures and checks which, with certain refinements, has been shown to be practical. One of the Canadian requirements is that the falsework drawings should be stamped by a properly authorised professional engineer. Such a man is examined and licensed by a provincial authority, and no design drawings may be acted upon unless he has signed them. It must, however, be remembered that in a continent as large as Canada some such form of standardised authorisation is essential because of the difficulty of establishing nationwide reputations for competence and integrity.

In the UK such rigid systems may not be required and would have the added disadvantage that they do not allow for the enormous variation of technical difficulty and complexity in falsework: nor do they make adequate allowance for the man with design experience but no paper qualifications. We would therefore only insist that all designs should be checked by a competent designer within the design office and that he should sign them off after examination: all major designs should be signed off by a chartered engineer.

It is the contractor's duty to ensure that this checking is done. However, the checker need not necessarily be within the contractor's own organisation. In the case where the design is unfamiliar or untried, or where new materials or new methods of assembly are introduced, and where clearance cannot properly be given by the head of the design organisation, then the whole scheme should be passed to an independent design engineer, qualified and well versed in falsework technology, for his opinion. This optional procedure is a parallel to the design check which the Merrison Committee required for all steel box girder bridges.

We have reviewed the practice of having a proof engineer on the German model and, while it would be acceptable on many counts, we think that his function is covered by the design checking scheme which we propose. Remembering that the number of qualified engineers is limited, we do not wish to multiply the checks required beyond those which are absolutely necessary.

In referring to experience in the foregoing discussion we must again emphasise that it is experience of the special problems of falsework design, construction and dismantling that is needed. It is the contractor's duty to ensure that the man authorised to sign off a falsework design has this experience and competence.

The man who signs must himself be satisfied that all those for whose work he is signing were also working within their abilities.

Acceptance of falsework drawings

We must now consider whether an additional check on the falsework design should be made by the Engineer or Architect.

It has been suggested to us that because of the different philosophy involved in permanent works design the Engineer is not really competent to assess the temporary works. He might indeed object to design assumptions or methods of construction which were quite reasonable for falsework although they would be unsuitable for permanent works. We do not accept this suggestion believing that there should be sufficient rapport between professional men to ensure that reasoned objections will either be accepted or countered in a reasonable way. There will doubtless always be a few cases where difficulties arise but this is not sufficient reason for rejecting the Engineer's involvement. Indeed if difficulties did occur they would indicate a lack of sympathy that was an indictment of a system which allowed permanent works to be designed without adequate consideration of how they were to be constructed.

The Engineer is in a special position to check falsework proposals. As designer of the permanent works he is well acquainted with the site and its special problems. He knows all details of the dead loads to be supported and the possible interactions between temporary and permanent works. There is also a great advantage in obliging the contractor to do what is already the practice in the best firms, namely, to sit down and prepare sound drawings and adequate calculations in the knowledge that these will be called for and looked at by the Engineer. Even where that system has been adopted we know of the very large number of faults which the Engineer has found in drawings submitted to him. We took special note in Canada and the United States of the comments by engineers who received drawings for critical appraisal. Such comments as "We have never yet seen a satisfactory drawing", or "We have learned never to trust anyone" although, no doubt, exaggerated, at least made the point of the need for an experienced engineer to check carefully the falsework proposals.

Furthermore an Engineer or Architect is employed as a professional to look after his client's interests. A client is not well served by a falsework collapse which will inevitably result in delay to the finished works. In the long run every collapse increases the total cost of construction works even if the individual client is indemnified.

We are therefore of the unanimous opinion that safety would be enhanced if the Engineer considered the falsework proposals carefully in their own right, and not merely as they directly affected the permanent works. It is clear from the institution of Civil Engineers contract that the Engineer has the right to call for the contractor's proposals. We recommend that this practice should be extended and that the Engineer should always require the presentation of all falsework drawings to him.

We would hope that the confidence developed from his previous discussions with the design team and his knowledge of their past experience would enable the Engineer to agree to the falsework proposals. Where he finds fault with them, he should refer them back to the designer with a clear indication of the area of disagreement and the reason for it. He may ask for further information or for a sight of the calculations.

He will not, however, offer a specific solution to the claimed fault since this would have the effect of blurring responsibility for the design and this responsibility must remain with the contractor.

For the same reason the Engineer does not "approve" the proposals. When an acceptable proposal has been found he will signify his acceptance in the form of a disclaimer notice such as, "If you proceed on these lines I shall raise no objection".

The term "Engineer" in the preceding paragraphs is used to refer to the primary design authority for the permanent works. He may delegate his duties, for example to the Resident Engineer on a particular site. But he must then provide a clear written statement of the terms of his delegated authority and whether these include powers to accept falsework proposals.

So far we have mentioned only the procedure under the ICE form of contract. We hope that these principles will be applied *mutatis mutandis* to all government contracts involving GC/ Wks/ 1 and 2 either by supplementary conditions to the existing contract or by subsequent re-drafting.

The same principles should be applied in building operations by requiring the contractor to provide the Architect with falsework drawings and requiring the Architect to refer them to a design engineer in his own organisation or to his consultant engineer: for it must be remembered that falsework failures on building

sites in the United Kingdom are several times more numerous than those on civil engineering contracts. The essentials of such a scheme are already practised in the United States, Canada, Germany and elsewhere.

It may be worthwhile pointing out here that of all European countries, the UK seems to be the only one where the construction of a building does not invariably involve a direct link between the client and the engineer.

The position under the standard form of contract for building under the Joint Contracts Tribunal (formerly known as the RIBA contract) is not satisfactory. The evidence received by the committee seems to indicate that architects would be content with a continuance of the present, conveniently simple, arrangement whereby no-one but the contractor is involved in any way in the design of falsework. However, we cannot be complacent about the large number of failures which occur on building sites. Some of these might have been prevented if there had been a professional check on falsework designs which later experience showed to be inadequate.

The necessary checking of falsework design on building projects cannot always be carried out by a member of the Architect's own organisation. Where the Architect has engaged the services of a consultant engineer to co-operate in the production of a design for permanent works then it would appear to be sensible for the Architect to receive the contractor's falsework proposals and to have these examined for him by the same consulting engineer. This arrangement may appear to be cumbersome but is forced upon us by the fact that the consulting engineer has no standing in the standard form of building contract and in many cases the Architect does not possess the requisite qualifications to undertake a falsework design check.

The only possible justification for the existing state of affairs is that in the past many architectural designs have presumed simple traditional methods of construction. This is not justified now that architects are designing structures which are so much larger and more complex. It may well be that future trends towards standardisation of the structural elements in a building will lead to a comparable standardisation of procedure for the design of falsework. It would be a fortunate concurrence if there were to be developed a range of structural standards for buildings and compatible falsework design standards; this would reduce the need for individual structural analyses after the intial matched systems had been proved to be successful from the design standpoint.

In the existing state of the building industry however, few of the smaller contractors have staff capable of undertaking a full design and the necessary calculations and drawings even using the resources of specialist equipment suppliers. They must therefore limit their work to the use of standard designs using standard equipment in accordance with the technical procedures which should be set out in the British Standard Code of Practice on Falsework and expressly designed for contractors in this situation.

Modifications

Even when acceptable falsework drawings have been produced, local circumstances may necessitate modifications. There may be a shortage of the particular material which a contractor planned to use; there may have been an unforeseen circumstance that made it necessary to transfer men and materials elsewhere; there may be an unexpected need to provide openings in the falsework for vehicular access or the passage of service lines. The effects of flooding or storms may necessitate re-appraisal of ground conditions. Such modifications often have to be made very quickly. It would be too onerous and, in most cases, unnecessary for each and every minor departure from the agreed drawings to be re-submitted for approval. But we have abundant examples of last minute alterations, made on the initiative of those on site, which have vitiated the concept on which the falsework was based. The vitally important thing is that the decision as to whether a change needs to be referred back to the designer is taken by someone competent to assess its significance. Modifications which introduce significant changes must also be referred back to the Engineer for his acceptance. It is considered that significant modifications should be made by issuing altered drawings and withdrawing the originals rather than by amendments of the originals on site.

The fact that a proper procedure for modifications exists does not exonerate a contractor from doing all he can to ensure that changes are not forced on the construction team by bad planning; for a contractor to argue that substitute material was used as he unexpectedly found that he was short of half a dozen props, or that slightly undersized timber joists had been delivered and that makeshift arrangements had been used to overcome the deficiency, is simply an admission of bad management. Satisfactory arrangements must be made in advance for storage, handling, transport and, if necessary, hiring of materials.

Inspection

The inspection of a falsework under construction should be a continuing process. The inspectors who form part of a contractor's team should have received copies of the detailed erection drawings and should have familiarised themselves with them at the earliest opportunity. The inspectors should observe the manner in which the falsework is constructed from its inception and, throughout its construction, up to the time it is loaded. They should adopt a standard procedure for correcting errors or omissions – for example by affixing a particular coloured tape to indicate a defect and another colour, or the same colour twice, for an omission such as a missing coupler or cross-bracing member.

Different contractors adopt different methods for indicating that the work has been attended to. Whereas the removal of warning tapes or chalk marks seems to have worked well on many projects, we have heard instances of the obliteration or unauthorised removal of the indicator without the appropriate rectification having been made. Some firms believe that the replacement of the warning tape by an "action taken" tape is required. It is essential that the system adopted should be understood by everyone concerned. In view of the mobility of the work force there is considerable advantage in a standardised system and we commend this to the Falsework Committee of the British Standards Institution.

We suggest that the use of numbered and lettered grids on the falsework drawings would make it easier to record the position of faults and to check that action has been taken, and indeed, it would facilitate accurate setting out in the first place.

It is important that faults should be discovered and rectified as soon as possible. Often apparently minor but important features are overlooked, for example failure to mount a base plate centrally on a load spreading sleeper, or failure to extend a diagonal bracing tube to meet a longitudinal ledger as required by the design, or incorrect use of couplers. Inadequate tightness of components, forgetting to fix headplates to wooden bearers by spikes or nails, excessive cantilevering of beams beyond their end supports, and the over-extension of fork-head screws, are all features which need correcting *before* the erection has advanced to a stage where remedial work becomes difficult.

A proper inspection of load-spreading bearers, such as sleepers, is important to detect subsidence, indentation, over-turning and possible splitting. Inspections should be made frequently and not only just prior to loading. Proper setting out is vital, especially on sloping ground where creep may occur. The inspection of foundations should be continued during and, indeed, after a concrete pouring operation and precautions should be taken to ensure that curing water applied to the concrete is diverted in purpose-made channels away from the area of the bearers.

On completion of the construction an inspection of the falsework must be made to ensure that all faults have been corrected. In the case of inspection on behalf of sub-contractors, a handing-over certificate should be given to the main contractor. Such a certificate may follow the scheme outlined in Appendix 3 of the Report published by the Department of Employment on "Safety of Scaffolding".

Near the sea, on-shore winds may cause brine to be deposited on steel members and protection against saline corrosion is needed: members should be inspected at frequent intervals if the falsework remains standing for any length of time. Diurnal variations in temperature produce successive tightening and expansion of members and joints: regular inspection is needed to ensure that stressed members such as threaded bolts have not sheared or become loosened in this process.

Loading of falsework

The response of the falsework when it is first loaded is an indication of its soundness. Lookouts should therefore be stationed at vantage points to observe any undue deflection or the escape of concrete through the soffit or the side formwork. Skill and judgment is needed to make sure that the placing of concrete or pre-cast beams does not impose high impact loads on the supporting members and that loads are distributed evenly over areas where this is critical.

Where concrete is to deposited from skips, crane drivers should either be in a position where they have a full view of the landing area or should be aided by a properly trained banksman. The driver should be made aware of the importance of avoiding impact and shock due to the dropping of the skip load. In the United States the representatives of the Iron Workers' Trade Union propose that one of their men is present as a banksman during all pouring operations.

Tell-tale devices or strain gauges are of value. The observers must check that snap ties do not yield and that the ends of timber bearers do not crush.

It is recommended that a diagram shewing the loading sequence should be produced by the falsework designer and supplied with the falsework drawings to the contractor for transmission to those in charge of loading operations. It is necessary to specify the sequence for loading of pre-cast beams as well as for concrete cast *in situ*. If the pre-cast beams are of different sizes they should be clearly marked to correspond with similar markings on the loading diagram. If concrete is to be cast for longitudinal beams or cross members in which the location of reinforcing bars or wire mattresses is critical, the loading diagram should indicate the order of in-fill so that no displacement occurs.

One school of thought recommends pouring concrete at the centre of a bridge first so that the maximum deflections occur early and thereafter pouring outwards to the two abutments of the bridge. This is thought to produce less movement of the falsework under the setting concrete. Other experts prefer to start pouring close to the abutments. In some countries, e.g. Canada, the United States and Germany this procedure is recommended in conjunction with the use of a plasticiser to retard setting. But in every case the procedure must be agreed by the falsework designer and specified in the loading diagrams. An agreed plan of action should be worked out for all operatives, and those operating spreaders, vibrators etc. should be made fully aware of the proper sequence of their particular operation.

A final check must always be made within 24 hours of loading falsework.

General site procedures

We have already discussed the need for the falsework designer to specify his assumptions about how the falsework is to be loaded having liaised with the designer of the permanent works in this respect.

Any major change in the planned sequence of loading, due for example to materials arriving on site either late or early, must be referred back to the designer and the engineer.

It is important that no-one should be allowed underneath or adjacent to falsework which is being loaded unless he has a specific duty to perform, such as monitoring leaks. Indeed the whole construction site should be planned to ensure that no-one is exposed to unnecessary risk at any time. This moral is pointed by the collapse of the Westgate Bridge over the River Yarra in Australia which killed a number of persons who had no need to be beneath it.

Temporary Works Co-ordinator

The procedures that we have outlined require that at each stage of the design and construction of falsework a check or inspection should be made by a competent person. A senior designer must countersign the plans: an inspector must sign off the construction. Many independent organisations are involved and the correction of faults often requires co-operation between more than one of them. We therefore believe that it is essential that one individual in the construction organisation be given the duty of ensuring that all the procedures and checks have been carried out. In our Interim Report we described this person as the Temporary Works Co-ordinator, or TWC.

Following publication of the Interim Report we received many encouraging comments on our proposal. Several organisations have told us that they have appointed Temporary Works Co-ordinators. In what follows we discuss the role in more detail.

It would be impossible to find a person who was so expert in every specialist field involved that he could himself check the work of all the individual specialists. Nor should it be necessary to check the checkers. The duty of the TWC is simply to satisfy himself that the appropriate checking has indeed been done.

The TWC must also ensure that where faults have been revealed they have been corrected to the satisfaction of the checker: and that where there are differences from the construction, loading and striking procedures specified in the design, they have been sanctioned by the appropriate authority.

In order to give the TWC sufficient authority to be able to control the falsework we recommend that no loading should take place until he has signed an official permit to load. This permit would last for 24 hours after which it would need re-authorisation. A copy would be lodged with the site agent and another with the resident engineer.

Similarly the TWC should be required to sign the permit to strike the various units of the falsework. This he will do after other interests have been satisfied, e.g. the Engineer or Architect will have laid down certain requirements such as the minimum time for curing the concrete, and may have indicated that he wants to inspect the permanent works before the falsework is struck.

Among his duties the TWC must pay particular attention to the following questions:

Is the design brief adequate and does it accord with actual conditions on site?

Has each element of the design been checked by a competent person and has the falsework been considered as an integrated whole and approved by a competent person?
Has the design been passed to the Engineer and his comments acted on?
Are the actual loads encountered on site, particularly the live loads, no greater than those assumed by the designers?
Is there a realistic programme for the delivery of materials to site?
Have there been any changes in materials or construction? Are these significant? If so, have they been referred to the designer and his approval obtained?
Has each element of the falsework and the whole assembly been inspected and the faults rectified or alterations to design approved?
Does the loading programme agreed on site accord with the designer's assumptions and intentions?

It will we hope be realised that the TWC is not a mere collector of dockets which signify that work has been done. He has to judge when an alteration is sufficiently important to refer back to the designer. He must spend time making sure that everyone has the information they need and that activities in one area do not compromise those in others. He must facilitate co-operation between everyone concerned. Co-operative effort is best encouraged by informal means and the formal documentation is a weapon of last resort.

We must therefore emphasise the importance of the role of the TWC and the authority and status he must have in the contractor's organisation, which bears full responsibility for the falsework.

On all major falseworks we would insist that the TWC should be a Chartered Engineer with experience of falsework. On smaller jobs he need not have this professional qualification but must have experience of falsework. When proper training courses have been instituted as we propose in Part 6 he will be expected to have attended one.

A major construction work will require the undivided attention of a TWC. On small sites the site agent himself may act as TWC. In other cases one individual may cover several sites. A contractor may perhaps find it useful to have a central TWC group at headquarters to whom those on sites are functionally responsible. A contractor who lacks the resources himself may even employ a TWC from outside. We would not be dogmatic about the arrangements which should be adopted by particular organisations to suit local convenience. What we do insist is that for each site the contractor nominates a competent individual who is responsible for co-ordinating temporary works there, and that everyone on site knows who this person is.

We do not advocate the appointment of a deputy TWC. This could lead to checks being omitted because of misunderstandings between the TWC and his deputy and to a general confusion of authority. Nor should the TWC be allowed to delegate any of his duties. In cases of sickness, holiday or similar absence the full authority of the TWC should be transferred to another nominee who would temporarily take over the complete role.

We suggest that temporary works such as access bridges which are not falseworks in the strict sense could with advantage be included within the responsibilities of the TWC.

Although dams, reservoirs and tunnels are outside our terms of reference, we see no reason why the role of TWC should not be equally applicable to such works.

The name, address and telephone number of the TWC should be posted in the site agent's office or other conspicuous position. Everyone on site should know that the TWC must be kept informed on all matters concerning falsework and must know where he can be contacted.

One would expect that the TWC would spend most of his time on the site or sites to which he was attached; in any case he must be readily available. His presence is particularly needed when the falsework is loaded or when striking commences. He should also be present when the designers visit the site and should be in close touch with the Resident Engineer.

The role of the TWC does not conflict with that of the site safety officer. The latter has responsibilities which cover all activities and not just falsework. The safety officer should however provide a valuable service to the TWC in advising him of statutory requirements and other practical points concerning the general safety and health of persons at work. The safety officer should vet plans and proposals in advance to assess and advise on safety implications. Normally the safety officer will not possess qualifications which enable him to pronounce on structural engineering matters: but he will, of course, be free to comment on features which appear to him to be unsafe from his understanding of codes of practice, his knowledge of regulations and his general experience. The TWC will obviously take note of his comments and will help to get faults put right.

Summary

The term falsework covers a very wide range of load-bearing temporary structures which vary not only in complexity but also in the size and nature of the understanding and in the consequences of an untoward occurrence.

Our evidence suggests that all falseworks can be hazardous, and in none is the risk of injury or death so small that correct procedures can be disregarded. It would however, be unrealistic to expect that the full range of procedures and checks described above should be applied in every situation.

In major civil engineering projects (which include high bridges, wide-span bridges, viaducts and similar structures where the cost of collapse is great and where the risk to individuals working on the site and to members of the public may also be high) we recommend the application of the full system of procedures and checks. We advocate a Temporary Works Co-ordinator who must be a chartered engineer qualified in civil or structural engineering. Where a project of this nature involves untried methods or new materials or is of a size outside previous experience, the check on falsework design should, by mutual agreement between engineer and contractor, be undertaken by a qualified engineer who is not directly involved with that particular project. We do not necessarily rule out the possibility that the 'independent' design check may be done by someone within the contractor's organisation because the ultimate responsibility for a design failure must rest with the contractor.

For larger building units (which include power stations and multiple column and slab buildings such as offices, and hotels) the procedures may be slightly relaxed. For example, the repetitive nature of the column and slab reinforced concrete structure makes it unnecessary to recalculate the loading and the falsework design at each level; a preliminary calculation for each sequence of similar structure with a separate calculation for variations and departures from the standard is considered adequate. The overall design must however still be checked by a competent engineer in the contractor's organisation and must be submitted to the architect who will solicit the opinion of an engineering consultant in cases where neither the Architect not a member of the Architect's own organisation is qualified in structural engineering. This is particularly important when the design involves a novel concept or goes beyond existing experience in the use of materials; or when the structure is larger than has been built before.

The procedures may be simplified for certain routine and standardised applications in the building industry provided that they had been fully applied to the first design. If a discrete range of standard building dimensions could be adopted, only the initial work of designing and calculating adequate falsework for each of the standard categories would be required. Thereafter, provided there was no significant variation, the standard drawings, the standard detailing and the standard checking would be built in and would need no further checks. This would save manpower and other resources so that there would be an incentive in terms of cost for the client to purchase one of the standard designed buildings.

In the smallest operations involving falsework, such as the repair and maintenance of buildings, most of the work is undertaken by the 'good practical man'. Undoubtedly much sound work is done safely by the skilled craftsman working to the rules which he has been taught as part of his trade. However, we consider that even in these instances, it is essential for a drawing of the work to be made. This may only amount to a freehand sketch with an estimate of applied loads and the known or warranted strengths of the support equipment used. Preparing such a sketch can indicate to the skilled operative that a margin of safety, which he had thought adequate, does not in fact exist. It is appreciated that, for this class of work, the operatives may work in units of two or three persons and training, instruction and effective supervision are all very important.

Responsibility and liability

In advocating that the falsework proposals should be checked by the designers of the permanent works – or by the structural consultants if the design responsibility was vested in an architect – we were concerned only with reducing the risk of collapse.

Many witnesses have impressed on us that although such a procedure is desirable from the point of view of safety, and is indeed practised in many areas, it does tend to blur the lines of responsibility as between contractor and engineer. Indeed it is quite impossible for anyone to check anything without being blamed if an error, which he might have found, is subsequently manifested. In consequence a few engineers, and apparently nearly all architects, take pains to dissociate themselves from considering falsework proposals in order to ensure that they can incur no liability for damages if a failure occurs.

The difficulty of split responsibility arises because in British practice the client usually makes two separate contracts – one with the Engineer or Architect, as design authority for the permanent works, and the other with the contractor for their construction.

Responsibilities would be clear if the same organisation took full responsibility for all design and construction. Some organisations do undertake such 'package deals', but we must accept that the majority of projects in Britain are not likely to be commissioned in this way.

Nor would there be quite such a problem if the designer of the permanent works also specified exactly how they were to be built and himself designed the falsework. But this would inevitably be uneconomical if only for the reason that the designer of permanent works has no information on the resources of men, materials and skill available to contractors. We must therefore accept the situation where the contractor takes full responsibility for the methods of construction.

Nor would the problem of responsibility exist if it were accepted that the contractor and no one else should be involved in the construction. Following this line the spokesman who gave the evidence to us for the Royal Institute of British Architects disclaimed all interest, knowledge and involvement in the temporary works. It was stated that such designs were entirely the concern of the contractor and the professional involvement of architects did not extend to temporary works of any kind. It was suggested that safety could be catered for by government enforcement agencies, through the statutes controlling the conditions under which a contractor arranged his work. We believe that this argument is not justifiable in principle or in practice and that the Architect has a professional duty to ensure that falsework proposals have been properly checked.

After considerable discussion, to which particularly valuable contributions were made by the Institution of Civil Engineers, the Association of Consulting Engineers and the representatives of contractors, we recommend that construction contracts can and should be worded to cover the following points:

Details of the construction programme and the falsework design must be furnished to the Engineer or Architect. (The sole exception allowed is in cases where the design is so traditional that there can be no possibility of novel techniques or unique designs being used).

The Engineer or Architect should be free to call for details of calculations, etc. if dissatisfied with any part of the falsework proposals.

The Engineer must examine the proposals and signify his acceptance in a form of words which does not imply approval in a legal sense. For example "I have examined these proposals using reasonable professional care and consider that their adoption will not jeopardise the successful completion of the permanent works".

A similar declaration must be required from the Architect, who must consult his own engineering advisers if he is not himself competent in falsework practice.

The contractor is responsible to the client for all losses and delays occasioned by falsework failure.

In accepting the proposals for falsework under these arrangements, the Engineer (or Architect) would incur no liability to the client or the contractor if it is subsequently found to be faulty, provided he had exercised reasonable professional care. On the other hand he might suffer some loss of professional reputation.

The arrangements we recommend do not appear to clash with the Conditions of Contract for use in connection with works of civil engineering construction commonly known as the "ICE Conditions of Contract". Under subsection 1 of clause 14 "within 21 days after the acceptance of his tender, the contractor shall submit to the Engineer for his approval, a programme showing the order of procedure in which he proposes to carry out the works and thereafter shall furnish such further details and information as the Engineer may reasonably require in regard thereto. The contractor shall at the same time also provide in writing for the information of the Engineer a general description of the arrangement and methods of construction which the contractor proposes to adopt for the carrying out of the Works". It is further noted that "Works" refers to Permanent Works together with the Temporary Works. Such a clause appears to us to be well-founded in that the engineer is already required to give approval for certain proposals and his expertise is thereby brought to bear upon the project. We would however suggest that there may be occasions when the time limit of 21 days could lead to unnecessary haste over the falsework proposals.

Under Clause 14 (3) "if requested by the Engineer the contractor shall submit at such times and in such detail as the Engineer may reasonably require such

information pertaining to the methods of construction (including Temporary Works etc) which the contractor proposes to adopt or use and such calculations of stresses, strains and deflections that will arise in the Permanent Works or any parts thereof during construction from the use of such methods as will enable the Engineer to decide whether, if these methods are adhered to, the Works can be executed in accordance with the Drawings and Specifications and without detriment to the Permanent Works when completed". This clause should allow for the engineer to examine the proposals in the detail we believe to be necessary.

We are aware that, under some other forms of contract, such as the British Railways Board Conditions of Contract for civil engineering work and for certain temporary works which affect the safety of the line the Engineer exercises his powers to ensure that the contractor always submits proposals for approval.

We have studied the revision of the general conditions of government contracts for building and civil engineering works, generally known as GC/Wks/1. We welcome the references to parties such as the quantity surveyor, resident engineer and clerk of works which were not included in the early document GC/Wks/1. We hope that such clauses will be included in other forms of government contract.

The standard form of building contract produced under the auspices of the Joint Contracts Tribunal, popularly known as the RIBA form of contract, makes no reference to structural or other engineering consultants, and none to temporary works. The structural designer of the permanent works appears to have no contractual responsibility to the client for any aspect of the project whatever, either permanent of temporary. All responsibility for temporary works is on the main contractor. In reality the structural designer of the new project is much involved in the whole process of design and building process and it is not possible to exclude him from the interlocking chain of responsibilities and communication.

We therefore propose that wherever an Architect will need the services of a consulting engineer the client's contracts with the architect and contractor should include clauses on the lines already discussed which insist that details of falsework proposals must be made available and accepted. The subsidiary contract between the Architect and his consultants would then include clauses to allow the consultants to consider and comment on the falsework proposals.

We would not advise the client to enter into separate contracts with both Architects and Engineers on the same project as this can lead to confusion over primary responsibility for design. But if he does do so, then the falsework clauses must always be included in the contract with the engineer.

Where a design is submitted by a contractor to a consultant engineer for independent assessment a separate contract is required between them. This does not alter the contracts between the other parties and the contractor is still responsible to the client for the construction. The consultant must however take responsibility for the advice he gives and could be liable to the contractor if it could be proved that he did not exercise reasonable professional competence.

In all the foregoing discussion we have referred to the Engineer or Architect, meaning the primary design authority. These persons must obviously be given powers to delegate portions of their work. It is particularly important that where the main contract is with the architect he should have power to authorise the engineer or his representative to have access both to the contractor's organisation and to the site itself in order to discharge his duty to check the adequacy of the falsework design.

Third party liability

As a completely separate issue all those mentioned have a responsibility to third parties such as people at work or the general public. Anyone suffering loss or injury as a result of a falsework failure may sue contractors, sub-contractors, engineers, architects or even clients irrespective of the contractual arrangements between them. There may also be prosecutions for dangerous practice under the new Health and Safety Acts, 1974.

We are convinced that it is neither possible nor desirable that professional people should seek to escape their responsibilities in this matter. The professional man has a duty of care to exercise his skills to improve safety and must do so responsibly. Like the Chief Investigator of the Vancouver Narrows collapse, we would argue that an engineer who did not examine falsework proposals was culpable – perhaps more culpable than one who failed to find a mistake in the proposals submitted to him.

There is considerable evidence that these views are widely held and that the professional man is no longer regarded as an arbitrator whose professional skill cannot be called in question. In the case of Sutcliffe v Thakrah and Others (*The Times*, 22 February, 1974) an architect was successfully sued for negligence when he had issued certificates covering building work

which was later to be found to be defective. Similarly in the case of Dutton v Bognor Regis Urban District Council, a council surveyor was successfully sued for negligence when foundations, which he had approved for a bungalow, settled several years later. The case of Greaves & Co (Contractors) Ltd, v Baynham, Meikle and Partners (QBD All England, 12 November 1974) showed that consulting structural engineers could be held liable for a failure to take account in their design of the effect of vibration caused by fork lift trucks.

We believe that professional men must accept that they will be held responsible for exercising proper professional skills in protecting people at work and the public. They may be sued and can be liable for compensation if it can be proved that they were negligent.

In apportioning blame, however, it must be remembered that it is usually easier not to commit an error than to discover it once it has been made. Even if an engineer has checked and accepted proposals for falsework the primary responsibility remains with the contractor. The contractor must never condone carelessness in his organisation on the grounds that if errors are made the Engineer is sure to find them.

Summarising then, we believe that safety is paramount. Because of their particular knowledge and expertise, engineers and architects have a duty to examine falsework proposals with professional care. If they do not do so they cannot escape liability.

The possibility of litigation, however, inevitably raises the question of insurance which is discussed in the next section.

Insurance

We must emphasize that we are concerned only with the question of whether the arrangements for insurance in the UK have any effect on falsework safety. Are there any changes which could improve safety?

We consider this question under the three headings of professional indemnity, principal's insurance and insurance company's assessments.

We have received evidence that some professional men were deterred from giving advice on matters affecting safety lest they should implicate themselves in any way in a collapse and become liable for damages. Although insurance against claims is possible, the premiums are high. The insurer may make conditions which restrain the insured from giving any advice for which he is not contractually liable even though his professional duty of care would prompt otherwise. Alternatively the professional may deliberately not insure (or conceal the fact of his insurance) to give the impression that he is a "man of straw" who is not worth suing.

The basic problem is that with large interdependent structures a single error by one man can cause a huge loss. The liability for damage can then be out of all proportion to the fee paid for professional advice. At the same time the number of actions for damages against professional men has been growing.

Most professionals are already conscientious in their work, for the sake of their reputations and future employment if for no other reason. The 'over-kill' effect of devastating damages does not make them more careful than they already are but could easily act as a deterrent to future recruits to the profession.

We realise that the whole question of compensation and liability for personal injury is being considered by the Royal Commission set up under the Chairmanship of Lord Pearson. We therefore confine ourselves to the comment that safety is not improved in a situation where those most able to give help are deterred from doing so by the risk of incurring penalties far greater than their earnings.

We have considered whether a possible answer to the problem of personal liability would be job insurance. In this system the work of all parties is covered by a single policy insuring against all third party risks. We were told that this system is disliked for two reasons. A single insurer finds it difficult to assess the overall risk when so many different sub-contractors and other parties are involved. By the same token a contractor who has been associated with an unreliable sub-contractor on one job finds it difficult to get an economical premium on the next even though he has changed his sub-contractor.

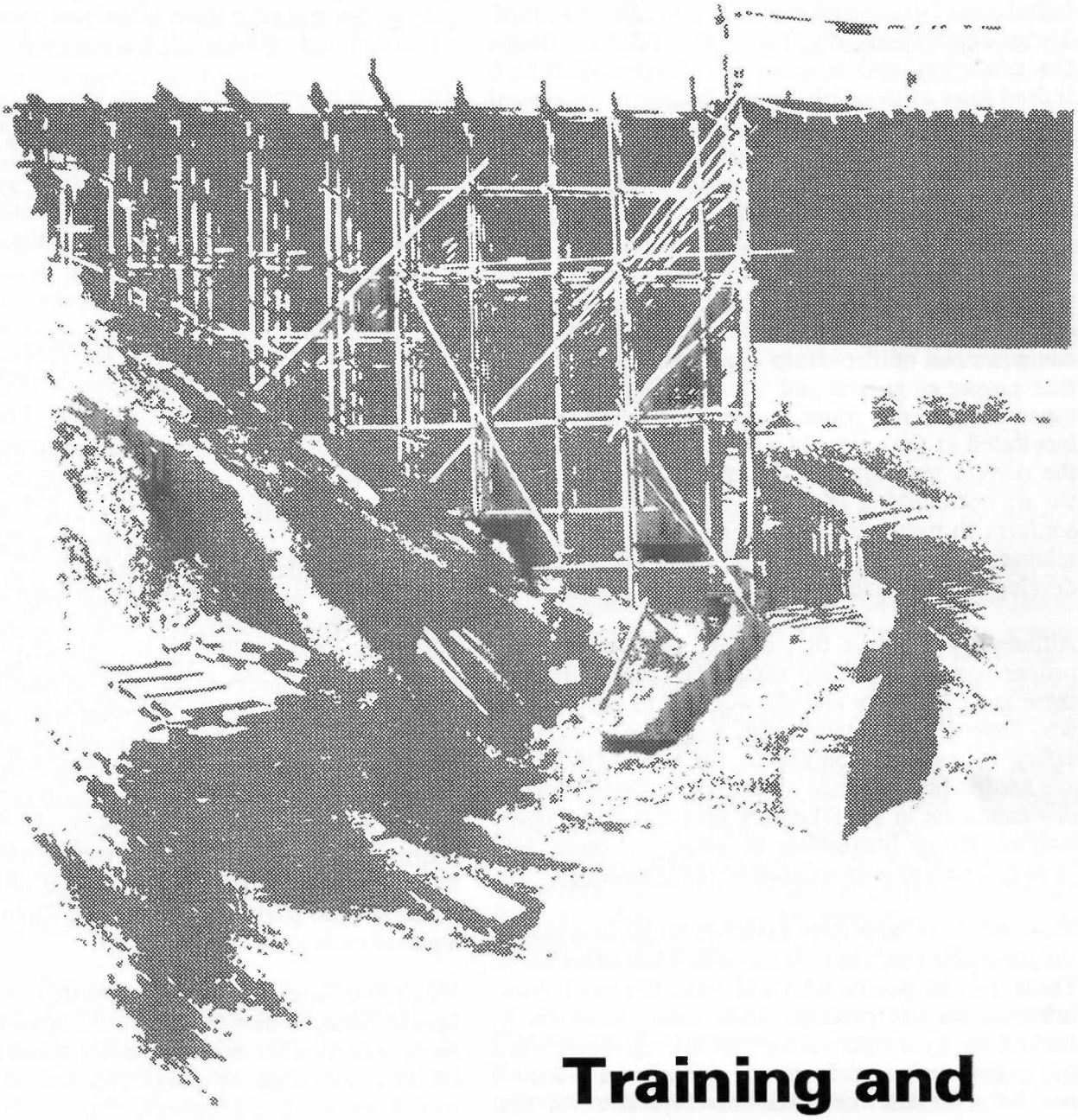
This raises the point that individual insurers do try to match their premiums to their experience with particular contractors. This is a form of 'no claim bonus'. In the same way an insurer would ask a large premium from a contractor who was undertaking a project outside his previous experience. These direct effects on contractor's costs are powerful incentives to safer practice. We believe that such working of the market forces should be encouraged.

Similarly most insurance companies exclude from their material damage policy any claims involving faults in design, materials or construction. This arrangement, too, appears to operate favourably as an inducement to a contractor to organise his operation so that such faults are avoided.

Finally there is the point that the insurers themselves, through the enquiries that they make to establish risks, can contribute directly to safer practices. Such activity in Britain is small. In France, however, some at least of the insurers engage independent experts to perform checks and surveys on their behalf. For example the independent organisations such as SOCOTEC and the Bureau Veritas can be engaged by insurers to check a contractor's designs and also to monitor construction. Presumably on the basis of these reports the insurers either secure an improvement in performance by the contractors or penalise the defaulting contractor by the imposition of punitive additions to his premiums. We have earlier given details of the German system which has similar features.

We were not able to assess the direct effects of this system but we would expect them to be beneficial. As the size of individual projects increases and costs rise British insurance companies may well be drawn towards a similar system.

6



Training and manpower

6 Training and Manpower

In preceding chapters we discussed technical faults and advised how they might be avoided. Similarly we discussed procedures for checking and inspecting so that those faults which do occur can be discovered and corrected. In nearly every case of failure which we considered, collapse could have been avoided if existing information had been used and if established techniques of design and construction had been applied. These observations highlight the need to improve the education and training of everyone involved. Indeed most of those who gave evidence to us stressed that the biggest single factor in increasing safety on construction sites would be better training arrangements. None considered that they were already adequate – indeed it is fair to say that training in falsework as a specialisation is virtually non-existent.

Faults can occur either through ignorance of the correct procedures or through failure to realise the consequences of departure from them. We believe that proper education and training must cover both aspects. That is, a proper respect for safety must be inculcated at the same time as instruction is given in the correct techniques and practice. In this context we are not thinking of safety in terms of the need to conform to particular regulations, but of safety consciousness as a basic habit of mind that must be developed simultaneously with technical proficiency.

Although we believe that correct techniques and a proper respect for safety should be taught together, there must be many already working in the industry who have not been taught this way. Special 'applied safety' courses may be needed for them. Thus there are needed both a range of integrated studies for the new candidate in the falsework field and 'topping-up' courses giving instruction in safety to those who already have some experience of the technology.

Most of those who gave evidence to us emphasised the particular need for training of first line supervisors. These are the people who will have the most direct influence on site practice. They must, however, be backed up by a safety-conscious management and a competent design staff who all appreciate the special problems of falsework. We therefore contend that training courses are needed at all levels.

Such courses can only be satisfactorily mounted at centres having adequate space, facilities, equipment and personnel.

We have already referred to the special characteristics of falsework – for example the need for assembly from available materials, the need to support the full design load immediately after construction and the need for dismantling. The design of falsework requires skill and experience additional to those normally possessed by civil or structural engineers. Similarly the safe construction of falsework requires an appreciation by those on site of the special hazards involved. In what follows we consider these additional elements in the education and training of all concerned.

The value of experience in acquiring a competency in falsework practice must not be forgotten. Although we specify in some detail the nature of the training courses which we consider essential, we must also make clear that the effectiveness of training depends on its integration with experience on site.

Professional training

Since the first requirement for falsework is a correct design, we begin by considering the need for professional training.

The education and training of Civil Engineers has recently been reported on by a Committee under Dr Chilver. In a communication to our Chairman, Dr Chilver wrote "It is probable that in the long term the greatest effect on safety and safe working will be achieved by making professional engineers (which must include employers and senior supervisors) more safety conscious. This may be achieved by reference to safety considerations in each subject included in the first degree courses. Together with practical experience in later training this would go a long way to making supervisors safety conscious and eliminate the consequences of a lack of co-ordination between design and subsequent construction". We warmly endorse these sentiments and believe that considerations of safety and the possible effect of failure must be an integral part of all degree and diploma courses, and not merely an optional extra.

Dr Chilver made the further point that the Institution should accept that an essential qualification for corporate membership should be proven awareness of the importance of safety and safe working. We would endorse this comment, too.

We also believe that a reference to falsework should be included in all courses on civil engineering design. In mechanical engineering the available manufacturing processes are a major constraint on design: no-one would dream of teaching design without referring to the methods by which the objects designed could be produced. In civil engineering education too,

reference to falsework problems would help to inculcate in future designers of permanent works a sympathy for falsework which might well lead to their designing permanent works which were easier to construct. In fact we suggest that the student asked to prepare a design for any permanent structure should at the same time be asked to produce his concept for the associated temporary works.

Incidentally we were pleased to learn that falsework designs are accepted by the professional institutions on a par with designs for permanent works as evidence of professional competence. However we would go further and recommend that submissions based on permanent works must be accompanied by a brief for the corresponding falsework and an outline scheme of how it might be effected.

Several people have asked us to report particulars of failures we have studied, and a selection is given in the Appendix. We believe that much more use could be made of case histories in educating engineers. Although government departments will occasionally issue reports on particular failures (e.g, Loddon Viaduct) it is the professional people closely involved who have most of the information. Difficulties will obviously arise when claims are *sub judice* and not all information may be freely available. However, any investigation brings to light faults which might have caused collapse in other circumstances even if they had no effect in the case considered: descriptions of these faults are just as valuable for educational purposes as description of the actual causes of failure. We therefore recommend that the professional institutions – perhaps through the newly formed Safety Committee – commission the publication of failure reports that could be used as case histories for study.

By the same token we recommend that information derived from general investigations undertaken after a failure – for example the tests at the Transport and Road Research Laboratory after Loddon – should always be made freely available.

Reference was also made during our discussion to the increasing use of computers which result in the design of permanent works becoming more and more sophisticated. Service conditions may be modelled accurately and very complicated theories may be employed. In contrast, falsework design is essentially *ad hoc* and working conditions cannot normally be stated precisely enough to justify complicated theoretical treatment. There is, therefore, a real danger that the particular type of engineering expertise required for practical falsework design in the field will disappear from normal curricula. Our proposals that all civil engineering courses should include reference to falsework problems must be interpreted with this practical point in mind.

One particular deficiency which has been highlighted by our study of falsework failure is a blindness of designers to what might be called three-dimensional effects. It is easy to forget that deflections in one direction may produce stress in others perpendicular to it. This is particularly important in structures which are not symmetrical e.g, bridges with skew spans where deflections and compensating reactions can be produced in both the directions at right angles to the load. It is often forgotten that beams tend to twist under load in practice, even though ideal beams do not do so in normal two-dimentional theory. Nearly all practical loads are applied eccentrically which enhances such effects. We have discussed the question of proper allowance for lateral loads in the earlier paragraphs on horizontal instability. What needs emphasis here is the need for engineers to be trained to think in three dimensions. They must never forget of the effect of eccentricity of loading and the possibility of deflection out of the plane of the paper.

We referred in the section on 'Responsibility' (page 73) to the lack of understanding between architects and engineers. It was argued that the advance in building technology has been such that no architect can afford to be ignorant of the fundamentals of structural engineering and materials science. The shape and layout of many modern buildings are determined to a large extent by the structural requirements and by the need to provide engineering services. So it is no longer possible, except in the simplest and most traditional projects, for the architect to act as sole creator with the engineer merely filling in structural details. Engineering and architecture must contribute as equal partners to a project and further education courses in both subjects must recognise this. In the context of temporary works this would mean that courses on falsework design should properly form part of the training of architects.

Professional short courses

We have heard of a number of short courses which include reference to falsework, for example those given at Fulmer Grange by the Cement and Concrete Association, but none specifically aimed at falsework designers. Perhaps one of the problems is that the number of experienced people available to teach is so small. Certain organisations run their own courses at which their experiences are shared. We have heard, for example, of one-day 'teach-ins' organised by British Rail for its staff.

These are certainly valuable, but there is a need for short professional courses devoted to those subjects which are of special importance in falsework. These would complement the basic engineering training and should be attended not only by those involved in falsework design but also those involved in designing permanent works. The latter group would thus gain additional understanding of the falsework problems which their own designs of permanent works may help to create.

We discussed a possible syllabus for a course suitable for senior engineers, site agents and temporary works co-ordinators with the tutors at the Bircham Newton Centre. Such a course might last three days. Details are given in the Appendix.

We would also encourage the holding of symposia and group meetings at which qualified professional engineers could discuss their problems and experience. Such meetings should not be used merely to discuss the technical features of designs but should relate these to safety of construction and use.

They could well be organised under the auspices of the professional associations and indeed there have been a number of symposia in the London area dealing with falsework problems. We suggest that architects, who may well not have the necessary training in structural considerations, could benefit from attendance and could enhance the value that others get from a short course by providing an extra element in a mixed group of professionally qualified people. It would be necessary in order to obtain the right audience to make clear in any publicity material the true intention of this type of inter-disciplinary discussion group.

Courses for senior managers

Courses in management training for the construction industry are sponsored by the National Federation of Building Trades Employers and organised by the Building Advisory Service of 18 Mansfield Street, London W1M 9FG. The Brooklands Technical College of Weybridge, Surrey also runs residential training courses in construction safety at the Brooklands School of Management. Neither of these series of courses appears from the latest prospectus available to us to include consideration of falsework safety.

Many courses are organised by the London Construction Safety Group and conducted at the Government Training Centre, Bilton Way, Enfield, Middlesex: arrangements can be made for safety courses designed to meet the requirements of particular employers or trades to be made available there.

Courses leading to recognised qualifications for managers in the construction industry are offered at technical colleges, colleges of building technology, and other institutions. Other courses are run by specialist establishments such as the Cement and Concrete Association and by the Construction Industry Training Board. It is important that considerations of safety should be an integral part of all such courses. The Department of Education and Science should consider what steps could be taken to promote this in the institutions under its control.

Courses for first-line supervision

Hitherto there has not been in the United Kingdom any established falsework course with built-in safety training, which catered for the needs of first line supervision. We consider that this is the most important of all the training courses that need to be started. The proposed syllabus for a course lasting ten working days has been discussed with tutors at the Bircham Newton Centre. Details are given in Appendix 5.

It is also important to provide 'topping-up' courses for existing first line supervision. The syllabus just described for new entrants could be adapted, placing less emphasis on the practical aspects with which the supervisor will already be familiar and more emphasis on safety. It would emphasize the attitude of mind and the site discipline which are essential at all levels if falsework failures and other accidents are to be avoided. This course could be limited to five days.

Courses for safety officers

It is assumed that candidates for a special falsework course will have already had practical experience as a safety officer in the construction industry and will have attended a general safety officers' course, although this would not have involved detailed consideration of the problems of falsework. Thus if a safety officer is appointed to a site where there are temporary works, and he has to co-operate with the Temporary Works Co-ordinator, he should receive a short course purely in the safety aspects of falsework. We suggest that this course should be of three days' duration and should be at a centre with facilities for practical work and demonstration such as those seen by the Committee at the Bircham Newton training establishment. A possible syllabus is given in Appendix 5.

Safety regulations

To many in the construction industry the expression 'training in safety' suggests the learning of rules and

regulations, perhaps illustrated with practical examples. This concept has been fostered by the wording of the statute dealing with safety supervision. This statute applies to every contractor and employer of more than twenty men in civil engineering and building construction work. Under the Construction (General Provisions) Regulations 1961, regulation 5, which deals with the appointment of a safety supervisor, defines his duties as:

> "(a) advising the contractor, and every employer as to the observance of the requirements for the safety or protection of persons employed by, or under, the Factories Acts 1937 to 1959, or the Lead Paint (Protection against Poisoning) Act 1926, and as to other safety matters; and
>
> (b) exercising a general supervision of the observance of the aforesaid requirements and of promoting the safe conduct of the work generally".

The emphasis is clearly laid upon compliance with the requirements of the relevant statutes. These include four detailed and substantial Codes of Regulations, made under the Factories Acts and continued in force under the Health and Safety at Work etc Act 1974, as well as regulations of more general application. We accept that such an emphasis contributes to overall site safety and believe that there are many site safety supervisors who do a first-class job within the terms of their appointments. There are several excellent training courses for safety supervisors, although others are of lower standard. Our only comments are that such courses are insufficiently patronised and that the industry could benefit if the intake included some of those who were technically qualified and some who were in positions of authority.

Safety training should not, however, be confined to regulations. We agree with the Committee on Safety and Health at Work under the chairmanship of Lord Robens when it reported thus:

> "People are heavily conditioned to think of safety and health at work as, in the first and most important instance, a matter of detailed rules imposed by external agencies. We have encountered this instinctive reaction many times during the course of our Inquiry. It was reflected, for example, in the attitude of those who argued that standards would be improved if work-places were visited much more frequently by inspectors. Given the hundreds of thousands of work-places in the country, this approach is manifestly impracticable. The matter goes deeper.
>
> We suggested at the outset that apathy is the greatest single contributing factor to accidents at work. This attitude will not be cured so long as people are encouraged to think that safety and health at work can be ensured by an ever-expanding body of legal regulations enforced by an ever-increasing army of inspectors. *The primary responsibility for doing something about the present levels of occupational accidents and disease lies with those who create the risks and those who work with them.* The point is quite crucial. Our present system encourages rather too much reliance on state regulations, and rather too little on personal responsibility and voluntary, self-generating effort".

The Robens Committee concluded that there was a role for regulatory law and a role for government action but that these roles should be predominantly concerned with influencing the attitude of those in industry so that a better safety and health organisation was created. Our own terms of reference are confined to one sector of one industry but the conclusions still apply.

Courses for skilled operatives

Any criticism of existing attempts to provide instruction on the safety aspects of falsework technology is secondary to our criticism of the almost total absence of training in falsework technology itself. While a number of courses involving formwork are available, courses specifically devoted to falsework as such are rare and usually of a 'one-off' kind. The great need is for a short intensive course catering for the needs of experienced operatives who have not had the benefit of specialised technical training.

One particular course of this type would be suitable for scaffolders and could be developed from a course such as is already running at Bircham Newton. A course of the order of one week is desirable.

It is equally important to devise courses for those who already have some experience in falsework but little training in safety. Such a course would be similar to that devised for newcomers and would be of the same standard but with less emphasis upon the practice with which the experienced candidate will already be familiar. However it may well be necessary to correct malpractices and to explain the risks run in adopting short cut procedures which, in the long run waste time, materials, money and lives.

Apprentices

The problem of training of apprentices is part of a more general problem of encouraging the annual total of some half a million school leavers to undergo further vocational training. It is estimated that some

300 000 boys and girls leaving school each year receive no training whatsoever from their employers. The practices in the United Kingdom contrast sharply with those of other countries in Western Europe. In Germany about 80% of the jobs into which young people go have some form of apprenticeship. A national policy is required from the Manpower Services Commission to establish courses of training in the long-term transferable skills and also to establish the so-called "gateway" courses which provide young people who have just left school with an insight into the variety of jobs available. There is certainly a need to encourage young persons to enter the construction industry and to want to be trained properly. Excellent work in this direction is done by the Civil Engineering College at Bircham Newton, under the auspices of the Construction Industry Training Board. The residential course at the college aims to train promising school leavers and others in the technology of the construction industry in order to fit them for skilled jobs and later on for first line supervisory appointments. We recommend that the course should continue to receive support from the TSA and that numbers be expanded if possible. The City and Guilds courses which cater for technical and craft training are of high quality but may need reappraisal in the light of our comments to ensure that sufficient emphasis is put on safety.

Course standards

The evidence which we have received indicates a wide variation in standard of such training courses as already exist. There are differences in content, in the standards aimed at, and in the results achieved. An employer is therefore uncertain about the standard which a trainee has reached and little reliance can be placed upon the mere fact that a person has attended a course. It is for this reason that we have given detailed syllabi for some suggested courses following our discussions with the Construction Industry Training Board and the management of the Bircham Newton Training Centre. It is essential for each course to have a clear objective, a consistent philosophy and a syllabus adapted to the needs of the people being taught. The teaching and learning hours need to be fixed. The syllabus should be regulated by a central body having experience both in training and construction technology. Any arrangements for regulation must allow for reappraisal and revalidation to take account of new techniques and improved styles of teaching. It is of vital importance that sufficient freedom is given for innovation and development.

We consider that any proposed course should be submitted to the Health and Safety at Work Commission who have responsibility for ensuring that employers fulfil their statutory obligations in instruction, training, supervision etc. The executive of that Commission has its own sections specialising in safety training and the technical problems of the construction industry. The Commission also controls the activities of its inspectors. We recommend that the Health and Safety at Work Executive should be made the approving body for the harmonising of all falsework training courses. We consider that course approval should be given on a two-yearly basis only. At the expiration of that period, the results should be studied and modifications made to improve the courses. Particular courses might be given a designation which would indicate the stage of development which they have reached. Initially, all courses would be classified (a) but, as modifications were made, they would become (b), (c), (d) etc. In this way it would be possible to tell which stage of course any individual had attended. If it were later considered that a course had reached a stage of development where those who had attended earlier stages could benefit from updating, it would be a simple matter to identify those requiring refesher training. This procedure would allow for different rates of development of different courses.

CITB facilities

We were invited as a committee to visit the residential training centre at Bircham Newton in Norfolk. This was originally designed as a training centre for plant operators and has extended its range of training activities under the influence of the Construction Industry Training Board. During our visit we discussed with the tutorial staff the prospects for establishing a range of practical and theoretical falsework courses which could incorporate our concepts of safety. The facilities for practical work at the centre appeared to be unrivalled: there is plenty of space, some of it under cover in former aircraft hangers. There is plenty of equipment including conventional tubes and fittings as well as proprietary falsework elements. These give every opportunity for sound practical demonstrations and staff are well-qualified to give instruction on site and in the classroom. We were also impressed with the residential accommodation and catering arrangements which make the centre entirely self-contained. We invited the programme organisers to devise courses which would provide the right balance of technical and theoretical content for each of the classes of student who could benefit from this custom-built training. The committee discussed the training scheme proposals at some length and the schemes in the Appendix are a result.

Certification

We must now consider how the effectiveness of training can be measured. We have been told of many courses which were carefully prepared but where no assessment was made of the effects of those attending. We have heard from a national safety organisation of students who have started courses during a period of wet weather, but were called away from the course when site conditions become dry enough for work. One example was mentioned of a student who sat throughout an entire training course without benefit, because he came from an industry different from that for which the course was devised.

Certificates of attendance are issued for some courses but the response to the final question session is often the only guide to the level of understanding reached. We consider it essential that students should be required to give an indication of their understanding of the basic principles being taught. The assessment should be made on an individual basis and for many grades it could be based entirely on oral question and answer. Some students may fail but this is inevitable if the standards set are those needed by an industry which is determined to put its own house in order by refusing to employ those who do not reach minimum standards of safety consciousness. Some of those who fail may benefit from a further training course, others may see fit to seek an alternative outlet for their abilities. Only those who have achieved the requisite standard will be given a certificate for the course.

Incentives

We must now ask why, given all the resources which are available and given the general agreement on the need for better training, no courses of the type we commend have yet been established. Surely it must be in the interests of employers that their personnel are trained to such a level of competence that falsework does not collapse causing delay, damage and injury. It is equally in the interests of employees that each one is well trained so that he is neither a danger to himself nor to others; and so that he can work as one of a team with comparative strangers knowing that they will all use common techniques.

In fact there has been very little demand indeed for this sort of training. Such an attitude of apathy and indifference to safety has been commented on forcefully in the Annual Reports of HM Chief Inspectors of Factories. The total effort expended on falsework training has been pathetically small. Employers may claim that the benefits of better workmanship do not compensate for the cost of training and the loss of working time while employees are being trained. They may also claim that the industry has become accustomed to existing standards and it is still possible to build within their limitations. They may also claim that employees will leave after they have been trained so that the benefit of their training is lost to the employer. The last argument is not a strong one because if all employers supported training schemes the loss of trained men by one employer would be balanced by his recruitment of those whom others had trained. Employees may well argue that there is a demand for their services which they can fulfil without further training: indeed the thought of any form of further schooling is an anathema to them. A recent report by the Training Services Agency of the Manpower Commission showed the difficulty of establishing schemes to train young persons in skills that they can transfer from one job to another. There is already a shortage of people with certain skills and there is a real risk that the situation will actually get worse.

Since exhortation, encouragement and appeals are apparently not enough to convince all parties of the need for training it is necessary to consider other incentives.

(i) *The legislative approach* It is a matter of some surprise that, until quite recently, legislation whose purpose was to safeguard the safety and health of persons working in the construction industry should have contained few requirements for training. The requirements which did exist covered only specialised jobs such as crane driving. The provisions of the common law made only general comments on the need to provide a safe system of work. It is therefore a welcome feature of the Health and Safety at Work Act 1974 that, in addition to general statements about the health, safety and welfare of persons at work, it requires specifically that every employer must arrange for "such instruction, training and supervision as is necessary to ensure, so far as is reasonably practicable, the health and safety at work of his employees". In our opinion such a statutory requirement was long overdue although it is still rather too general to be of much immediate value. It remains to be seen what detailed interpretation and subordinate legislation are produced by the Health and Safety Commission. We advocate that the instruction and training provisions should be implemented with the least possible delay: it is expected that the streamlining of procedures which was one of the principal objectives of the Committee under the Chairmanship of Lord Robens will facilitate this.

(ii) *Licensing of contractors* We have given some thought to the desirability of introducing a system which would allow only licensed contractors to undertake various grades of operation involving falsework. The issue of a licence would be conditional on the contractor being able to demonstrate that all those employed had been properly trained and certificated. The nature of the falsework operations which the firm had successfully completed in the past would also be taken into account and it was even suggested that the firm's safety record might be invoked, particularly where substantial falsework collapses had occurred. We do not, however, advocate such a system at the present time. Within the relatively small confines of the United Kingdom, a contractor's reputation should be sufficiently well-known to make licensing unnecessary if the proposals for a certificate of proficiency of individual skilled men are adopted. Such a licensing system may be kept in reserve and introduced only if necessary at a later stage.

(iii) *Restricted tendering list* The tendering system adopted for certain civil engineering projects is an alternative to licensing. An approved list of the organisations which have sufficient experience, expertise and financial standing, is issued to a number of clients, particularly in the public sector. Contracts may not be placed with any firm not on the list. Such a scheme could be implemented in the civil engineering side of the industry. But it would not be practicable in the case of the smaller contractor whose performance depends upon the staff he happened to employ at a particular time and may vary from month to month. Once again we consider that an extension of this system is not immediately desirable though it could provide a fall-back position.

(iv) *Registration* The fourth possibility is that only those who have been trained should be allowed to work on falsework. We have already said that it is essential that a certificate should be issued on successful completion of a training course. This would then become the qualification required for working on a project which involves falsework.

It is encouraging to see that the Sub-Committee of the Joint Advisory Committee on Safety and Health in the Construction Industries recommended in their Report that a certificate of competence should ultimately become compulsory for all who erect, substantially alter or dismantle scaffolds: in the meantime these operatives should carry an official record of their training and experience. The view of the National Association of Scaffolding Contractors was expressed in a pamphlet "Training for the Scaffolding Industry". They wrote "to achieve general adherence to accepted safety standards and training standards some form of sanction needs to be introduced such as a requirement that scaffolding operatives must hold a certificate of competence before they are engaged". We welcome this proposal in a related industry.

Our object is that everyone working on falsework should have had a minimum technical training and should understand the safety implications of his particular work. This cannot, of course, be achieved overnight, but we estimate that about 10% of the skilled labour force could be trained in any one year. To ensure that this rate is maintained we consider that each employer and contractor should keep a register of all trained employees. This will need to be revised at frequent intervals, probably monthly. Into it will be entered a copy of the certificate of attendance and competence that each employee has obtained from one of the approved courses. This register should be made available for inspection at all reasonable times by authorised representatives of employed persons, such as trade union officials, by the client and by HM Inspectors and others. Such conditions could be included as a standard clause in the contract, and failure to meet them be made an offence under the appropriate statutory regulation. A contractor who could not provide proof that the proportion of his workforce which had been trained met the minimum requirements would, *prima facie*, be deemed not to provide a safe system of work. Such a scheme would have the advantage of imposing a distinct, understandable and reasonably practicable duty upon the employer. The necessity for training would be made clear to those attending courses, for they would not be allowed to continue working on falsework unless they were certificated. The date at which the scheme came into operation must allow time for the training organisations to marshall their resources to cater for the progressively increasing demand for training.

Time scale

It is clearly necessary to give some indication of the time scale which we have in mind for programming the courses of instruction. It is impossible to obtain exact figures of the number employed in falsework and difficult to obtain reliable estimates. We do know that there are about 3500 people employed on formwork and from an estimate of the proportion of the carpenters and joiners, scaffolders, bar benders, concreters and other support groups, there would seem to be upwards of some 60 000 persons employed on projects where falsework is important. Less than one-tenth of these constitute first-line supervision and of course not all are directly involved in constructing the falsework. As we said before, we consider that

the greatest improvement in safety standards would be by concentrating resources on first-line management and we accordingly recommend that in the first year 15 courses, each of 2 weeks duration, involving not more than 20 persons per course, should be established. This would give a capacity for any one establishment for training 300 persons per year which probably approaches 10% of the supervisory force. We are informed that this figure would be within the resources of the Construction Industry Training Board's establishments. This capability would also be sufficient to meet the need for training all new first-line management. Thereafter the rate of training must be accelerated and must certainly never be less than the loss rate due to transfer, retirement etc. As far as general training courses for skilled operatives involved in temporary work are concerned these should also aim to be on such a scale that not less than 10% of the total work force is trained during the first year after the inception of the scheme. Thereafter about 10% of the total force should be trained every year.

Financial arrangements

The question of financing this intensive programme of training requires careful consideration. It is appreciated that there would be considerable expenditure involved in the intial stages of training. It would seem inequitable for the employers to bear the whole cost directly, partly because of the mobility of personnel and partly because they do not have the immediate resources to make up quickly for years of neglect of training. We note that the Annual Report of the Construction Industry Training Board 1973/1974 reveals the high investment that has been made at the centres at Bircham Newton and Merton. The Board's resources should be made available to provide the equipment and facilities for the range of courses envisaged. Through their grants system the Board could also help to provide better incentives to train at the time when the industry is acutely short of skilled men.

As far as running costs are concerned, we would hope that the Training Services Agency would regard the training of falsework personnel as a key training area. We are in no doubt that the Government should be ready to make sufficient money available to ensure that these courses are started off on a sound financial basis. Once the back of the problem has been broken the cost of training could be borne by the industry, using the system of levies and private payments which already exists.

Trade Unions

So far we have considered the action which industry and government should take. It is also important the trade unions should have a positive influence in the promotion of health and safety. We note that the trade unions are joint partners with the employers on the Construction Industry Training Board and we have been impressed by the high standard of evidence received from them. We have every reason to believe that the recommendations we made would receive the wholehearted support of the TUC and of the unions involved in the industry.

The need for a text book of falsework technology

In the course of our work we have amassed a considerable bibliography culled from journals, periodicals, proceedings of learned societies, research reports, technical papers, books on a wide range of disciplines, reports on collapses and drafts of standards from several countries. It has become clear to us that most of the information necessary for a full understanding of falsework problems is available somewhere but it is scattered and comes from a wide variety of sources. Anyone studying the subject must spend time and effort in sifting through a mass of material. Indeed authorities in many parts of the world told us that, in their view, the establishment of a committee such as this Advisory Committee was, in itself, commendable in providing a focus where existing information might be brought together.

There is clearly a need for an authoratative textbook on falsework. This would, however, have to be a substantial work if it had any claim to be comprehensive. There is also a need for works of smaller compass giving practical guidance on the design, erection and use of falsework from the engineer's standpoint.

In the past the production of text-books or handbooks has normally followed the development of a course of instruction in a subject. A teacher or lecturer has to assemble his material in a logical and consistent order. Once he has done this he is all ready to put it on paper. It may well be that there are no textbooks on falsework because there have been no courses devoted to the subject. We therefore hope that the developments in professional and operative training that we have already discussed, will lead to the preparation of appropriate texts and we recommend that every encouragement should be given to commissioning such works.

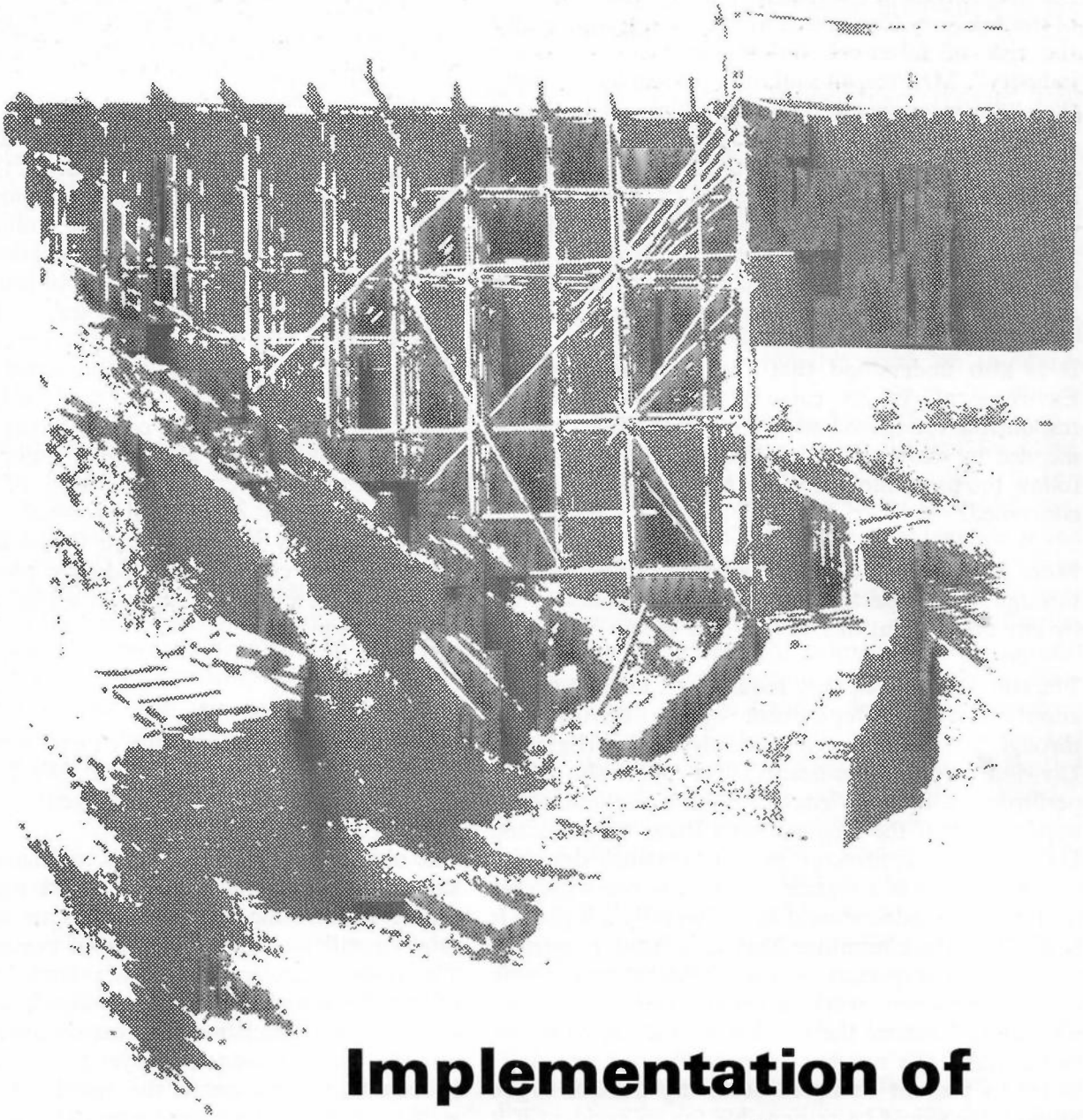
In addition to a designer's reference book we strongly advocate the production of booklets and pamphlets specifically directed to the needs of the craftsman and his specialist interests. For example, we think that the production of a table of the safe working loads of various struts and props would be of value, especially in the smaller operations where the work may be left to the experienced foreman or chargehand who has been trained on the job. It will be necessary to ensure that the operative is trained to use the data correctly. For example, he must realise that the strength of a strut or prop is related to specific conditions of use and varies with the way in which the ends are fixed, the accuracy of placing and alignment and so on. The tables must quote the effects of misalignment or lack of bracing on the allowable strength. They should preferably be illustrated. It is clear that the provision and explanation of simple handbooks is an integral part of the training processes that we have advocated.

Summary

In conclusion we reaffirm our unanimous view that resources of men, materials and capital must be deployed without delay to the establishment of approved practical training courses. We think that an initiative should be taken by the authorities established under the Industrial Training Act 1964, and the work executed through the auspices of the Construction Industry Training Board with their existing centres in Norfolk and London. As far as the Employment and Training Act 1973 is relevant, it is hoped that the Training Services Agency would recognise that falsework training is a key training area. The imperative need is to bring a nucleus of operatives and first line supervision up to an agreed level of competence.

A system of registration must simultaneously be introduced to ensure that the proportion of trained employees increases.

7



Implementation of recommendations

7 Implementation of Recommendations

In our interim report, now incorporated in this report, we made a number of specific recommendations, as well as some more generalised suggestions on which the industry was invited to comment. In submitting the recommendations to Ministers, the then Minister of Housing and Construction Industries, Mr Reg Freeson, "welcomed the recommendations of the Advisory Committee which could greatly reduce the risk of falsework failures in the construction industry". Mr Freeson said, in a parliamentary reply, that "the recommendations fall mainly to be implemented by the industry and I am accordingly writing to them (i.e. the industry) strongly commending the adoption of the recommendations by their members as setting a standard of good practice which they should follow. My Department is taking all steps open to it to ensure that the recommendations are adopted by contractors employed on its own projects".

It is also understood that the Department of the Environment, in its capacity as the Department responsible for liaison with local authorities, recommended by circular letter that local authorities should follow the procedures as far as its own contracts were concerned.

More bridges are commissioned by the Government through the Department of the Environment than by any other client in England and Wales.

The standards which they require and the procedures adopted by the Department of the Environment through its regional organisations in the Highways Division have a significant effect upon the safety performance of most contractors. In particular, the requirement of the Department's Road Construction Units that the contractor submit falsework drawings to the engineer as a matter of course is one which we have recommended should be universally adopted. It is clear to the committee that it is most important to enlist the expertise of the engineers responsible for the permanent work in order to provide checks which could reduce the number of undetected errors and thereby the number of potential failures. It is better to prevent collapses occurring than to argue about who would be responsible for an accident if it occurred.

Industry was further encouraged to implement our recommendations when they were accepted by the Department of the Environment which includes the Property Services Agency. General conditions of contract which require contractors engaged on government work to comply with the recommendations help to establish the recommended procedures, which may then be adopted by contractors for other work.

Through its Department of Housing and Construction Industries, the Department of the Environment also advises and regulates the construction work undertaken by local authorities. This is an important function as it directly affects the private sector of the building industry.

Thus the government have taken measures through the appropriate Departments of State to implement the recommendations of the interim report in relation to its own contracts. We hope that similar action will be taken over the further recommendations of the final report. No opportunity should be lost to stimulate local authorities and the private sector of industry to follow suit so that good practice becomes established throughout that sector of the construction industry where, as this report shows, the need for improvement is particularly needed. We consider that government policy and finance will also have a major role to play in the development and expansion of grant-aided training schemes on the lines which we suggest. Similar schemes may commend themselves to other sectors of the construction industry where technical training, with an inbuilt emphasis on safety, is no less urgently required.

Statutory enforcement

We have also considered the extent to which safety is affected by the laws of the land. We do not believe that additional legislation is required.

The objective of the 1974 Act is to secure the health, safety and welfare of persons at work and to protect others against the risks to health or safety which might result from the activities of persons at work. The scope of protection is thus extended to members of the public and to the self-employed. This is a welcome reform which removes earlier anomalies. It is also the duty of every employer to ensure, so far as is reasonably practicable, the health and safety and welfare at work of all employees. This puts a general obligation on the employer to control working conditions in addition to any specific obligations under particular regulations. There are corresponding obligations upon both employed persons and the self-employed at work. In addition the Act provides for enforcement by the issue of improvement notices and prohibition notices.

The new provisions also permit the Health and Safety Commission to adopt codes of practice which will have the same standing in law as codes of regulations, with some variation in the defence available in the event of legal proceedings. We hope that the British Standards Institution Code of Practice which will follow the publication of this Committee's report may provide the basis for early approval under this procedure.

The Factories Act 1961 and its subordinate four-fold Code of Construction Regulations will continue in force until replaced by legislation made under the 1974 Act. The number of regulations dealing specifically with falsework is small in comparison with the number relating to general construction operations, which include falsework. Regulation 49 of the Construction (General Provisions) Regulations, 1961 is one of the few which do relate to the construction of temporary structures. It is a general requirement which gives little or no guidance on particular standards and merely states that "any temporary structure erected for the purpose of operations or works to which these regulations apply not being a scaffold or other structure to which Regulation 11 of the Construction (Lifting Operations) Regulations, 1961 applies, shall (having regard to the purpose for which it is used) be of good construction and adequate strength and stability and shall be of sound material, free from patent defect". We are aware that proceedings have been taken under this regulation after a falsework collapse resulting in death and injury, and also where falsework has failed to comply with the conditions of the requirement even though no actual collapse has taken place. The acceptance of a code of practice for falsework will increase the safeguards. We would however suggest that any of the procedures recommended in our report which are not covered in the code should be adopted in future approved standards.

There is also some confusion as to whether a falsework which is also used as a means of access constitutes a scaffold or not. If it does, then some of the regulations on inspection for example, are much more strict than those applying to falsework itself. We do not see the desirability of producing a code of statutory regulations applicable exclusively to falsework. We do recommend, however, that in any revision of existing codes or in any new construction codes made under the 1974 Act, the requirements relating to overall structural stability and load-bearing capacity of scaffolding and temporary structures in general, which apply in a wide range of constructions, should be made equally applicable to falsework. This would be in addition to the adoption of an approved code of practice for falsework itself.

BSI Code of Practice

Our terms of reference required us to draw up interim technical criteria for use in advance of the publication of a British Standard Code of Practice together with such procedural guidance as the committee might consider appropriate. This injunction has led us at all stages to pay attention to the work of the British Standard Code of Practice Committee. Our interim report made recommendations on the steps which were immediately necessary and gave provisional guidance on technical factors pending the production of the code of practice.

In the course of our deliberations various draft technical codes on falsework have been produced and been examined by us. We paid particular attention to the 66 page note of guidance produced in 1973 by the American Association of State Highway Officials with the title "Construction Manual for Highway, Bridges and Incidental Structures".

In 1973 The Bridge Department of the State of California produced a valuable work on standards entitled "Bridge Falsework". Towards the end of 1974 the Canadian Standards Association produced a fourth draft of their proposed Canadian Standard, entitled "Falsework for Construction purposes". This was based on extensive experience of falsework construction and of the effects of the state regulation and procedural requirements which were introduced as a result of failures of falsework structures. We have also received information from other authorities preparing standards which are applicable to standards in falsework: these include DIN standards from Germany and various treatises from France such as the records of the Technical Institute of Building and Public Works, which has produced a work entitled "Recommendations for the execution of Falsework". We have also consulted the works of various organisations involved in technical studies: these include the Building Research Station, Garston and the Stichting Bouwresearch, Rotterdam which have produced relevant technical reports such as Study No B 18 on adjustable steel struts.

We commend all these reports, which are included in the appended bibliography, to those involved in drawing up new codes of practice. The existing British Standards specifications on related matters have, of course, also been consulted.

Throughout the proceedings of this committee we have been fortunate to have as one of our members the Chairman of the British Standards Falsework Committee and we are confident that our ideas and arguments have been made available to that Com-

mittee. It is to be hoped that the two bodies have been thinking along the same lines. We also hope that the more technical matters which this committee has discussed, but on which it has not made quantitative judgments, will receive detailed treatment in the code produced under the auspices of the British Standards Institution.

Note of thanks

The work of this Committee has been sponsored by the Department of Employment and the Department of the Environment and we wish to acknowledge the help which we have received. We are indebted to several Divisions of the Department of Employment whose premises have been used for our meetings and to the Health and Safety Executive whose staff has been mainly responsible for the organisation and the running of our affairs. We are also particularly indebted to HM Chief Inspector of Factories for allowing members of the Construction Engineering Section to give evidence on four separate occasions providing information drawn from their extensive experience in the investigation of falsework failures.

We wish to express our appreciation to the Overseas Division of the Department of Employment for its good offices in approaching overseas embassies to obtain literature on falsework on a world-wide basis. We are grateful to the Department of the Environment for providing detailed information at an early stage on the latest practice and procedure in bridge construction in England and Wales.

We wish to express our gratitude to HM Factory Inspectorate for providing the secretariat which has been responsible for obtaining, processing and handling all the papers, letters and correspondence which were the raw material on which the committee's work was based. Members of the committee would like to record their particular appreciation of the work of their Secretary, who, helped by his assistants, has dedicated himself to serving the committee for such a long period. We also wish to express our gratitude to the staff now of the Health and Safety Executive who contributed to the organisation of the work and the preparation of the report.

We are greatly indebted to the learned societies and professional Associations, Institutes and Institutions. They provided carefully prepared written statements based on the considered experience of members who have given much of their professional life to the study of construction problems. They presented their evidence through some of their most senior members as well as through officers expert in technical and legal matters. Not only were these persons prepared to discuss their views fully and frankly but they were also kind enough to correct the verbatim transcripts and indeed to add further points which had occurred to them afterwards.

We wish to express our appreciation for the most comprehensive and well-argued case which the TUC prepared in written evidence and for the presentation of this case by a most experienced and knowledgable team. The Employers' Associations in the civil engineering and building sectors of the industry gave us most valuable evidence on the implications of our recommendations, on their impact on the industry and on how the procedures could be implemented. Those who represented safety organisations gave us a very clear picture of the state of safety training including, in all frankness, the inadequacies which the present organisation seems to force on them.

We have been particularly appreciative of the number of independent persons with a special interest in falsework and safety who have taken the trouble to write and give us the benefit of their experience. Letters from consulting engineers, architects, contractors' engineers, research workers, university departments of engineering and many more have added information, emphasis and colour to the formal nature of the evidence we received during our meetings. Some letters have laid special emphasis on particular points of technology, procedure or research and we hope we have covered them adequately in the report.

Our task has been made easier by the desire of all concerned to make a positive contribution to our enquiry. We believe that having been helped by this goodwill, we can now make recommendations which are realistic and which will make a material contribution to the safety of falsework.

Appendix I Case Studies

Summary of the report of the British Columbia Royal Commission, Second Narrows Bridge Inquiry 1958

Brief history and description

The bridge was being constructed in the Greater Vancouver area between the north and south shores of Burrard Inlet.

The bridge consisted of four northern approach spans leading from a viaduct, a main cantilever section with a central span of 1100 ft and two anchor spans of 465 ft. The spans were numbered from north to south, 1 to 7 inclusive, span 5 being the north span, span 6 the central span, and span 7 the south anchor span. The bridge deck, about 80 ft in width, was designed to carry six lanes of highway traffic and two sidewalks.

The piers of the sub-structure, which had been completed at the time of the collapse were numbered consecutively from north to south, 1 to 17. Pier 14 supported the south end of span 4 and the north end of span 5. Pier 15 supported the south end of span 5.

The erection scheme called for two temporary piers known as false bents, numbered N4 and N5, between piers 14 and 15, to provide temporary support for the cantilevering of span 5 from pier 14 towards pier 15.

Prior to the time of collapse, the four approach spans had been erected. Span 5 was in process of erection. This work had proceeded to a stage where the two top chords, the cast bottom chord, the two diagonal members and the two vertical members had been connected in place. At that time there were located on the deck of span 5 No 1 Traveller or Crane (155 tons), a diesel locomotive and two railway trucks (38 tons), the bottom west chord (52 tons), and miscellaneous erection equipment (85 tons), making a total superimposed load of 330 tons. A sketch is shown overleaf.

Preparations were being made for the crane to move the west bottom chord upward and outward from the railway trucks, to clear the bridge deck, and then downward to its position on the west side of the structure where it was to have been connected up. At the actual moment of the collapse of span 5 none of the equipment on the span was in active motion and the actual lifting of the chord from the railway trucks had not commenced.

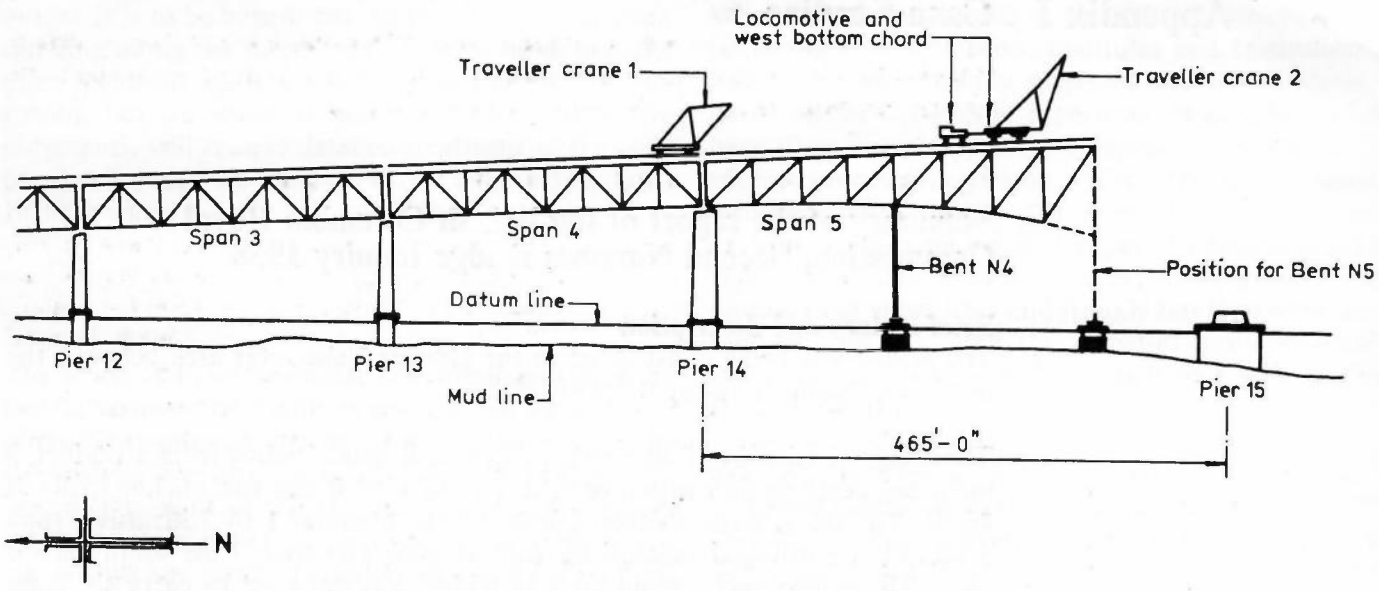
It was at this stage on the afternoon of 17th June, 1958 that without any warning, the south end of span 5 collapsed into the water. This was followed almost instantaneously by the collapse into the water of the south end of span 4. Eighteen of the men working on the structure at the time lost their lives.

Some conclusions from the evidence

Collapse sequence

(1) The collapse of span 5 took place in three stages:

(a) a short initial dip or drop, variously estimated by eye-witnesses as from from 1 to 6 ft



(b) a pause, or "hesitation"
(c) the collapse into the water of its south end, the north end remaining supported on pier 14;

(2) The top of pier 14 was deflected towards the south;

(3) The south end of span 4 collapsed into the water from the north side of pier 14.

Elimination of possible causes

From the evidence which included the opinion of experts who testified, the following possible causes could be eliminated.

(a) Design and specifications of permanent structure.
(b) Unusual external forces such as sabotage, explosion, extra-ordinary winds or earthquake. The velocity and direction of the tide were normal; no ship was in collision with any part of the structure or foundations.
(c) No 1 Crane (Crane at extremity of span 5).
(d) Careless or faulty workmanship on the part of the workmen.
(e) Inherent weakness in the erection methods, equipment and devices used by the contractor (except for the four beams comprising the upper tier of the grillage of false bent N4).
(f) Possible disturbance of tie-downs in Pier 14.

Cause of collapse

From the evidence adduced it was found that the cause of the collapse was the failure of the upper tier of grillage beams in false bent N4. A number of Advisers, retained by the Commission, unanimously but independently arrived at this conclusion. No other part of false bent N4 was considered sub-standard.

Accordingly the Chief Justice of the Supreme Court of British Columbia felt "entitled to rely with confidence" and based his findings as to the cause upon the advisers' conclusion, namely:

"The primary cause of the accident is elastic instability of the webs of the stringer beams of N4 grillage, accentuated by the plywood packings above and below the beams. The instability was due to the omission of stiffeners and effective diaphragming in the grillage, and this in turn was basically due to an error in the calculations. Such diaphragming as was provided was inadequate".

Errors in calculations
There was produced in evidence a design sheet which was made by the Assistant Engineer and checked by the Field Engineer. This sheet contained the calculations for the design of false bent N4 and two errors appeared on it.

The sheet bore the title "design of caps and distributing beams using 36WF160 beams between pairs of bents". Under the heading "CHECK SHEAR", it appeared that in determining the shear stress the area had been taken as the gross area of the whole beam including flanges and webs (47·09 sq in) instead of the gross area of the webs (23·5 sq in) as is required by accepted elastic theory and all design specifications. The shear stress had therefore been wrongly calculated to be 6 ksi instead of 12 ksi. If 6 ksi had actually been the shear stress, it might have justified the use of the adopted beams without stiffening, as was the conclusion recorded on the calculation sheet; but this would not have been justified if the correct shear stress had been calculated. Stiffeners and diaphragms would then have been provided, and the accident would not have occurred. There is a second error on the same sheet, under the heading "CHECK FOR WEB STIFFENERS", in which the flange thickness (1 in) has been used instead of the web thickness (0·653 in). A correct calculation would have called attention to the high general stress level in these beams even though they would still have been permissible in this case.

The first of these two errors was not detected by either the Field Engineer who checked the sheet, or his Assistant who prepared it. The second was detected and a pencilled note was made crossing out the figure "1" and substituting the figure "653". Nobody knew definitely who made that note but whoever did so did not make a recalculation on the basis of the corrected figure.

It appears that the decision to use the four WF160 stringers in the upper grillage without stiffening, as shown on the sheet, was not reviewed or checked by anyone except the Field Engineer.

The upper grillage was subsequently placed in bent N4 without stiffening.

Comment on the use of plywood
If the upper tier had been fitted with stiffeners and effective diaphragms the plywood would not have interfered with the intended performance of the grillage.

However, the arrangement of the grillage was such that the pressure on the plywood was about 1340 lb per square inch under the west leg of bent N4. This pressure was beyond the elastic range of the material. If plywood were to be used as soft packing the grillage should have been arranged so as to keep the pressure on the plywood well within its elastic range. This would have avoided the "creep" in the plywood and would have mitigated the undesirably high lateral bending stress in the flanges of the upper grillage beams.

Other major points extracted from the inquiry documents

(a) The Consulting Engineers had a reputation of being "a firm of first class calibre in the matter of building major bridges". The Contractors had a high reputation, had been carrying out business throughout Canada for 75 years, employed highly qualified engineers and had built many large and difficult bridges.

(b) The Engineers prepared design drawings and specification which were examined generally by the Bridge Division of the Department of Highways of the Province of British Columbia and found to be satisfactory.

(c) Two separate contracts were let, one for the foundations and another for the superstructure.

(d) The contract specification included this clause:

"2-2-3. Falsework. The Contractor shall furnish, construct and subsequently remove all falsework required for the erection of the steelwork. Falsework shall be properly designed and substantially constructed and maintained for the loads which will come upon it. The Contractor shall submit to the Engineer, plans showing the falsework he proposes to use to enable the Engineer to satisfy himself that the falsework proposed to be used complies with the requirements of this Specification. Approval of the Contractor's plans shall not be considered as relieving the Contractor of any responsibility . . .".

It further provided that approval of the Contractor's plans should not be considered as relieving the Contractor of any responsibility.

(e) The second contractual obligation on the Contractor, namely to submit to the Engineer plans showing the falsework he proposed to use in bent N4, was not performed. When asked why not, a spokesman for the Contractors frankly replied that as far as he could find out it was "purely an oversight".

(f) The partners from the Consulting Engineers, both stated in their evidence that they would approve the procedure of erection but not any of the details or equipment. Nevertheless the Chief Justice commented in his report that:

It is clear from the evidence before me that had the Engineers called for plans showing the falsework which the Contractor proposed to use, in sufficient detail to enable the Engineers to satisfy themselves as to compliance with the requirements of the specification, the inadequacy of the upper grillage probably would have been discovered and the collapse avoided.

Accordingly, I must find there was a lack of care on the part of the Engineers in not requiring the Contractor to submit plans of the falsework.

(g) The Chief Justice in his report stated:

Accordingly, upon the evidence the collapse was caused by and was the result of negligence which consisted in:

(a) failing properly to design and substantially to construct false bent N4 for the loads which would come upon it as required by Clause 2-2-3 of the contract specification, and

(b) failing to submit to the Engineers plans showing the falsework the Contractor proposed to use in the erection of span 5 as required by Clause 2-2-3, and

(c) leaving the design of the upper grillage of false bent N4 to a comparatively inexperienced engineer, and failing to provide for adequate or effective checking of the design and the calculations made in connection with the design.

Summary of a report by the Main Roads Department of Western Australia on the collapse of falsework to the Welshpool Road Overpass 1966

Description of structure

The bridge was a three span prestressed concrete bridge and was designed by the Main Roads Department of Western Australia. Each end span was 36 ft in length with the central 54 ft span clearing two sets of railway tracks. The bridge was 38 ft in width overall and provided a final clearance of 20 ft between the rail tracks and the underside of the bridge deck. The four piers of the bridge each comprised three precast columns resting on a concrete footing supported by piles (fig. overleaf).

Falsework

The falsework for the erection of the deck slab consisted of scaffolding with timber cross beams immediately under the deck formwork on the two end spans. Somewhat similar scaffolding was used under the central span with gaps being provided to allow track laying trains to pass whilst the structure was being erected. A central scaffolding tower was provided between the two sets of tracks. Steel RSJ beams were provided to span the tracks and to support the formwork during construction.

Test loading

Following the erection of the original scaffolding, officers of the Main Roads Department raised doubts as to the adequacy of the scaffolding in relation to the ground bearers, which were 12 in × 2 in karri planks. Taking into account the then current ground bearing conditions, it was considered that these ground bearers were inadequate in strength. A 30 ton test load was used, being equivalent to the load that a section of the scaffolding would have to carry whilst the concrete deck was being constructed. This was applied to one end of the central supporting scaffolding located between the sets of tracks. The scaffolding for this load just met the limit of three-eights inch deflection in the deck formwork which had been established for the purposes of the test.

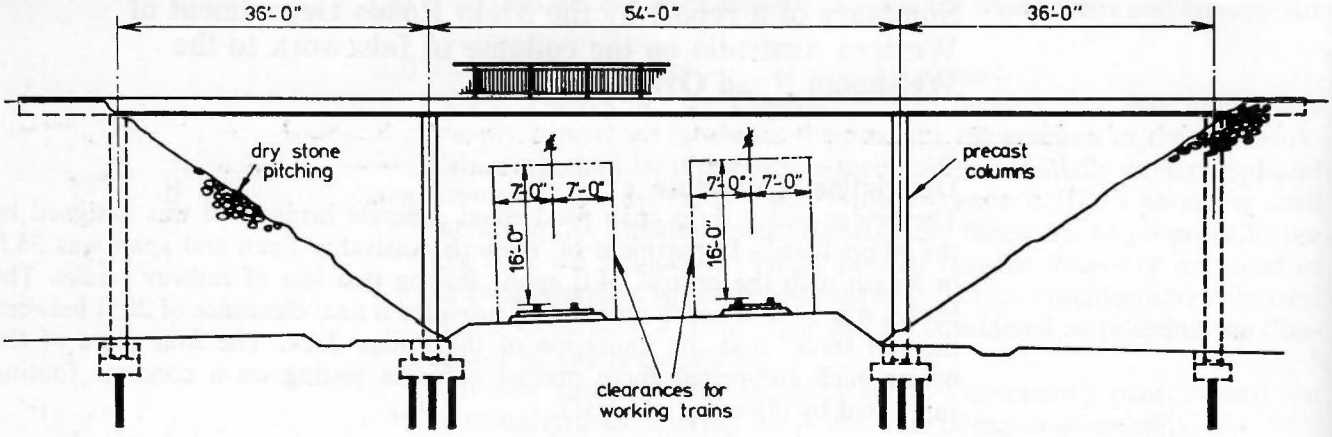
First failure

Following the test loading, concreting of the deck slab commenced on the eastern end. After completing the end span and a portion of the central span, the scaffolding supporting the eastern end of the central span subsided about 2 ft. This subsidence was subsequently shown to be caused by the splitting of the 12 in × 2 in karri planks referred to above. The scaffolding tubes used in the falsework were placed directly on to the planks without bearing plates.

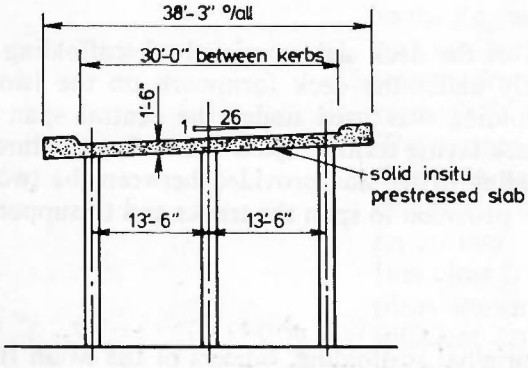
Following the first failure the contractor strengthened the scaffolding. The Departmental site engineers, whilst being unhappy with the original falsework, were completely satisfied with the strengthened falsework.

Second failure

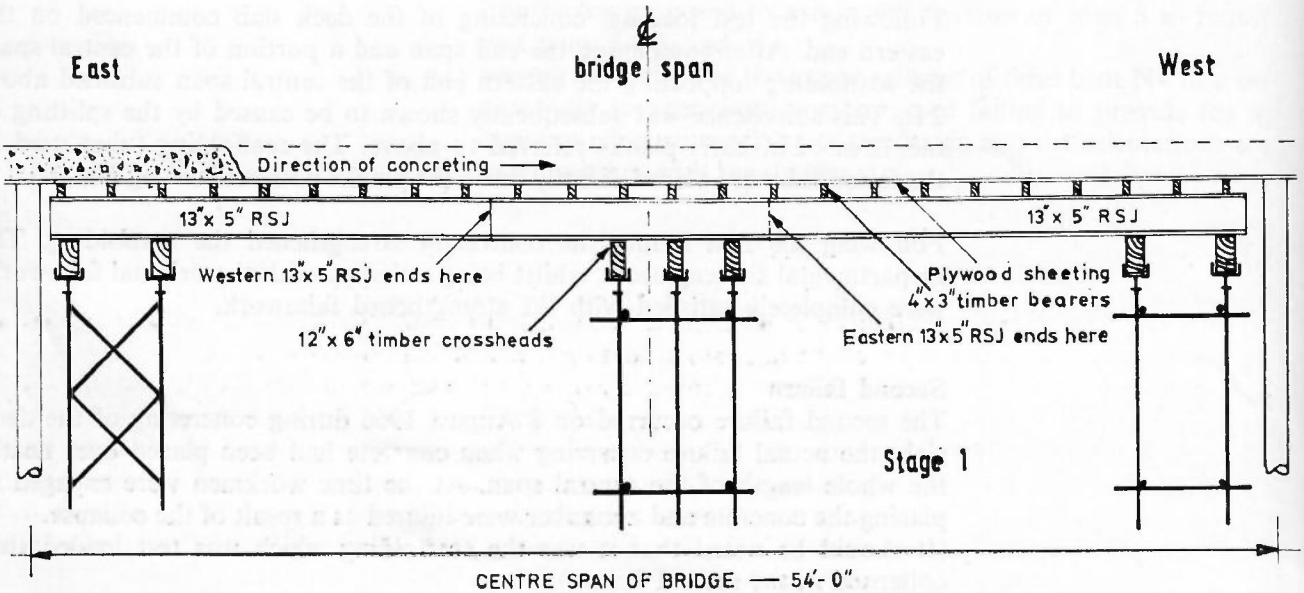
The second failure occurred on 8 August 1966 during concreting of the deck slab, the actual failure occurring when concrete had been placed over nearly the whole length of the central span. At the time workmen were engaged in placing the concrete and a number were injured as a result of the collapse.
(It should be noted that it was the scaffolding which was test loaded that collapsed in the second failure).

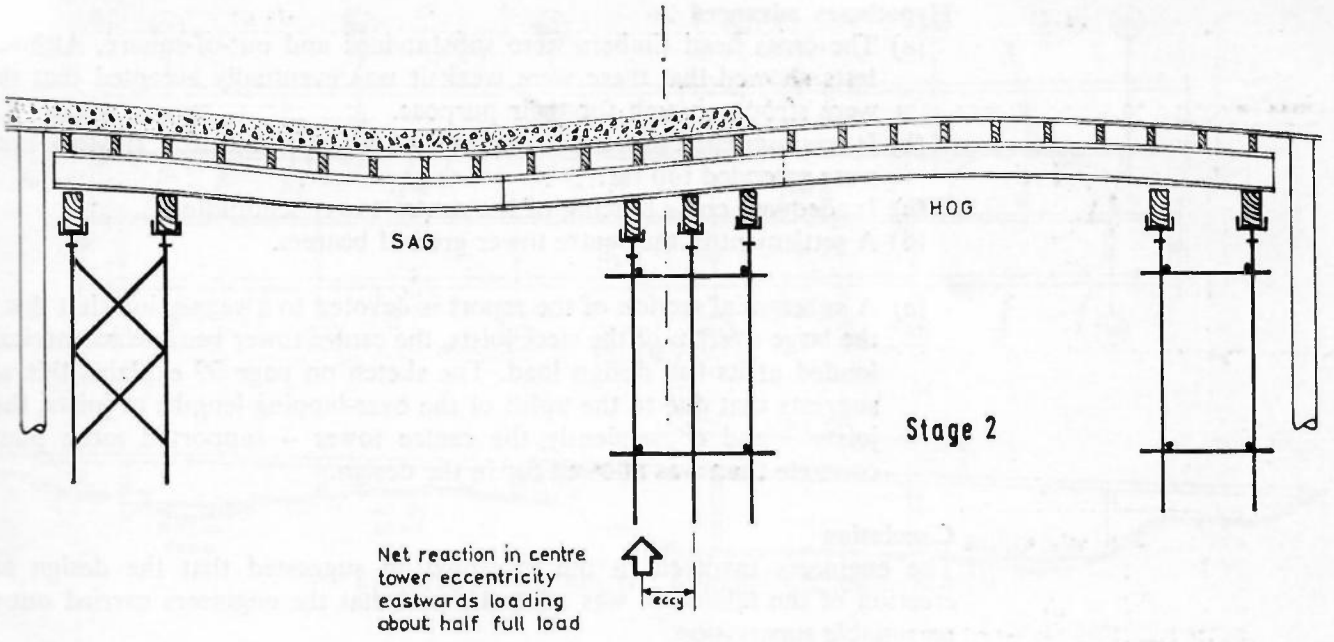


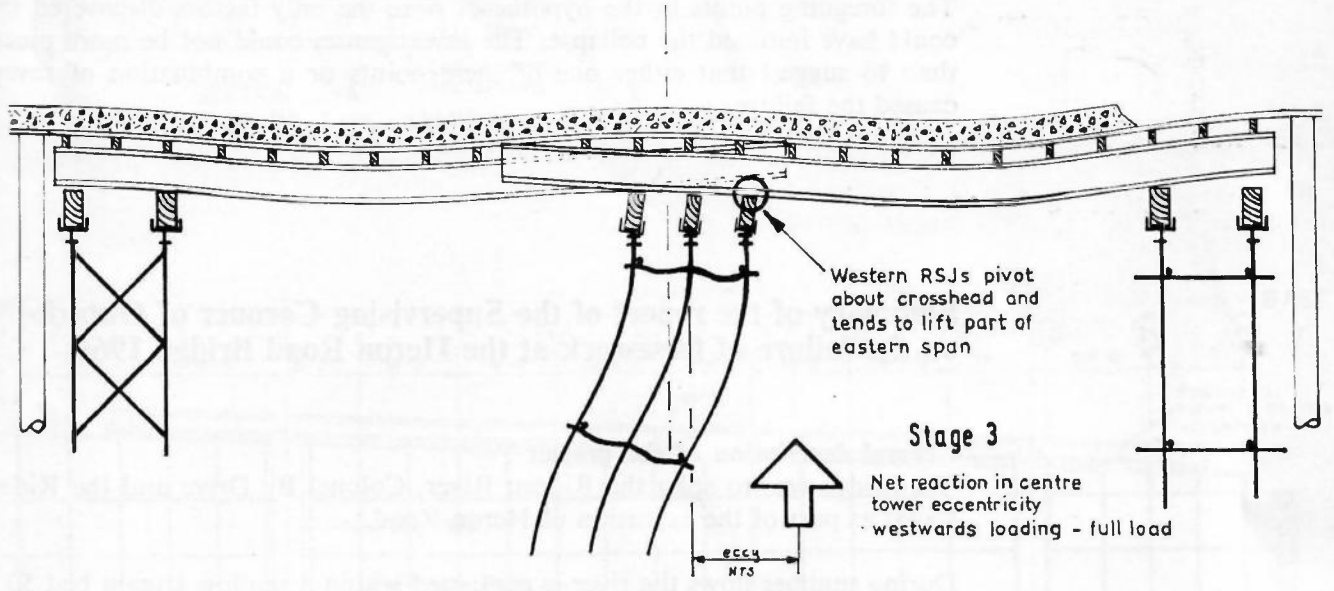
South Elevation



Typical Cross Section







Results of investigations

(a) In spite of all attempts the failure could not be attributed to any specific cause. (The railway onto which the falsework collapsed was cleared of debris within 7 hours). Various hypotheses were advanced by engineers associated with the investigation as to how the failure might have been caused; however no one was able to substantiate his case.

(b) From all opinions expressed, the collapse was associated with the failure of the central scaffolding tower located between the rail tracks.

(c) The central tower collapsed by buckling in a bow towards the east in a typical Euler shape but essentially remaining as a frame.

(d) Although both the first and second failures occurred in the falsework there was no other relation between them. The first failure was due to splitting of weak ground bearers which failed under load whereas no such splitting occurred in the second failure: also the failures occurred at different locations.

Hypotheses advanced

(a) The cross head timbers were substandard and out-of-square. Although tests showed that these were weak it was eventually accepted that they were strong enough for their purpose.

(b) It was suggested that due to the camber in the bridge deck, the fork heads were extended too far.

(c) Inadequate cross bracing of the centre tower scaffolding.

(d) A settlement in the centre tower ground bearers.

(e) A substantial section of the report is devoted to a suggestion that due to the large overlap of the steel joists, the centre tower became eccentrically loaded at its full design load. The sketch on page 99 explains this and suggests that due to the uplift of the over-lapping lengths of joists, these joists – and consequently the centre tower – supported more plastic concrete than was allowed for in the design.

Conclusion

The engineers involved in the investigation suggested that the design and erection of the falsework was adequate and that the engineers carried out all reasonable supervision.

The foregoing points in the hypotheses were the only factors discovered that could have initiated the collapse. The investigators could not be more precise than to suggest that either one of these points or a combination of several caused the failure.

Summary of the report of the Supervising Coroner of Ontario on the failure of falsework at the Heron Road Bridge 1966

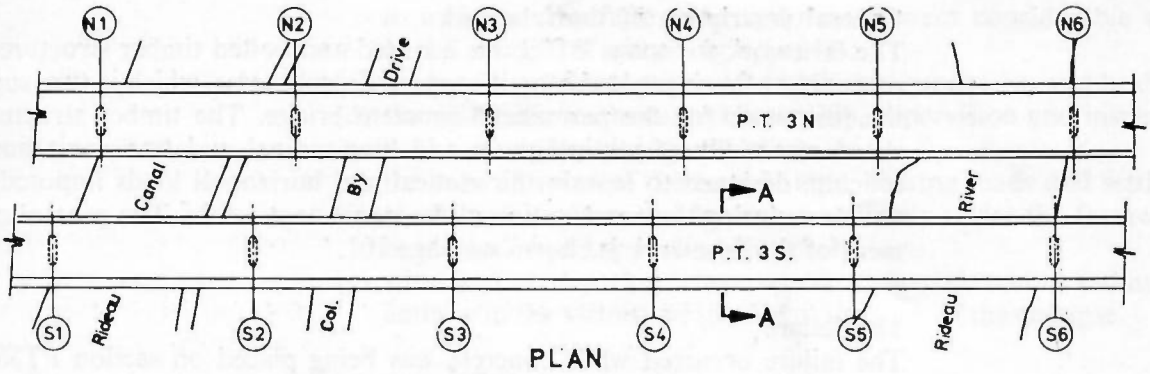
General description of the project

The bridge was to span the Rideau River, Colonel By Drive and the Rideau Canal as part of the extension of Heron Road.

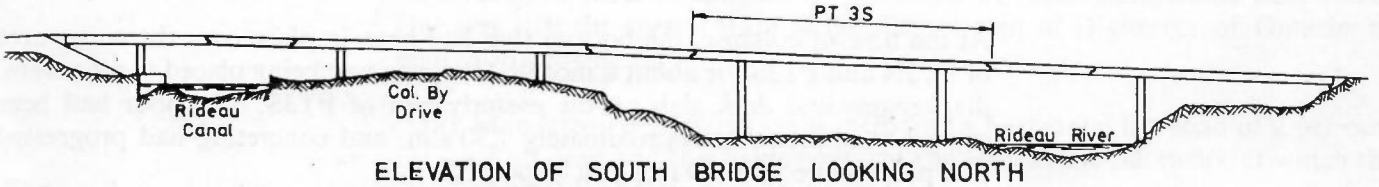
During summer flows the river is contained within a shallow stream bed 50 to 100 feet wide. A flood plain, 200 to 300 feet wide, forms the western bank of the river. The plain is exposed except during periods of flood. Immediately south of the bridge, the surface till of the flood plain is one or two feet thick but the bedrock surface drops rapidly in a northerly direction, resulting in till thicknesses of up to 20 feet in the vicinity of the north side of the bridge.

The proposed design required the construction of two separate 3-lane concrete bridges of seven spans each. Each structure was 877 feet 6 inches in length from centre to centre of abutment bearings and comprised five intermediate spans of 147 feet 2 inches plus two end spans, one of 52 feet 6 inches at the west abutment and one of 112 feet 9 inches at the east abutment. The general arrangement of the bridge is shown opposite.

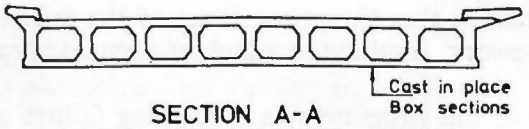
The abutments and piers N1 and S1, N2 and S2 and N3 and S3 were supported on steel H-piles driven to rock. Piers N4 and S4 bearing directly on bedrock whereas piers N5 and S5 and N6 and S6 were supported on spread footings founded in dense granular material in the bed of the Rideau River.



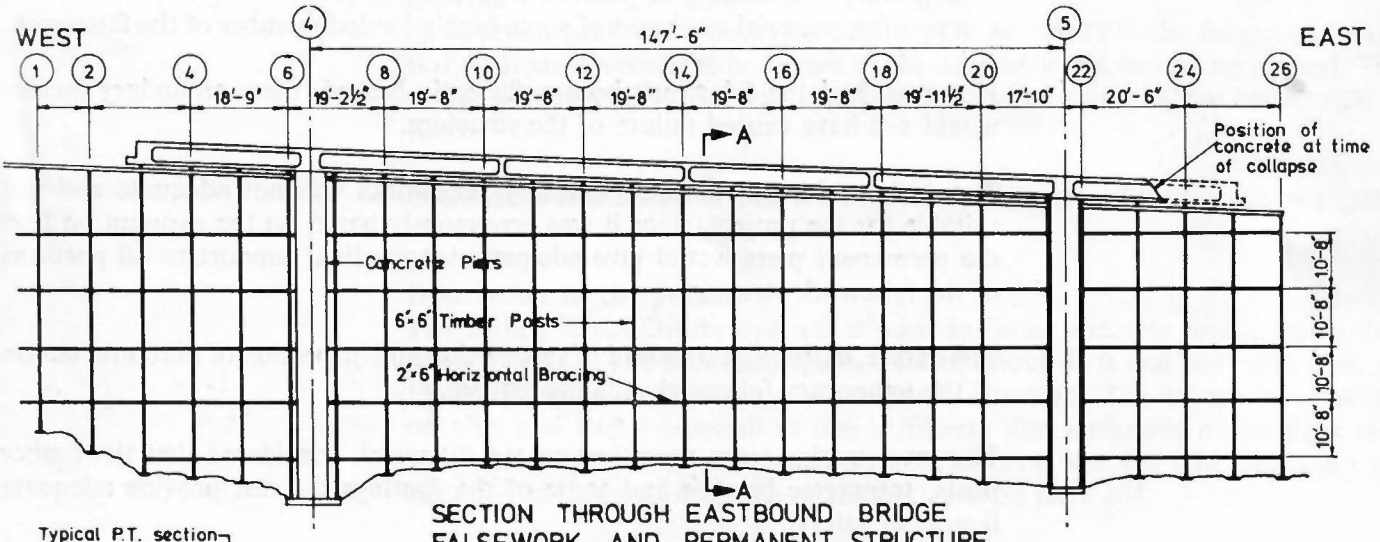
PLAN



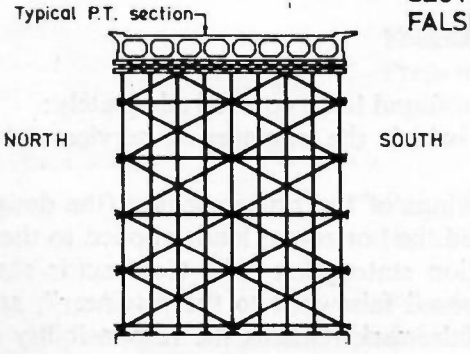
ELEVATION OF SOUTH BRIDGE LOOKING NORTH



SECTION A-A
TYPICAL FOR P.T. TYPE SPANS



SECTION THROUGH EASTBOUND BRIDGE
FALSEWORK AND PERMANENT STRUCTURE



SECTION A-A

Falsework for span P.T. 3S.
General arrangement and
typical details

General description of the falsework
The falsework for spans PT3S was a nailed and bolted timber structure resting on concrete footings. At the top it supported steel beams, which in turn supported the formwork for the permanent concrete bridge. The timber structure consisted essentially of vertical posts and longitudinal and transverse horizontal bracing, designed to sustain the vertical and horizontal loads imposed on the structure during the construction of the permanent works. The general arrangement of the falsework is shown on page 101.

The failure
The failure occurred while concrete was being placed on section PT3S on 10 August 1966. Workmen were killed and injured as a result of the collapse.

At the time of collapse, the bottom slab had been in place over the entire area of PT3N and PT3S for about a month. Concrete was being placed for the webs, diaphragms and deck slab on the easterly half of PT3S. The pour had been started at midspan at approximately 7.30 a.m. and concreting had progressed to a point some 15 to 20 feet east of pier S5.

The cause of the failure
The investigating engineers concluded that the prime cause of the failure was an error in the design of the falsework, resulting in a lack of adequate bracing.

The basic cause of the collapse of the structure was a buckling failure of the falsework which was insufficiently braced in the longitudinal direction. The occurrence of the failure at that particular time may have been influenced by one or a combination of the following secondary factors:
differential settlement of footings,
temporary overloading of posts of transverse bent 23,
a possible material weakness of some highly loaded member of the falsework.

However, had the falsework been sufficiently braced, these secondary factors would not have caused failure of the structure.

The design adopted for the temporary falseworks was not adequate and not suitable for the project, since it was erroneously based on the assumption that the permanent piers would give adequate longitudinal support to all portions of the falsework structure.

The nature, extent and standard of supervision and inspection of the construction of the temporary falsework was inadequate.

The investigating team reporting on the falsework considered that the timber posts, transverse bracing and some of the footings did not provide adequate factors of safety.

Other areas of investigation
The following parts were investigated and found to be covered adequately:
(a) the terms and conditions upon which the engineering services were obtained
(b) the design, specification and drawings of the bridge project (the design of the bridge piers had not included the horizontal loads applied to them by the falsework). The specification stated that "the Contractor shall submit detailed plans of the proposed falsework to the Engineer", and that "notwithstanding approval, falsework remains the responsibility of the Contractor". The job records show that this procedure was adhered

to and that the falsework design underwent considerable modification in the process of obtaining approval.

(c) the tenders and acceptances for both the foundations and bridge structure
(d) the materials, methods, workmanship, supervision and inspection related to the permanent bridge structure
(e) the subsoil, most of the foundations, bearing loads and settlements
(f) the formwork, the steel beams immediately under the formwork and the hardwood caps supporting the steel beams.
(g) wind and earthquakes; there was no appreciable wind and no earthquake activity in the vicinity of the site at the time of the collapse.

Recommendations

As a result of these investigations, a number of recommendations were made. One was that the specification of the Department of Highways of Ontario be revised to provide for:

(a) Mandatory design live loads including a horizontal live load of 2 per cent of all dead and live loads acting at the level of the falsework at which the vertical loads are applied.
(b) A requirement that approved design and construction drawings for falsework carry the stamp of a Registered Professional Engineer (Civil).

Summary of a report of the failure of falsework at the Birling Road Overbridge, Kent 1971

General

At approximately 1500 hours on Monday 22 March 1971 the falsework to the Birling Road Overbridge collapsed as the deck concrete was being poured. The bridge was part of a contract to provide a by-pass around Ditton on the A20 in Kent.

One man was killed, five men were seriously injured and twelve others slightly injured.

Description of the project

The Birling Road Overbridge was a post-tensioned concrete bridge, consisting of three spans. The approach spans were of about 46 ft and the main span of 138 ft, all lying in a roughly north-south direction. The bridge was curved on plan and had a crossfall of one in fifteen. The underside of the deck was approximately 18 ft above ground level. The deck was 4 ft 6 in deep and contained void formers. A sketch of the bridge is on page 104.

Foundations

Preparations for the construction of the bridge started early in 1970 with the replacement of peaty ground which lay above firm gravel. This entailed excavation to a depth of about 9 ft and replacement with compacted Folkestone sand.

Piling for abutments and piers took place in June 1970 and the construction of the abutments and piers was completed during November.

Falsework and formwork

A 'birdcage' type of falsework employing conventional 2 in diameter scaffold tubes and couplers, was erected on sleeper foundations. A gap was left to enable

construction traffic to pass through the structure. The original intention was for this gap to be bridged by steel beams but it was finally decided to fill the gap with shoring frames. Some jacking was done to provide the correct soffit profile.

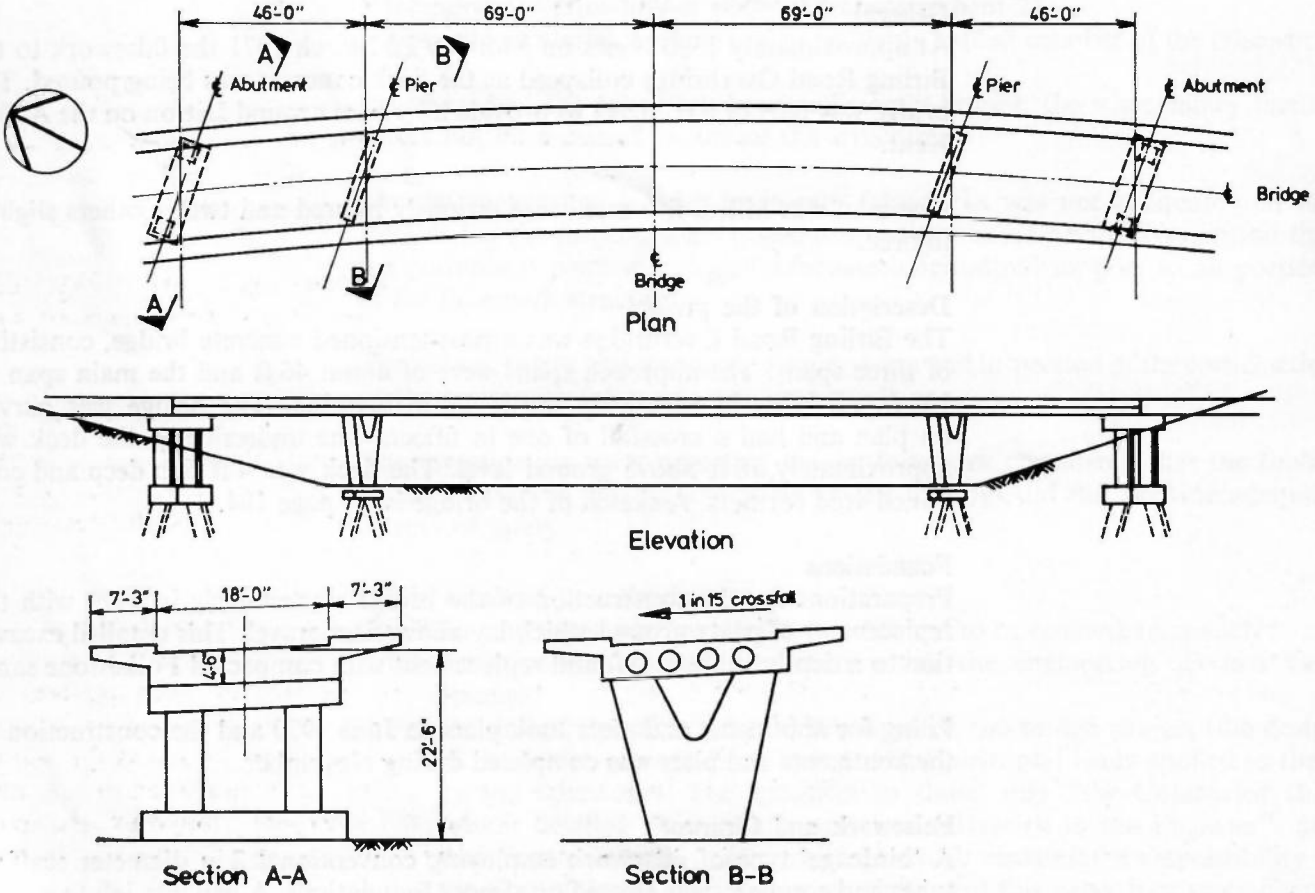
Formwork consisted basically of $\frac{3}{4}$ in plywood on 6 in × 3 in bearers at approximately 1 ft centres. These in turn were carried by double 9 in × 3 in timbers supported in the forkheads. The walkway areas of the bridge were cantilevered from the main deck and the shuttering for these was somewhat different.

The collapse

The concreting operation began at 0100 hours on the morning of 22 March at the south end and shortly afterwards work started at the north end. Both operations continued until 1500 hours when the collapse occurred. At this stage there remained a gap of about 37 ft between the two advancing faces of concrete. The south face was more advanced than the north and had reached the centre of the main span. Concrete was deposited by two pumps, one at each end of the bridge.

Witnesses both on and off the bridge described the collapse as starting with a sharp noise. All suggested the collapse started at the north end close to the pier and progressed in a wave across the span to the south end.

The main span collapsed entirely but the side spans remained more or less intact.



Matters arising from the investigations

There was no evidence to suggest that movement of the piers and abutments to the permanent works occurred.

Some areas of fill were more compact than others due to the movement of heavy traffic along the line of the future carriageway.

Timber sleepers had been bedded using sledge hammers.

The day after the collapse it was noted that there was evidence of a very high water table in the area of the bridge. Ponds could be seen either side of the span. The immediate top surface of the sand close to the bridge was moist.

Rainfall records obtained for the period 1 November 1970 to 22 March 1971 showed a total of 52·6 mm of rain in December, 63·6 mm in January, 17·3 mm in February and 54·2 mm up to 22 March. During the period 14–22 March a total of 41 mm was recorded and the heaviest rainfall of the three month period occurred on 17 March (14·6 mm). There was no rain on the day of the collapse.

On 22 March in the period of 0600 hours to 1500 hours the maximum wind speed recorded as 21 knots with an average of 17·7 knots for the period.

It was suggested that there had been a spring in the area of the north abutment for some time.

There is evidence to show that after the rain on 17 March the ground was waterlogged and erosion of the ground beneath some sleepers had occurred. Concrete was placed under some sleepers on 19 March.

The nature of the filled ground and its load bearing capacity was a subject for investigation. It was calculated that a symmetrically loaded sleeper would impose a load of about 1·8 tons per sq ft on the ground, but sleepers which were not symmetrically loaded were observed and calculations showed that in at least one instance pressures of 3 tons per sq ft could be expected.

Sleepers in the region of the north pier were examined and it was obvious that some were more deeply embedded in the sand than others. This suggested that settlement had occurred but not on a large scale.

There was difficulty in establishing whether final working drawings of the falsework provided at Birling Road ever existed. It was obvious that the structure which remained standing, that is the side spans, was not in accordance with a preliminary drawing produced. Enquiries suggested that the scaffolders used this drawing to obtain broad guidance.

No evidence could be found of swivel couplers having been used. The fact that the bridge was curved and skewed on plan meant that the angle between the transverse and longitudinal horizontal members was not 90°. The significance of this is that transverse bracing connected to the longitudinal members would not necessarily be in the same place as the rows of standards across the width of the bridge and could not be connected to them. An examination of the side spans confirmed that bracing in those areas was somewhat haphazard and that few connections were possible close to standards or at each lift because of the geometry.

The drawing previously referred to showed all bracings on the line of the standards. The drawing also specified the use of chairs with right angle couplers. No chairs were found on site.

Investigations showed that the bracing system was not uniform throughout the span and that connections were made at levels which meant that some bracings were unrestrained for relatively long distances.

From examination of the wreckage of the main span it was clear that the majority of standards had all failed in one direction and that the mode of failure was in a single curve from top to bottom. This suggested that the actual effective length of the standards in the collapse condition was not related to the distance between intermediate horizontal members. There was very little evidence of contraflexure between these members, i.e. between nodes.

Calculations had not been obtained for the falsework prior to the collapse.

The preliminary drawing gave an indication of design loads but a copy of the original calculations was not available.

Calculations to BS 449, assuming standards to be loaded concentrically and with an effective height between restraints of six feet, showed that there was a slight overstress but not sufficient to cause failure.

With the same restraint conditions but with a simple eccentricity applied at the forkhead and the resulting moment transferred into the vertical standard and the horizontal members according to their relative stiffnesses, a factor for combined bending and axial stress of 1·24 was obtained. (The appropriate factor recommended in BS 449 is unity).

The condition of an effective length based on the total height of the standard acting in single curvature and concentrically loaded, showed that the standard would fail. Similarly the assumption of full fixity at top and bottom again showed that the standard would fail.

Enquiries established that the falsework had been inspected in the week prior to the pour. As a result some additional bracings and standards were added.

A pile of unused bracing units were discovered in the wreckage. These were surplus to requirements. It was observed that in places the erection of the units was not in strict accordance with recommendations in respect of bracing and that in order to make up differences in height across the width of the bridge (due to crossfall), ordinary mild steel scaffold tubes had been coupled (with single couplers) to the tops of the towers.

An attempt had been made to connect together adjacent towers but it was difficult to establish the extent of this tying.

Some additional falsework supports below the cantilever at the side of the bridge had been fixed with the prime purpose of varying working platforms. It was connected to the rest of the falsework. Additional standards in the side span at the north end were added again connecting to the falsework. Scaffolds were also provided at the extreme ends of the bridge.

Calculations on the timber members comprising the formwork showed them to be stressed between 500 and 700 lb per sq in.

An absence of wedges in the forkheads was noted despite the obvious crossfall.

Concrete consolidation was by the use of six shutter vibrators in addition to poker vibrators. Three men did the job and at the time of the collapse were in the centre of the span and under the middle of the deck moving the vibrators. The vibrators were clamped to the 6 in × 3 in timbers under the soffit.

There is evidence of movement of the shutters (or the falsework) on two occasions during the pour. Witnesses reported a slight movement of the deck at about 5.0 a.m. This was not reported to any of the engineers present.

About an hour before the collapse it was noticed that small pavement shutters on the east side of the bridge were beginning to lean over, the bottom spreading towards the centre of the bridge. This was investigated and apparently rectified by the carpenters.

Summary of report of the collapse of falsework to the Arroyo Seco Bridge, California 1972

Description of bridge and falseworks

The bridge is located in the City of Pasadena, California and carries the highway known as Route 210.

The Arroyo Seco bridge was designed as two parallel bridge structures separated by an expansion joint. The bridges are three spans in length and prestressed by a reinforcement system of tensioned steel strands embedded in the concrete. (A sketch is given on pages 108 and 109).

The bridge superstructure was a box girder constructed in two stages. The bottom concrete slab and the vertical stems were constructed in the first phase, then the side forms were removed from the stems, and forms were constructed across the tops of the stems forming the hollow cells. In the second stage the concrete deck slab was placed across the cells and made integral with the stems. This sealed off the cells and the buried top slab forms remain in place for the life of the bridge.

The bottom surface of the Arroyo Seco bridge was arched. Because of this, the contractor constructed the falsework of two structural forms. The lower portion consisted of heavy duty steel towers supporting steel cap beams and steel stringer girders. On this a planked working platform was laid. The falsework above the platform was constructed of timber posts and beams. (See page 109).

The collapse

The collapse occurred at about 13.30 on 17 October 1972. The first phase of the concreting was nearly completed on the south structure and just starting on the north structure. Falsework for both structures was in place. On the day of the failure concrete was being placed in the bottom slab and stems of the centre portion of the bridge and the day's operation was about 80% complete.

A conveyor belt system was in use to transport concrete from transit-mixers to the required position (three witnesses stated "that the pour was being made faster than usual"). Concrete was placed in the stem forms in 3 lifts, each lift progressing from south to north and then vibrated with hand held vibrators.

The following is a description of what is believed to be the most probable failure mechanism:

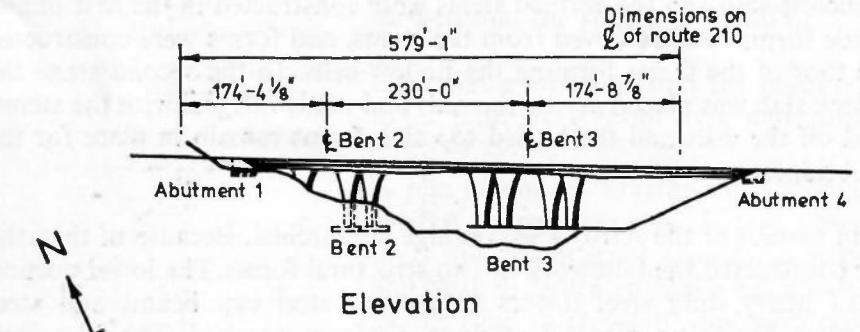
About five minutes before the collapse, during the final concrete placement in the outside stem forms, there is evidence that a form-tie broke and the forms began to spread. Further failure was probably arrested as adjacent ties took up the load and the form was carefully filled with concrete to the top.

Minutes later, when the operator put the vibrator into this form, a complete rupture of the form probably occurred with several ties failing. The form would not have opended widely, however, because the inside form was braced solidly to the second stem form and the outside form was held tightly to the extended soffit form. The pressure of the fluid concrete would produce a large horizontal force pushing the soffit form outward.

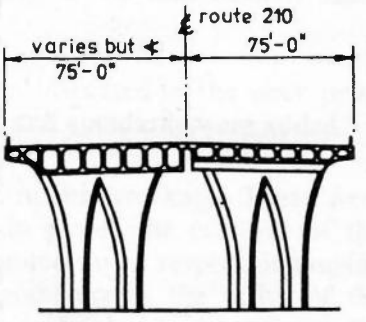
The horizontal outward force, it is believed, pulled open the joint in the soffit form under the second girder stem and concrete began to fall down onto the working platform.

Opening of the joint probably caused the inside 4 in × 8 in stringer to roll onto its side, dropping the soffit form several inches and in so doing increasing the horizontal thrust.

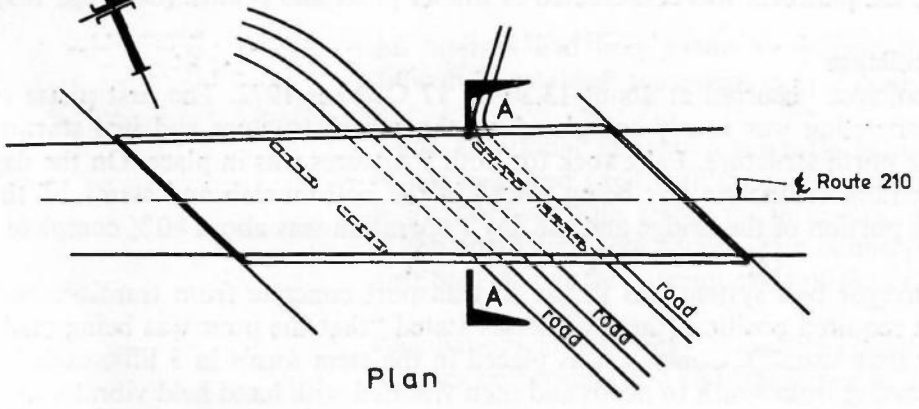
The timber falsework frame under the two exterior stems would transfer all the horizontal thrust loads down to the tops of the two outer steel falsework stringer girders. It should be pointed out that the 2 in × 10 in planks in the working platform were not nailed and offered no resistance to a spreading force. Also the X-bracing between the steel girders which was merely butted up to them, would not offer any resistance to a spreading force.



Elevation



Typical Section A-A



Plan

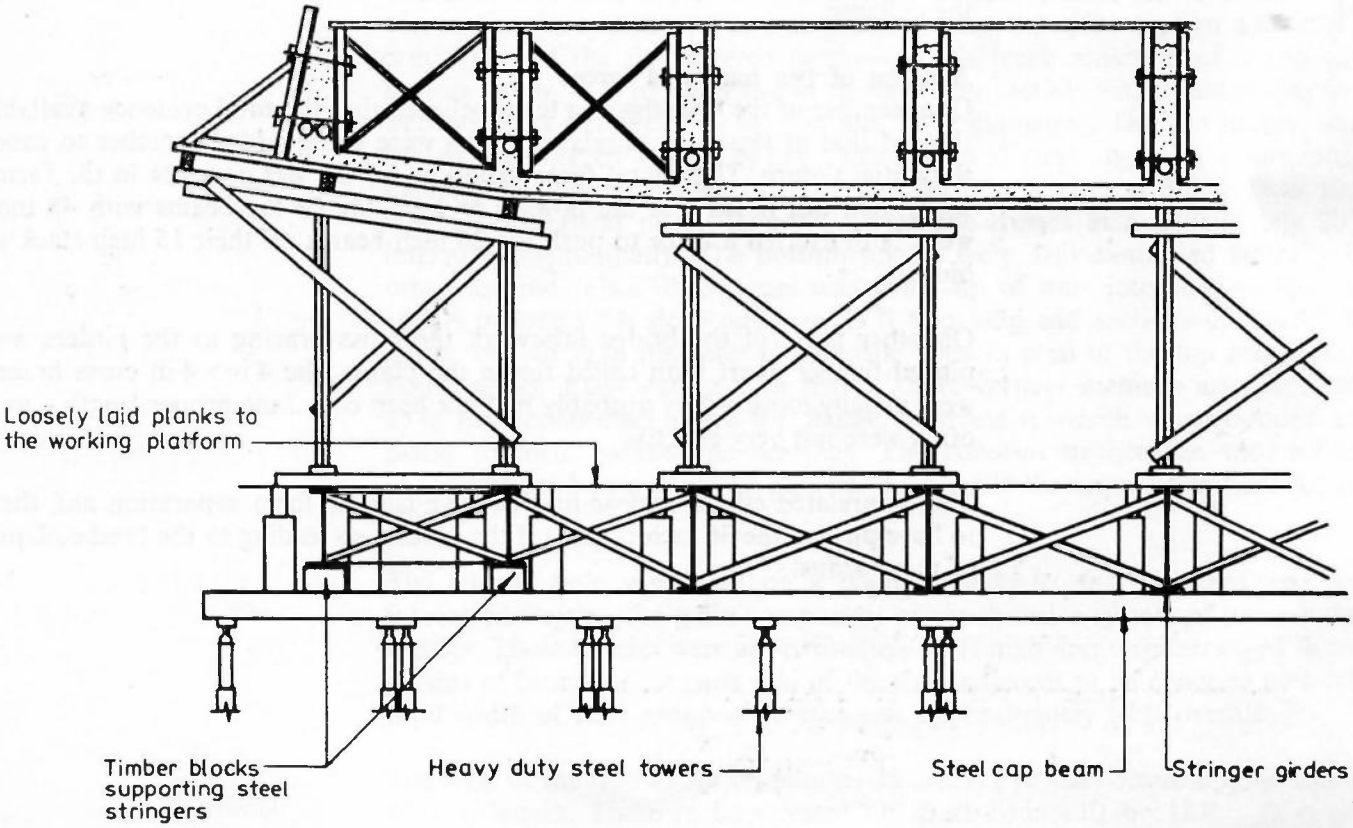
At this point the outermost 36-inch steel girder must have slipped off the wood block which was supporting the east end and dropped the 15 inches to the steel cap.

These events would have resulted in a large outward thrusting force being applied to the cap beam of bent number 10 at the girder's eastern end.

The tower bent was on a 45 degree skew to the stringer girder so that the outward thrusting force coming into it would tend to rotate the bent clockwise. There is some flexibility in the sixty-foot high towers and it is probable, that as the rotation started, the joint in the steel cap of bent 10 (which had no provision to resist tensile forces) started to open. At the same time the lowest diagonal brace in the outer tower frame buckled in compression and the outermost tower leg folded under.

Evidence indicated that continued rotation caused complete collapse of the two outer towers.
It is possible that a few workmen noticed the original failure but were not greatly concerned because stem form failures are not uncommon in the USA and in fact minor ones had occurred during pouring earlier in the day.

Other possible causes investigated but not found to be responsible
(a) Earth tremors
(b) Wrong location of shoring members
(c) Sabotage
(d) Excess stresses in structural steel
(e) Weakness in steel towers
A portion of the collapsed member was removed and tested. On cutting open the member, which is a hollow rectangular tube, it was apparent that it had been



heated and straightened previously in the same location where the buckling had occurred.

The investigation team believes the weakened diagonal brace, in not preventing the tower collapse, contributed to the complete failure.

(f) Inadequate foundations

(g) Inadequate cross bracing between the steel girders

The 70-foot span of the steel girders was so great that they would have buckled laterally if they had been unbraced. Because of this, 4 in × 4 in wood cross bracing had been installed which would transmit compressive forces but not tension forces. This bracing, by itself, would permit all the girders to buckle northward simultaneously were it not for the resistance provided by the wood decking which lay across the tops of the girders, but was not fastened to them. This bracing system, because of the lack of positive connections, would not be very effective after collapse had progressed to a certain point and would not have provided much resistance against complete collapse. Inadequacies of the bracing systems, however, did not cause the collapse.

Possible factors initiating collapse

Snap-ties

Two types of ties were used on this bridge, both having equal ultimate strengths.

It was discovered, however, that the factor of safety between the prescribed working load of 5000 pounds and the failure load was very small. The average failure strength was 6400 pounds and the lowest of 11 tests was 5240 pounds.

A hazard of working form ties at so near their ultimate strength is that if one tie should fail, for whatever reason, the adjacent ties do not have the reserve capacity to prevent the failure from propagating for the full length along which fresh concrete is exerting fluid pressure.

It was believed that this low factor of safety could have been a factor in initiating the collapse.

Addition of two unrelated forces

One member of the investigating team believed that the total evidence available showed that at least two unrelated forces were being added together to cause the initial failure. The lateral force produced by the wet concrete in the forms which had not failed and the bowing and leaning of the beams with 48 inch webs both exerted a force to push the 36 inch beams off their 15 inch stack of blocks.

On other parts of the bridge falsework the cross bracing to the girders was placed further apart than called for in the plans. The 4 in × 4 in cross braces were usually loose – they probably had not been cut to the proper length – and often were not very effective.

These unrelated effects appear first to have caused form separation and then to have pushed the 36 inch beams off the blocks, so leading to the total collapse of these spans.

Summary of reports of the failure of falsework for the viaduct over the river Loddon, Berkshire 1972

General

On 24 October 1972 the temporary structure supporting a road bridge under construction over the river Loddon at Woodley, near Reading, Berkshire, collapsed killing 3 men and injuring 10 others.

The investigation was particularly difficult because a good deal of the falsework was buried in the river bed and under reinforced concrete which had fallen on top of it and set hard.

A concrete viaduct of the post-tensioned type and continuous over 13 spans formed part of the A329 Relief Trunk Road which is a link road to the M4 motorway.

The viaduct had two separate carriageways each 53 ft 8 in wide with a gap of 2 ft 10 in between each carriageway. The north carriageway span which collapsed was being constructed over the river Loddon. At that place and time the river was approximately 90 ft wide and 2–3 ft deep. The distance between and normal to the piers was 93 ft and each pier was 35 ft 6 in wide at approximately 33 ft above the water level. The deck of the viaduct was to be formed by *in-situ* concrete 4 ft deep over the 31 ft 6 in wide main central 'spine' section and of a mean depth of 1 ft at either side which cantilevered from the spine. The deck was skewed longitudinally in relation to the piers at an angle of approximately 37 degrees and had a 1 in 29·25 crossfall; sketches on pages 112 and 113 show the arrangement.

Falsework

The falsework over the river consisted of fabricated steel lattice trusses 98 ft 4 in in length, spaced at 1 ft 8 in centres under the spine section and at 4 ft centres under the cantilevered sections. Each truss consisted of a top and bottom boom of 6 in × 6 in broad flange beam section with tubular diagonal web members mainly of $3\frac{1}{2}$ in, 3 in and $1\frac{7}{8}$ in diameters. The top booms were braced together by bolted $2\frac{1}{2}$ in × 2 in × $\frac{3}{8}$ in mild steel angles in a horizontal plane. Other bracing in the form of steel scaffold tubes and fittings, was provided in a vertical plane, laterally across the trusses at approximately 20 ft intervals longitudinally. The bottom booms were also connected laterally by other scaffold tubes. Each truss was made up of four intermediate sections 14 ft 9 in long × 7 ft deep and two 19 ft 8 in long end sections connected by means of two $1\frac{3}{8}$ in diameter high tensile bolts in each of the top and bottom boom joints. Each end section had a short vertical member approximately 13 in long connected to the top flange, attached to which were rounded end plates to form rocker-type bearings. The connections between the sections in the bottom boom could be adjusted to provide the requisite camber for the trusses.

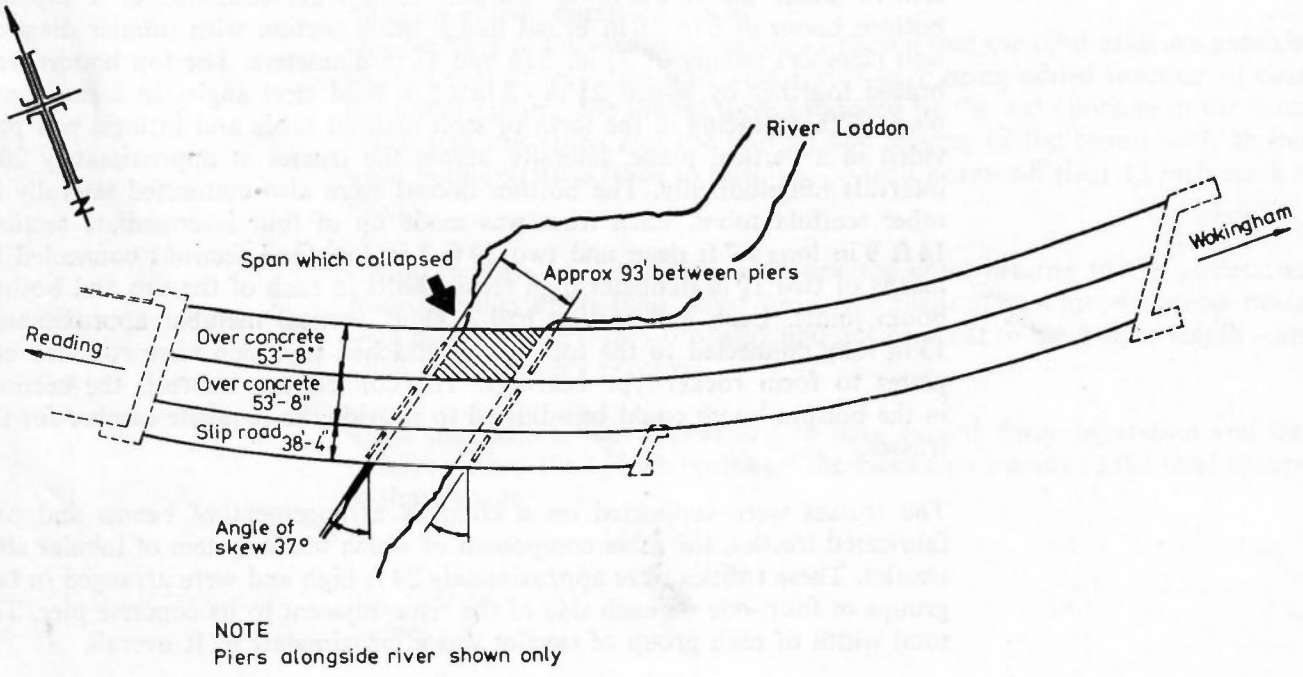
The trusses were supported on a complex arrangement of beams and prefabricated trestles, the main component of which was a system of tubular steel trestles. These trestles were approximately 24 ft high and were arranged in two groups of four, one on each side of the river adjacent to its concrete pier. The total width of each group of trestles was approximately 62 ft overall.

The base of the trestles sat on parallel 33 in × $11\frac{1}{2}$ in steel beams approximately 80 ft in length. These in turn rested on short 10 in × 10 in × 12 in × 12 in uni-

versal columns standing on the permanent pile caps (the foundations) of the bridge piers. The 33 in × 11½ in universal beams were at 3 ft 4 in centres and their top flanges supported the outer legs of all the trestles. Inner trestle legs were supported on numerous 8 in × 4 in × 17 in RSJs placed at intervals between the beams.

Forkheads with 2⅜ in diameter jacking screws were fitted to the top of the trestles. The uprights of the trestles were of 4 in diameter tubes with telescopic sections inserted at their bases and mid heights, perforated by 1⅛ in diameter holes at approximately 4 in centres to receive 1 in diameter steel fixing pins. Thus the height of the trestles was adjustable by means of the forkheads and the perforated insert tubes within the main trestle members, which were actuated by hydraulic jacks fitted on the outside of main members. Fine adjustments of the trestle heights were generally made by means of tapered steel plate clamps bearing against the fixing pins in the perforated legs.

In order to distribute the load carried by the 26 trusses over 16 pairs of forkheads, each end of the trusses rested on a two-layer grillage of steel beams placed on top of the trestles. (See page 114). Each upper layer of this grillage consisted of header beams of 10 in × 10 in × 49 lb universal column sections, with special bearing pads 12 in long × 12 in wide on the top flanges. the upper surfaces of which mated with the rocker bearings of the trusses. These bearing pads were either tack welded, or clipped by bolted steel flats, to the upper universal column sections. The latter were supported on short lengths of 12 in × 6½ in × 31 lb universal beams at right angles to the 10 in × 10 in × 49 lb header beams, and spaced generally at intervals of approximately 3 ft 6 in along the top of the trestles either side of the river and rested in the trestle forkheads at 2 ft 4 in centres. Short lengths of 5 in × 2½ in rolled steel channels were fitted inside the forkheads to centralise the 12 in × 6½ in × 31 lb universal beams over the backing screws. Tapered timber packings were also used with the centralising RS channel pieces, to fix the beams in position.



General Site Plan

Movement of falsework
Early in 1972 the steel falsework for the construction of the span of the southern carriageway over the River Loddon had been erected without incident and used to support the full weight of the concrete deck. In August 1972 operations were commenced to move the falsework to the corresponding span of the northern carriageway.

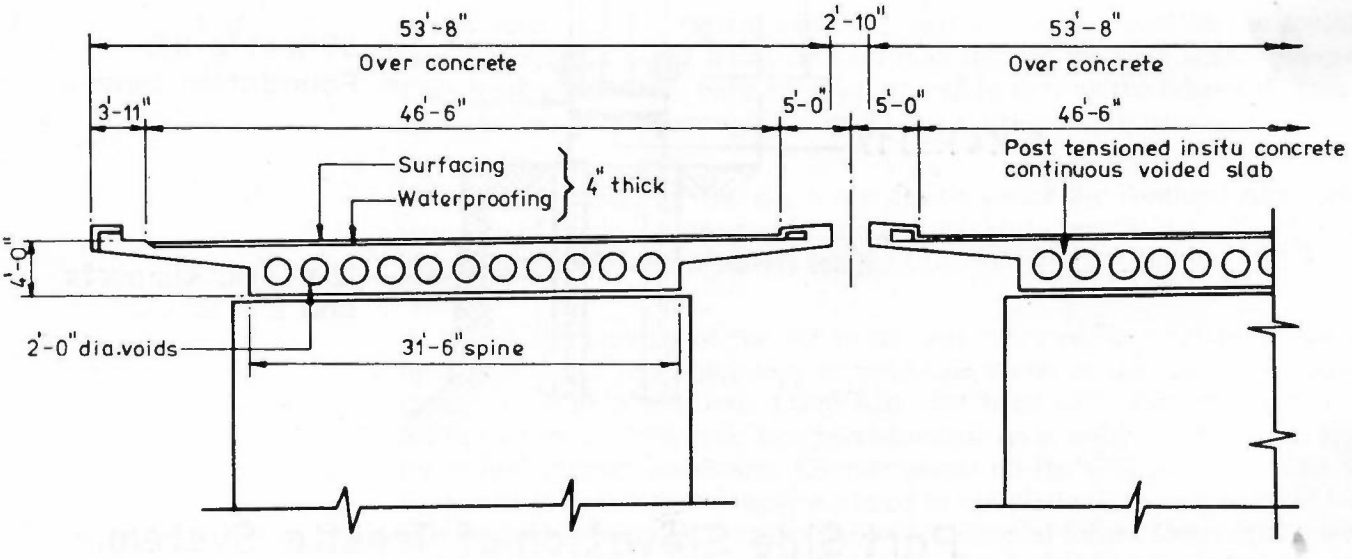
Skates were fitted under the trestle legs and single rows of sheet piles were placed horizontally on top of, and welded to, each 33 in × 11½ in steel foundation beam, forming a flat track along which the assembly was hauled to its new position by means of a pulling device, operated from each bank of the river.

Checks were made after every foot of travel and no difficulties were experienced.

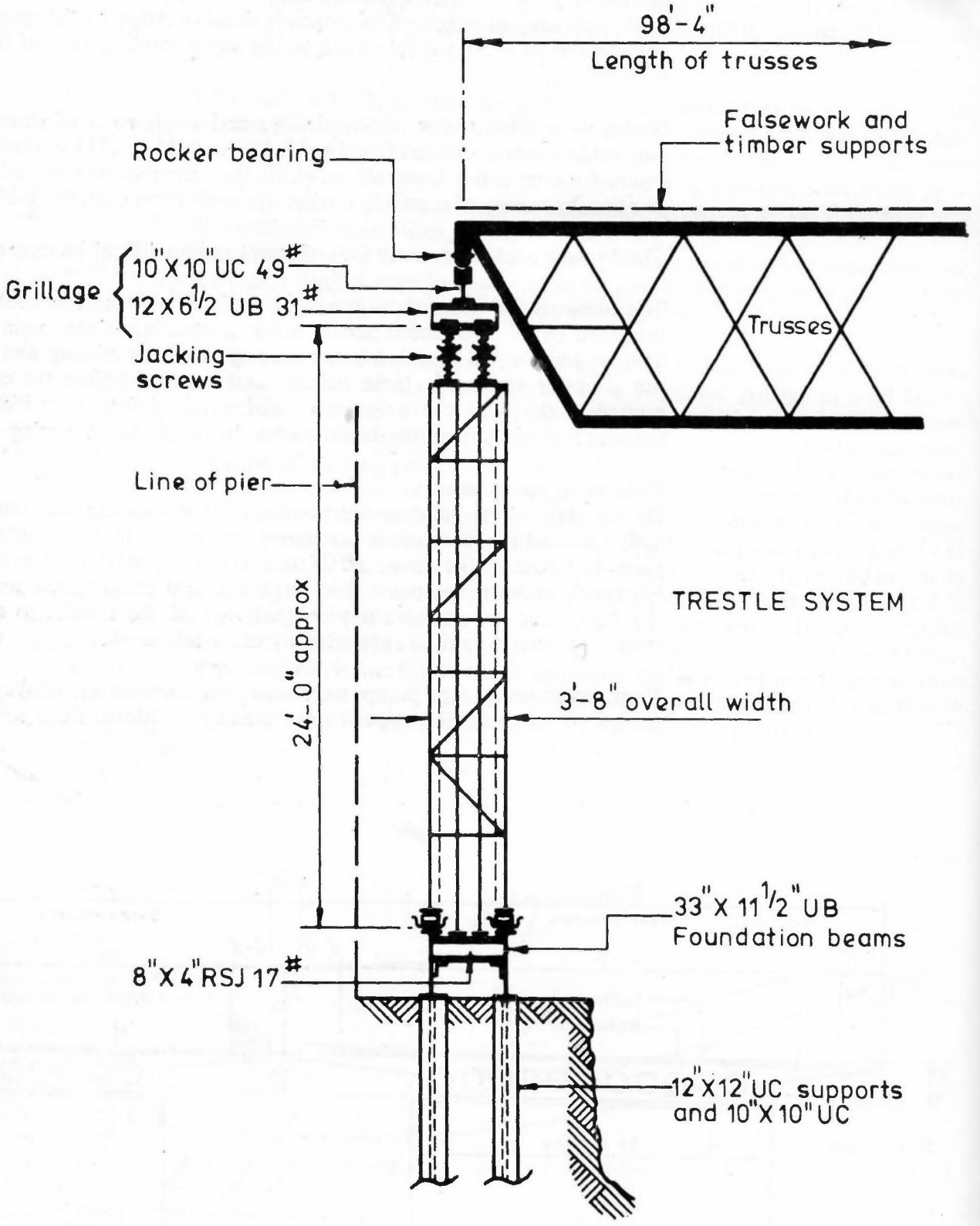
The falsework for the southern carriageway of the river span had been thoroughly inspected by an experienced person before concreting of that span took place. This inspection had revealed many bracing members missing and some bolts not properly tightened; these defects were rectified before the concrete was poured. A thorough check was made and certain defects were rectified before the concrete was poured on the falsework for the northern carriageway.

Concreting operations
On the day of the collapse the pouring of the concrete had commenced at 8.30 a.m. and the intention was to complete the continuous pour of 750 cubic yards by 6 p.m. on the same day. Of this, 500 cubic yards would be carried by the falsework between the piers. The remaining 250 cubic yards, was to extend the deck over the permanent piers just beyond the trestles to the adjacent spans, where it would be supported by other falsework.

Four reciprocating type pumps were used. The concrete was conveyed from the pumps, through flexible pipes to the placing positions. Four separate gangs



Part Section Through Finished Bridge



Part Side Elevation of Trestle System

totalling 30 men were attending to the placing of the concrete in the formwork. Concrete was first deposited near the centre of the span, then pouring proceeded outwards towards the piers. The rate of pour during the first hour was 84 cubic yards dropping to 53 cubic yards in the second hour, after which it rose to 88 cubic yards an hour prior to the collapse.

Consolidation of the concrete was by means of 14 poker vibrators.

The collapse

At about 13.35 a downward movement occurred (one estimate being of 6 in) towards the east end of the span. A few seconds later the span collapsed into the River Loddon. From an inspection of the damage it appeared that the falsework deck fell in the line of the skew, the trusses overturning sideways. The trestles at the east side of the river overturned and fell on top of the trusses, whilst at the west side, only one of the trestles overturned, namely that at the south end. The others at the west side remained vertical but in places had moved laterally 12 in towards the adjacent concrete pier. All the grillages of steel beams at the east side of the span were badly twisted or buckled, particularly the 12 in × 6½ in × 31 lb universal beams which sat in the trestle forkheads. Some of the grillage beams at the west end remained in position on the trestles but were damaged.

Possible causes of the accident

Having eliminated the possibility of foundation movement or defective formwork as potential causes of the accident, attention was concentrated on the steel falsework. The overall stability of the falsework was suspect in that the pin-jointed type of framework was not firmly anchored. In other words, although the uprights were standing freely on the foundation beams at their bases and the trusses were merely resting on the bearer plates at the top, the uprights were not tied back to or braced against the concrete piers alongside them. In addition, the lateral stability of the connected trusses was doubtful. However, there was insufficient evidence to suggest that these two factors substantially reduced the stability of the structure.

It was noted that the system had been used without incident on the southern carriageway span under a heavier load than that on the span which collapsed. Thus weaknesses might have been introduced in moving the falsework from its first position and re-arranging it under the northern carriageway.

During the striking of the north-east trestle under the southern carriageway span two of the lower legs had been damaged. However, the actual loads in the legs of this trestle were relatively small.

Although the moving of the falsework was reported as a relatively smooth operation it had been necessary to weld side plates at the rocker bearings to maintain them in position. There had also been difficulties in aligning the trestles when the falsework was re-assembled. As a result of these alterations the actual support conditions for the trusses on the grillage beam assemblies bore little resemblance to those assumed in calculations, namely vertical loads applied centrally on the bearings without horizontal forces. Other effects which had not been allowed for included frictional forces in the rocker bearings. the inadequate fixing and the eccentricity of the bearing pads on the 10 in × 10 in × 49 lb header beams, and the poor seating of the grillage beams in the forkheads.

No calculations were available from the contractor in respect of the buckling and twisting effect of the thin webs of the grillage beams.

Although the bracing was typical of the standard found generally in falsework it was not sufficient to ensure the high standard of stability necessary to cater for the horizontal and dynamic forces likely to occur. It was not however considered that this caused the collapse.

Although the trusses buckled and twisted, they had withstood the effects of the collapse very well except for the weld failure in one of the top boom connections and the detachment of one of the diagonal tubular members.

Conclusions (All opinions are those of HM Factory Inspectorate)

It may never be possible to establish the precise order of events in the collapse. The fact that only part of the final load was sufficient to cause the collapse is significant and indicates defective construction or inadequate strength. On the basis of the evidence so far established, defects in the grillage and its immediate supports probably led to the successive failure of parts of the grillage as the load was applied. If the grillage had started to collapse, the trusses would have bowed and buckled and become displaced. The complete collapse of the structure would then have been inevitable. The factor of safety of 1·3 in the grillage, which was revealed by tests carried out after the accident, was too low when the possiblity of horizontal forces being applied under site conditions is taken into account.

The sliding of the falsework from under the completed southern carriageway to the site of the northern carriageway was not undertaken with sufficient care and weakened the structure. The final examination of the falsework, before pouring commenced, was also open to criticism.

The deficiencies enumerated below indicate that insufficient consideration had been given to the design and construction of this falsework and that the combined effect of these deficiencies reduced the theoretical overall factor of safety below that acceptable for such temporary structures in which there are many unknown factors relating to design and construction:

(a) The clearance between the trestles and the adjacent concrete piers was appreciable. It is considered that the trestles on one side of the span should have been positively anchored to the adjacent pier and movement at the opposite side restricted.

(b) The damaged legs of the trestles were straightened and re-used instead of being replaced.

(c) Many of the bolts connecting the component parts of the trestles were missing and others were not sufficiently long to accommodate a full depth of nut.

(d) There were no stiffeners fitted to the thin webs of the 10 in × 10 in × 49 lb universal coloumns and 12 in × 6½ in × 31 lb universal beams of the mild steel grillage assemblies supporting the trusses. These were subject to considerable buckling and twisting loads.
It is considered significant that in the only place where a web stiffener was fitted (because slight damage had occurred before use to one of the 10 in × 10 in × 49 lb universal columns) no distortion of the adjacent web or flanges occurred.

(e) The ends of some of the 12 in × 6½ in × 31 lb universal beams had been tapered by flame cutting, so reducing the effective web areas by approximately 30 per cent at points of appreciable loading.

(f) The bearings of the 12 in × 6½ in × 31 lb universal beams in the forkheads on the trestles were not flat as had been assumed in the design. In many cases, deformation of the bases of the forkheads over the jacking screws had resulted in near knife-edge supports, thus reducing the buckling and twisting strengths of the universal beams.

(g) The bearing pads on some of the 10 in × 10 in × 49 lb universal column sections in the grillage assemblies were only clipped or tack-welded in position. This was not good practice bearing in mind the horizontal forces they had to sustain.

(h) Some of the bearing pads on the 10 in × 10 in × 49 lb universal column sections were found to be eccentrically located by up to 1½ in. Such eccentricity was not allowed for in the design and resulted in unintentional eccentric loadings.

(i) The main design assumption of pin joints at the bearings between the trusses and the trestles was not realised due to the crudity of the rocker arrangement. This relied on two rough curved surfaces, exposed to the elements and not lubricated which did not provide the low resistance to rotation assumed in the design.

(j) The diagonal bracing provided between the trusses was not sufficient to ensure the high standard of stability necessary to resist the horizontal and dynamic forces which may have occurred.

Additional comments

It was considered that the flexural shortening of the compression boom of the trusses would have applied a horizontal force to the top of the trestles.

There was some concern over the variation in dimensions caused by inaccurate rolling of some of the steel sections.

The verticality of the structure after the moving operation was questioned.

The effects of vibration from a nearby railway were considered but were not thought to contribute to the failure.

Although German and French operatives were involved in the erection of the falsework no language problem was evident.

Summary of the investigation of the collapse of the Skyline Plaza, Fairfax County, Virginia 1973

Description of structure

The Skyline Centre Complex which was located near Baileys Crossroads, Fairfax County, Virginia was a development planned to contain eight apartment buildings, six office buildings, a hotel and a shopping centre. The building which collapsed was designated A-4 and was of reinforced concrete flat plate construction supported on a 4 ft 0 in thick foundation mat. The completed structure was to have had 26 storeys of apartments plus a penthouse and a four storey basement. The typical storey height above ground was 9 ft 0 in from top of slab and the floor slabs were 8 in thick. The building was to be approximately 386 ft long by 76 ft wide. Normal weight aggregate concrete of varying strengths was used in the columns and lightweight coarse aggregate concrete in the floors. Inspection on 2 floors showed that the lightweight aggregate concrete floor slab passed through the columns. The floors were cast in 4 sections which are shown on a plan view on page 118.

The collapse

The collapse of this building occurred at about 14.30 on Friday 2 March 1973, killing 14 men and injuring 34.

The collapse extended between shear wall H and column 33 on the south face, a distance of about 65 ft and on the north face extended between columns 12 and 17, a distance of about 104 ft. The collapsed portion of the building was located approximately under the slab being cast and extended vertically for the full height of the building, 23 storeys plus 4 basement storeys.

The collapse progressed vertically, the debris from one slab overloading the floor below and collapsing that, so that it fell onto the one below, which in turn became overloaded. It also caused failure of the entire adjacent garage area (approximately 300 ft × 340 ft on plan) for which one entire floor and part of the next had been cast.

Investigations

Investigations were conducted by officials from various US Departments and covered such items as concrete and steel strengths, stress analysis of floor slabs and of falsework systems. The effects of the tower cranes on the building were also considered. Although some of the factors relating to tower crane installation and usage deviated from the prescribed regulations there was no suggestion that the cranes had initiated the failure. There was a complete lack of field-cured concrete specimens but it has not been suggested that the concrete mix and control were inadequate in any way.

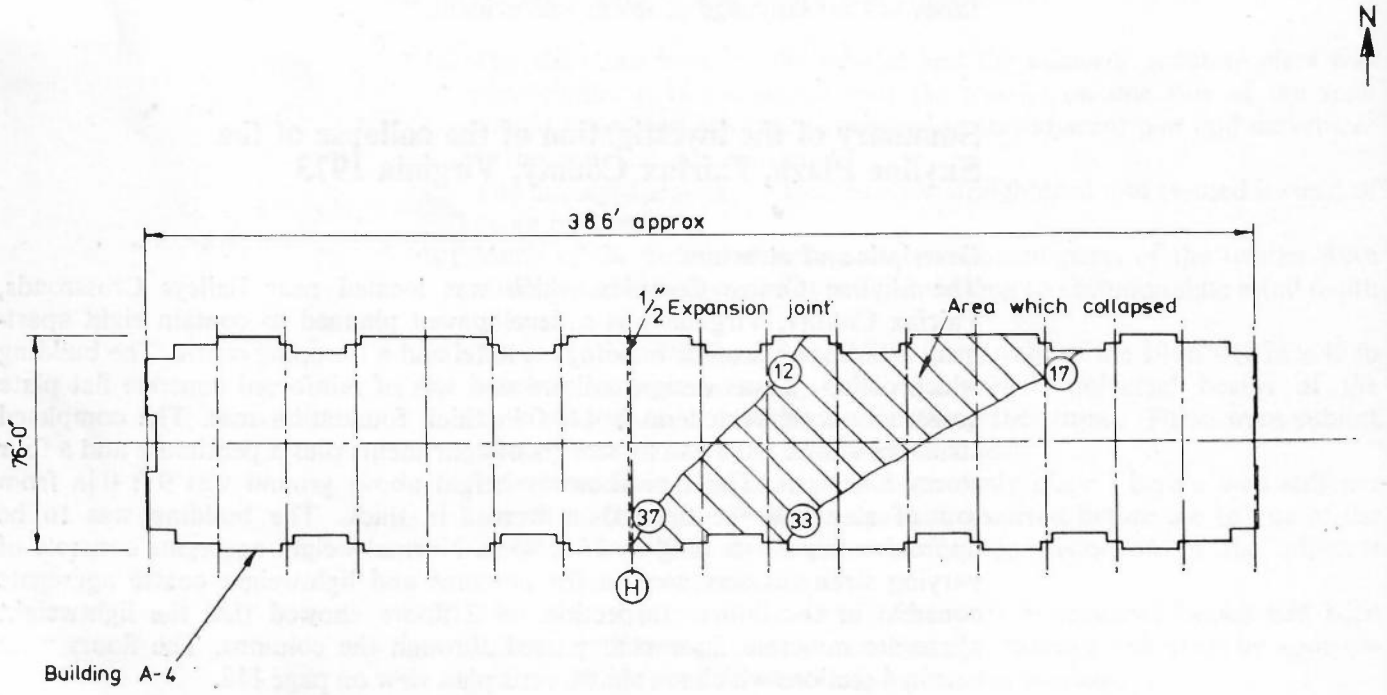
Findings of investigations

Cause of collapse

The premature removal of the propping system initiated the failure.

Mode of failure

On the basis of evidence as well as analysis, it appears that the collapse was initiated at the 23rd floor level.



An analysis of the 23rd floor slab indicates that its most likely mode of failure was in shear around one or more columns in section 3 of the floor slab. The strength of the 23rd floor slab on the day of collapse has been found to be of a magnitude that complete or partial removal of shoring underneath the slab would have produced a shear failure in the slab. The weight of debris resulted in failure in the slabs below and carried through the height of the building.

Shoring in Section 3 of the 22nd storey

Examination of physical evidence and employees' statements indicate that the 22nd storey forms were being removed on the day of the incident. Occupational Safety and Health Administration (OSHA) regulations require adherence to engineer's specifications and local building codes in determining length of time for forms to remain in place. The engineer's requirements were expressed in the form of a note on the structural drawings. This note required the "slab being poured to be shored for two floors and back propped at centre of span each way and at centre of bay on next floor down". The architect's specifications required that "In all cases, two floors shall be fully shored". The removal of the 23rd storey forms left only one storey of formwork in place under the recently poured 24th floor.

Premature removal of 22nd storey forms

The length of time forms were required to be left in place was not explicitly stated by the engineer, architect or local code. In such instances OSHA regulations provided minimum curing times. The 4-day old 23rd floor slab had spans exceeding 10 ft. The forms removed on the 22nd storey were in an area with spans exceeding 20 ft and therefore, according to the regulations, should have been in place for 10 days of temperatures exceeding 50°F.

Lateral bracing

OSHA regulations require the design of braces and shores to resist all foreseeable lateral loads. Minimum value of 100 pounds per foot of floor edge or 2% of the total dead load of the floor, whichever is the greater, is required. No evidence has been found which indicates that lateral load was considered in the design of forms. The lateral bracing provided (about 2 nominal 3 in × 4 in timbers per 16 ft, would not provide this resistance.

Shoring out of plumb

OSHA regulations allow a maximum deviation of $\frac{1}{8}$ in per 3 ft out of plumb. Deviations of shoring exceeding these limits were found on the 23rd and 24th storeys.

Damaged shoring

OSHA regulations required removal of damaged or weakened shoring. On-site inspection after the incident indicates this was not done on the 23rd and 24th storeys.

Inspection

OSHA regulations require inspection immediately before, during and after placing concrete. Either this was not done or deficiencies in the shoring were not corrected.

Summary of the principal features from the study of a selection of falsework collapses

Case 1

An *in-situ* concrete bridge of 65 ft span of flat slab construction was being built for a by-pass road over a canal.

The falsework consisted of Hunnebeck trusses 8 ft deep and spaced at 4 ft centres across the width of the bridge. The tresses were supported on timber trestles approximately 7 ft deep and sat on the abutments of the bridge which had already been cast. The timber formwork for the deck slab was suspended from the bottom tie members of the trusses. The trestles were made from baulks of timber and were similar in form to vierendeel girders with some scaffold tubes to maintain the rectilinear shape of the panels. The timber members were nailed together. No bracing or shoring was provided to prevent sideways movement of the trestles, their stability being dependent upon the width of the timbers. There was no horizontal bracing between the top booms of the Hunnebeck trusses but some vertical bracing in the form of scaffold tubes was provided between the trusses at intervals along their lengths.

Collapse occurred when concreting was being carried out at one edge of the bridge. Concrete had been placed at the centre of the span and work was proceeding towards the abutments when one of the trestles collapsed sideways.

The cause of the collapse was considered to be the instability of the trestles against horizontal forces arising from the concreting operations.

Case 2

A concrete building 100 ft 0 in long × 80 ft 0 in wide and two storeys high was being constructed. The first floor, which was 15 ft above ground level, was under construction.

The falsework consisted of adjustable steel props, on timber sole plates, with flat heads to support the timber formwork bearers. The bay size of the floor was 33 ft 0 in × 20 ft 0 in. In one bay the props had been arranged in pairs in three lines parallel to the 33 ft 0 in length of the bay giving formwork spans of 10 ft 0 in. The adjacent bay had two lines of props parallel to the 33 ft 0 in length with a centre line at right angles to these, thereby giving formwork spans of 17 ft 6 in.

The bay with 10 ft span bearers was poured successfully, but during the concreting of the adjacent bay the floor collapsed, the centre line of props failing under load.

The cause of the collapse was considered to be overloading of the centre props. These carried more load than those in the adjoining bay because of the different spacing. No drawings had been provided for the scheme and a change in lay-out had been made by the site staff without any consideration of the consequences. In addition there were the following serious defects in construction:

(a) no bracing or ties were provided to the propping arrangements
(b) props were out of alignment and eccentrically loaded
(c) a mixed assortment of lengths of props had been used, and it was probable that one prop had been placed on top of another in some instances
(d) pieces of reinforcing bars were used instead of proper pins in the props.

Case 3
The first floor of a building on a power station site under construction. The floor was 18 in thick and was about 10 ft above ground level.

The formwork for the floor slab was supported on lightweight adjustable centres 12 in apart, which in turn were supported on 5 in × 2½ in rolled steel joists. The latter were carried on shoreload frames spaced 6 ft apart, by means of cross head 5 in × 2½ in RSJ bearers which sat in the forkheads of the shoreload frames. Very little bracing was provided between the frames and the forkheads which extended 18 in were not braced. In addition the 5 in × 2½ in RSJ main bearers were eccentric in the forkheads.

As the pouring of the floor was being completed the decking caved in and the floor collapsed, as the frames distorted.

The cause of the collapse was thought to be overloading of the shoreload frames, as a result of eccentricity at the forkheads and the absence of bracings or ties.

Case 4
The concrete roof of an assembly hall 102 ft long × 76 ft wide, for a new school, was under construction. The roof was 17 in thick, of cellular construction and supported on brick walls.

Single adjustable props on a 6 ft × 4 ft grid supported the formwork for the roof deck. Since the height of the strutting required exceeded 16 ft, the flat heads of the props were connected by rolled steel joists which formed the base for another storey of props. Rolled steel joists also provided support for the roof deck. Scaffold tubes at three levels connected the props together and there was also some diagonal bracing. The props were fitted with base plates which rested on the concrete ground slab.

Just after about half of the roof slab had been concreted, the falsework moved sideways and then collapsed.

It was thought that instability of the props was the prime cause of the accident. These were inordinately long, split at the middle, and out of plumb. Furthermore there was an absence of diagonal bracing in two directions to compensate for the break in the props.

Case 5
The roof of a two storey reinforced concrete factory building, 40 ft × 32 ft in plan was under construction. The roof was 11 in thick, the two bay sizes being 40 ft × 15 ft, and the height from first floor to roof was 12 ft.

The timber formwork for the concrete beams composed of three layers of bearers was supported on pairs of adjustable props 4 ft apart. Adjustable centres to support the ply formwork at 16 in spacing were carried on the sides of the timber boxes for the roof beams. The bases of the props were founded on the concrete first floor slab.

During the pouring of the second bay, the roof collapsed.

The cause of the collapse was not certain as the props were not overloaded under direct loads, but the following items of poor construction were considered to have contributed to the accident:

(a) Defective timber in the lower layer of the formwork

(b) Insufficient bearing of the spade ends of the adjustable centres on the formwork
(c) Absence of bracing or ties between the props
(d) Out of plumbness of some of the props.

Case 6

A single storey telephone exchange, 75 ft × 46 ft × 17 ft high was being built of *in-situ* concrete. The roof slab was 12 in thick, the whole being composed of hollow blocks and *in-situ* topping, which were supported on *in-situ* concrete beams.

The timber boxes to form the beams were supported on a double line of adjustable props fitted with adjustable forkheads, and base plates. Adjustable centres 12 in apart spanned on to the sides of the timber boxes, and supported the plywood lining for the deck slab. The falsework was founded on timber sole plates which rested on the 12 in thick ground floor slab. The props were laced together and tied back to the concrete building columns. No drawings or calculations were prepared for the falsework.

The whole of the concrete roof was to be poured by pumping. A bay about 24 ft square had been completed and collapsed as it was being screeded level.

The cause of the collapse was the result of inadequate bearing of the adjustable centres onto the timber formwork. The spade ends of the centres at one side of the roof rested on two thicknesses of timber, each $1\frac{1}{8}$ in thick, which were inadequately nailed to the timber boxes. One of these timbers was displaced thereby resulting in the spade ends bearing on a single $1\frac{1}{8}$ in thickness. This timber crushed under the load and released the centres at one end of the span.

Case 7

The opening in a factory floor, measuring 28 ft × 14 ft was being filled in with *in-situ* concrete 9 in thick.

The plywood lining was supported on adjustable centres 1 ft 6 in apart, which in turn rested at one side of the opening on a 5 in × 2 in timber bearer which spanned 8 ft between the existing rolled floor joists.

When most of the concrete floor had been cast, one of the 5 in × 2 in timber bearers broke in the middle and the floor collapsed.

No calculations or drawings had been done for this work. The general foreman decided on the size of the falsework members. Check calculations showed that the 5 in × 2 in timber bearers were grossly overloaded.

Case 8

The roof of a two storey factory building of *in-situ* concrete, measuring 30 ft × 25 ft was under construction. It was 15 in thick.

The falsework consisted of three lines of scaffold tubes, the outer lines being of single tubes spaced 4 feet apart and the centre line being of twin tubes also spaced 4 feet apart. All the scaffold tubes were fitted with adjustable forkheads and base plates. Timber bearers rested in the forkheads to support the timber boxes for the centre roof beam. At the two sides of the roof, the timber bearers sat in the forkheads but were also bolted to the concrete walls of the building.

Adjustable steel centres 12 in apart spanned on to the centre formwork boxes and the outer bearers to carry the ply lining. Only a few bracing members for the whole of the falsework were found in the wreckage.

When approximately 75% of the area had been cast the roof collapsed.

No calculations were done for the falsework by the contractors, but a check made later revealed that the standards would have been 25% overloaded even if properly braced. The lack of bracing however meant that their slenderness was increased and that there was a 60% overload. In addition some of the timber bearers were overstressed.

Case 9

The roof slab of a single storey concrete factory building 60 ft 0 in × 30 ft 0 in × 12 ft 0 in high was under construction. It was 6 in thick.

The falsework consisted of timber runners 16 in apart supported on beams at their ends. These beams were carried in metal hanging brackets and were also supported by props at their intermediate positions.

When most of the roof was poured it collapsed.

The hangers opened out under load allowing the end beams to loose their bearing and thus fall.

Case 10

The construction of a multi-storey car park was a mixture of precast and *in-situ* reinforced concrete. The columns and edge beams were cast *in-situ* and the main span beams, at 5 ft centres were precast. Between the main beams were laid short precast in-fill panels to support the *in-situ* floor deck.

The *in-situ* and precast beams were supported on twin adjustable props 2 ft apart and spaced at intervals ranging from 3 ft and 5 ft. Along two sides of the building the main precast beams rested on the timber formwork for the *in-situ* beams. The props had flat heads and the timber bearers sat eccentrically on these. Furthermore the distribution of loading from the heavy pre-cast beams was unbalanced due to the way the falsework was arranged. In addition there was a lack of bracing and generally the falsework was of poor construction, evidenced by the number of makeshift pins and split timbers that were used.

The accident occurred when one of the side shutters to the *in-situ* concrete edge beam overturned causing a progressive collapse of four of the main pre-cast beams.

The collapse can be attributed to eccentric loading on the formwork to the edge beam coupled with a generally very poor standard of construction.

Case 11

The domed roof of a concrete reservoir 240 ft diameter × 30 ft high was under construction. It was 9 in thick and supported on concrete columns.

The falsework was composed of towers made up from scaffold tubes in 16 ft × 4 ft units. These towers were fitted with base plates and adjustable forkheads, and were about 30 ft high. They were not tied back to the concrete columns, nor were they braced in any way, but merely connected together by ledgers and transoms.

The forkheads, which carried the timber bearers for the formwork, were extended to 18 in in many cases and were unbraced. Adjustable centres spanned on to the timber bearers to give support for the curved plywood lining.

Owing to the large areas involved the concreting was done in segments working from the centre downwards towards the edges of the circular tank. Two segments had been successfully poured and a third was two-thirds complete when the falsework moved sideways and then collapsed.

The cause of collapse was attributed to the instability of the towers which were 30 ft high, unbraced and untied. They probably moved sideways under horizontal loading, thereby releasing the adjustable centres from their 2 in seatings on the timber bearers. This falsework was very poorly constructed, despite the fact that a drawing had been produced which showed the towers tied to the concrete columns and properly braced and that forkhead bracing was detailed. In addition the timber was of poor quality and some bearers were eccentric in the forkheads.

Case 12

The first floor of a multi-storey hotel was being concreted when the accident occurred.

The falsework consisted of plywood lining carried on 9 in × 3 in timber bearers at 16 in centres, the bearers in turn being supported by timber beams. These beams were supported on adjustable props on a grid 22 ft × 8 ft 6 in.

One bay of the floor had been successfully poured and another was almost completed when it collapsed.

It was not certain what had caused the collapse, but the load on each prop was nearly 3 tons and because of slenderness they were probably grossly overloaded. The spacing of the props was certainly excessive.

Case 13

The first floor of a multi-storey supermarket in a shopping centre was being built. It was of 'Kaiser' construction. This consisted of 2 ft deep ribs with 'honeycomb' pattern slabs between, the floor slab being 4 in thick and the pattern effect being formed by the use of domed fibreglass formers. Each panel of flooring was approximately 35 ft square.

Timber bearers spanning two ways supported the ply lining. These bearers were generally supported on adjustable props in a diamond pattern in plan, but in some areas the props were arranged in a conventional manner i.e. in rectangular panels. The props were generally on a 4 ft grid and were laced together, but were neither tied back to a firm anchorage nor diagonally braced. They were fitted with flat ends top and bottom.

After an area of floor 50 ft × 30 ft had been cast, it folded in the middle and collapsed.

The failure occurred where the diamond pattern and rectangular panels were adjacent but not connected. The absence of bracing and tying, in conjunction with the heavy loading in this area from the 2 ft deep ribs, were thought to be main cause of collapse.

Case 14

A motorway bridge over a river was under construction. The bridge was of *in-situ* concrete spanning 100 ft on to concrete abutments.

Lattice type girders carried on steel trestles in groups of four, which were founded in the river, provided temporary support for the wet concrete. The foundations for the trestles consisted of precast concrete rings filled with mass concrete.

This was only a partial failure in that some of the concrete rings had been washed away or moved by flood water. Remedial work had been completed by bracing groups of trestles together, sand-bagging scoured areas, and providing temporary foundations to replace those that had disappeared.

The cause of this partial failure was attributed to the designers underestimating the effect of flood water, in an area where it was likely to occur. The remedial work was not satisfactory and the reconstruction of the foundations entailed removing part of the falsework, concreting over the river bed to prevent further scouring and rebuilding the foundations.

Case 15

In an *in-situ* concrete sub-station, 60 ft long × 35 ft wide, the 6 in second floor slab was under construction.

Adjustable steel centres 2 ft apart, supported on a centre row of props and on the concrete walls of the sub-station at their ends, carried the ply lining for the floor slab. The centres spanned 10 ft between the end wall and the props. They rested on timber bearers at the prop positions, the bearers being spiked in places to the flat heads of the props. The props were founded on the first floor of the building some 16 ft below the second floor, and were laced together in the longitudinal direction.

The area of floor which collapsed was 23 ft × 20 ft.

An accumulation of defects was thought to be the cause of this collapse. These included: props not vertical; timber bearers not fixed to flat heads of props in many cases; and absence of diagonal bracing. In addition there were large bundles of reinforcement placed on the formwork during concreting operations, imposing heavy loading on the falsework.

Case 16

The first floor of a water treatment plant building was under construction. It consisted of 9 in thick slabs in bays 16 ft × 14 ft.

The ply lining to the formwork was carried on adjustable centres 2 ft apart and supported on adjustable props, These centres spanned 14 ft and were supported on timber bearers which rested on the flat heads of the props. The height of the props was 13 ft 6 in. There was no bracing or ties between the props.

One bay had been completed and two-thirds of the second when the whole area of floor collapsed.

It is most probable that the centre row of props was overloaded. This was the result of mis-alignment of the props, and lack of diagonal bracing. Another factor may have been the low resistance of the timber bearers to tipping.

Case 17

A multi-storey concrete building 316 ft high was under construction. Falsework was erected around the services tower to support formwork for the cantilevered floor 18 in thick, of the boiler room.

The falsework was in the form of a conventional heavy duty scaffold, 40 ft wide, with double standards for the bottom 80 ft. The timber formwork to support the 18 in thick slab consisted of 4 in × 3 in joists at 15 in centres, carried on 8 in × 3 in joists at 4 in centres, which in turn were supported on the adjustable forkheads to the scaffold. Ladder beam sections were also used in this area because of the heavy loading and bending effects. This falsework had originally been designed for a 12 in thick floor slab. To accommodate the thicker slab, standards were doubled up and a raking system introduced whereby it was hoped that some of the load could be carried on the shell of the building.

After the boiler room floor slab had been cast, the standards in the upper section of the scaffold buckled but were held in position by the ties. Thus the scaffold did not fall to the ground.

It was difficult to arrive at a firm conclusion regarding the cause of the collapse. Access to the damaged falsework was difficult. Clearly the standards had failed though buckling and the form they took suggested that the effective length was at least two lifts, i.e., 13 ft 0 in. This could have been the result of inadequate tying and/or bracing on one of the corners of the structure. There was also doubt about the effectiveness of the raking system mentioned above.

Case 18

The third floor of a reinforced concrete hospital was under construction at the time of the accident.

The soffit of the floor slab was supported by falsework. This was a proprietory system consisting essentially of plywood panels set in steel frames which fitted between fabricated beams. The beams were located on lugs on drop-head units which were carried on adjustable steel props. The drop-head units permitted the soffit shuttering to be struck leaving the props in position until the concrete had cured sufficiently to achieve its required strength. Single horizontal tubes were fixed to the steel props in the direction of the steel beams and these were occasionally tied together with tubes at right angles.

It was during the laying of the panels between the beams that the accident occurred. Some of the panels would not fit between the beams and when force was applied by kicking the panel, the whole assembly collapsed.

This collapse resulted from the instability of the falsework when subjected to horizontal loading. The provision of temporary diagonal bracing with horizontal tie tubes in two directions would have stabilized the structure. Alternatively the falsework could have been tied back to the existing building.

Case 19

The roof, 52 ft 0 in long × 9 ft 8 in wide × 8 in thick of a reinforced concrete building was under construction at the time of the accident.

The falsework consisted of adjustable centres 12 in apart supporting the plywood lining, which rested on 5 in × 3 in timber bearers. These were carried in adjustable wall brackets spaced at 4 ft. centres. These brackets were suspended from the *in situ* concrete roof beams which had been cast three weeks previously.

When about half the slab had been poured the entire support system collapsed. It was noted at the time that concrete had broken away from the edge of the beam for a distance of $1\frac{1}{2}$ in. Also the toe of the bracket which had rested on the concrete wall was bent upwards at an angle of 60° to the horizontal.

This collapse was attributed to the failure of the concrete under the bracket seating. It had failed under a load much lower than the safe working load of the bracket as given in the manufacturer's trade literature. Clearly the strength of wall brackets of this type is dependent upon the bearing surfaces by which it is supported. The manufacturers have since co-operated by drawing attention to this fact and have also de-rated the safe working load.

Case 20

A three storey hospital, 130 ft long × 56 ft wide was being built. The structure consisted of steel columns with precast concrete floor and roof beams running only in the logitudinal direction. Steel tie beams were provided in the transverse direction as temporary supports.

This building relied on the completed floors for its stability and thus while the frame was being erected falsework was necessary to provide temporary support until the permanent structure was self-supporting. This falsework should have been in the form of guy ropes or temporary bracing but none was provided and only a few of the tie beams were used.

Collapse occurred when all the framework had been erected and a start had been made on laying the precast concrete floor units. The wind at the time was moderate.

Collapse was the result of overall instability because of the lack of temporary bracing or guys. The only resistance to sway forces was provided by the few ties connected to the beams, and this was inadequate.

Details of some inspections carried out by HMFI following the Loddon falsework collapse

Case 1

A road bridge was being built to span a river. It had a prestressed concrete deck slab 4 ft deep, supported on *in-situ* concrete columns on dry land.

The falsework on dry land consisted of millshore frames supporting conventional timber formwork, that over the river consisted of auto-fab girders which supported transverse universal beams to carry the timber formwork.

Defects

(a) *Foundations* Base of millshore supports placed on edge of timber sleepers. Timber sleepers not placed horizontally in some cases.
(b) *Structure* Some millshore support frames were tilted. Diagonal braces on frames were not properly connected. Adjustable forkheads not properly used in some cases.
(c) *Formwork* Timbers were not properly secured together.

Case 2

Two motorway bridges were being built with prestressed concrete deck slabs 2 ft 9 in deep supported on concrete piers.
The falsework on one bridge consisted of trestlex frames with rolled steel

joists supported in the forkheads to carry the timber formwork.
Indumat trestles were used on the second bridge, with similar supports for the timber formwork.

Defects
Structure Absence of plan bracing in the trestlex and indumat trestles.
Forkheads were extended above 15 in in some cases but no bracing was provided. It was claimed that reduction in the safe load of the trestles allowed for this.
Trestlex trestles were not adequately braced together.
Trestles were free standing, i.e. no tying back to a strong point to provide stability.

Case 3
A reinforced concrete arched bridge with clear span of 130 ft and a height of 40 ft above the river, was being built to carry a single carriageway on a deck 46 ft wide.
The falsework consisted of Mills V 800 type trussed beams of 40 ft span, which were supported on a centrally placed millshore tower and radial raking shores at the abutments thereby creating a two span structure. Curved timber formwork panels rested on the falsework structure.

Defects
(a) *Foundations* This supported the raking shores and the birdcage scaffolding which formed the end support of the falsework. It was heavily fissured and weathered. Upstream of the central tower, a temporary breakwater had been constructed but no protection had been provided for the tipped rock base support for the north side raking shores.
(b) *Structure* The intention was to commence concrete pouring operations with only one set of trussed beams erected between the central tower and one abutment. This was not as the designer intended and might have had serious consequences. Many loose couplers were found and there was a lack of bracing in the raking shores.
The central towers were not diagonally braced together.

Case 4
The first-floor beams, 23 in × 21 in for a multi-storey concrete car park with clear span of 50 ft were under construction.

The falsework consisted of timber boxes carried on a two tier system of 6 in × 3 in timber bearers which in turn were carried on adjustable steel props spaced on a 4 ft grid. The beams in the lower tier were nailed to the flat heads of the props.

Defects
(a) *Structure* Most of the props were out of plumb and were not in line under the beams. No ties or bracing between the props were provided.
(b) *Formwork* In some cases the nails were only partly driven into the timber bearers. Generally the 6 in × 3 in bearers butted together over each prop with a total of four nails provided, but there were instances where the bearers lapped and thus it was not possible to nail them correctly to the props.

Case 5
The first floor of a multi-storey concrete library was under construction.

The falsework to the *in-situ* concrete beams consisted of shoreload frames spaced 5 ft apart, fitted with adjustable bases and forkheads. Timber bearers sat in the forkheads to support the timber boxes for the beams.

Defects

(a) *Foundations* The site was very untidy with a mixture of timber sole plates which sat on the concrete ground floor slab.

(b) *Structure* Most of the shoreload frames were seriously out of alignment. Some of the forkhead screws were damaged and had been re-used.
Bracing had only been provided on one side of the frames and there were no horizontal ties.
A reinforcing bar had been used instead of a proper pin on one of the props.

(c) *Formwork* The general standard of the timber formwork was poor, as evidenced by split joists, warped timbers, and the untidy arrangement of members.
Some of the timber bearers were eccentric in the forkheads.

Case 6

A multi-storey car park was under construction. Floors were precast and there were *in-situ* main beams with in-fill precast panels.
The falsework consisted of adjustable props at 3 ft centres under the beams and the precast main beams rested on the boxes for the *in-situ* edge beams.

Defects

(a) *Foundations* Some of the bases of the props were supported by cantilever timber beams.

(b) *Structure* There was a lack of bracing between the props.
Some props which were of considerable height supported the timber bearers in a precarious manner.
Reinforcing bars were used instead of proper pins in the props.

(c) *Formwork* The arrangement of timber members for the *in-situ* concrete edge beams was poor, resulting in unbalanced loading on the falsework.
The quality of timber in many cases was poor.

Appendix 2 Organisations giving evidence

Amalgamated Union of Engineering Workers – Construction Section
Association of Consulting Engineers
Berkshire County Council, Chief Resident Engineer's Department
British Insurance Association
British Railways Board, Chief Civil Engineer's Department
Concrete Society
Construction Industry Research and Information Association
Construction Industry Training Board
Costain Civil Engineering Ltd
Department of the Environment, Highways Division
Federation of Civil Engineering Contractors
HM Chief Inspector of Factories
HM Construction Engineering Inspectors of Factories
Institution of Civil Engineers
Institution of Industrial Safety Officers
Institution of Structural Engineers
Marples Ridgway Ltd
National Federation of Building Trades Employers
Royal Institute of British Architects
Royal Society for the Prevention of Accidents
Trades Union Congress
Transport and Road Research Laboratory

Appendix 3 List of persons giving evidence

T Ackroyd, Institution of Structural Engineers
K J Adams, Mabey & Johnson Ltd., 2, Caxton Street, SW1
D Barclay, Practice Section, Royal Institute of British Architects
C Boswell, HM Construction Engineering Inspector of Factories
N Buckley, Legal Secretary, Federation of Civil Engineering Contractors
R. F. Chadney, Managing Director, Marples Ridgway Ltd.
H Clamp, Royal Institute of British Architects
D J D Clark, Institution of Civil Engineers
J C Corrin, Midland Employers Insurance Ltd., representing the British Insurance Associations
L Creasy, President of the Institution of Structural Engineers
W A Dawson, Institution of Civil Engineers
D V R Fawell, British Insurance Association
F. Godley, Chairman of the London Group of the NFBTE
J Hanna, TUC Economics Department
Sir William Harris, President of the Institution of Civil Engineers
B H Harvey, HM Chief Inspector of Factories
R Hearn, Director of Industrial Safety Division, RoSPA
P Jacques, Secretary, TUC Social Insurance Committee
R. Johnstone, Legal Adviser, Royal Institute of British Architects
P G Jordan, National Federation of Building Trades Employers
P M Lee, Superintending Engineer (Civil), Highways Division, Department of the Environment
Glyn Lloyd, Member TUC Social Insurance Committee
J D Maiden, Centre Manager, CITB Training Centre, Bircham Newton
R J W Milne, Institution of Structural Engineers
J F O'Hara, Project Engineer, Costain Civil Engineering Ltd.
K Owen, Director, CITB Training Centre, Bircham Newton
T Parry, General Secretary, Fire Brigades Union
W I J Price, Transport and Road Research Laboratory, Department of the Environment
Major-General M W Prynne, Secretary, Association of Consulting Engineers
P Pullar-Strecker, Director of Information, Construction Industry Research and Information Association
D W Quinion, Tarmac Construction Ltd., representing the Concrete Society Ltd.
E H Ramage, President, Federation of Civil Engineering Contractors
E Revill, HM Construction Engineering Inspector of Factories
G W B Scruby, Senior Partner, Frederick Snow & Partners, representing the Association of Consulting Engineers
M Simpson, Chief Resident Engineer, Berkshire County Council
E V Taylor, the Commercial Union Assurance Co., representing the British Insurance Association
K Tomasin, HM Deputy Superintending Construction Engineering Inspector
J M Totterdell, President, Institution of Industrial Safety Officers
C Tucker, Chief Civil Engineer's Department, British Railways Board
C Turner, Managing Director, Rapid Metal Developments Ltd.

Appendix 4 Papers considered by the Committee

The Committee's terms of reference and Chairman's proposed programme of action
Paper on "Responsibilities" by Bridges Engineering Division, DOE
The Loddon Viaduct collapse, presented by Marples Ridgway Ltd.
The Loddon Viaduct collapse. Reports of HM Construction Engineering Inspectors of Factories
The organisation of falsework inspection by a national contractor
Rules for inspection and certification of concrete falsework by a national contractor
Falsework. A statement of shortcomings by DOE
The Employers' Liability (Compulsory Insurance) Act, 1969
The Employers' Liability (Compulsory Insurance) Act, 1969 – Guide
The Employers' Liability (Compulsory Insurance) Act, 1969 – General Regulations, 1971
Proposed British Standard Code of Practice on Falsework – Terms of Reference
Pro forma for falsework failure analysis
Proposed revision of Construction Safety Orders by the State of California, Dept. of Industrial Relations, Division of Industrial Safety
The appraisal and checking of civil engineering and structural work: Technical Instruction CE DOE May 1972 Serial 75
Falsework contract: summary of action taken by DOE, Bridges Engineering Division
"Responsibilities", Draft paper by the Chairman
Paper on the Loddon Viaduct failure by the Berkshire CC Chief Resident Engineer
Paper on the Loddon Viaduct failure by the Berkshire CC Chief Resident Engineer – calculations only
The Concrete Society (ICE) Report: DOE comments
Paper on vertical buckling and crippling of webs from Design of Modern Steel Structures, by Grunter, published by Macmillan & Co. Ltd.
Technical approval of DOE Highway Structures on Trunk Roads and Motorways by Bridges Engineering Division, DOE
Circular to Road Construction Units No 15/73; Technical Approval New Procedures, DOE
Clauses 13 and 14 of ICE contract, 5th edition: DOE commentary
DOE commentary on Advisory Committee on Falsework Committee procedure
Technical papers: Kerensky and Others on proposed basis for estimating lateral buckling stresses
The Construction (General Provisions) Regulations, 1961
The Construction (Working Places) Regulations, 1966
The Loddon Viaduct Report: DE corrigendum
Collapse of Birling Road Overbridge: HMFI Synopsis
Verbatim transcript of evidence by Marples Ridgway Ltd.
Unsatisfactory falsework conditions: HMFI photographs
Collapse of falsework for the River Loddon viaduct: DOE commentary
Published Report by HM Factory Inspectorate on the Collapse of falsework for the Viaduct over the River Loddon, 24/10/1972, published by HMSO
Verbatim transcript of evidence for published Report by HM Construction Engineering Inspectors
Verbatim transcript of evidence for published Report by Berkshire CC Chief Resident Engineer
Precis of verbatim transcript of evidence for published Report by Marples Ridgway Ltd.

Dimensions of universal beam cross sections: letter from Transport and Road Research Laboratory, Bridges Construction Division
Lessons from the Loddon Accident: comments by the Chairman
Case studies on falsework collapses: HMFI Synopsis
Case studies on falsework collapses: HMFI Photographs
Paper on Report on communication of design
Final Report of the Merrison Committee – An enquiry into the basis of design and method of erection of steel box girder bridges. Published by HMSO
BS Co-drafting Committee CV CP 2: DOE proposals
Birling Road Overbridge: Drawings
Birling Road Overbridge Collapse: Drawings
The Advisory Committee on Falsework draft Interim Report
JAC on Safety and Health in the Construction Industries: Sub-Committee Report on Scaffolding
Falsework failures: verbatim transcript of general evidence by HMFI
Box Girder Design Committee Interim Report
The Advisory Committee on Falsework draft Interim Report – Members proposals
Written evidence by Trades Union Congress on Falsework problems
The Advisory Committee on Falsework: final draft of Interim Report
Transcript of verbatim evidence on falsework failures by Costain Engineering Ltd.
Statistics of accidents in the construction industry
Questionnaire on falsework to research establishments
The Advisory Committee on Falsework: Chairman's report on progress to Secretary of State, and reply
Draft recommendations for construction propping. French proposals
Commentary on ICE conditions of contract
The Advisory Committee on Falsework: revised draft of Interim Report
Local falsework collapse. Press report and photographs
Memorandum on reportability of no injury-producing falsework failures
The Advisory Committee on Falsework. Press notice on Interim Report
Verbatim transcript of TUC evidence
Collapse of Loddon Viaduct: Transport and Road Research Laboratory progress report on testing programme
Verbatim transcript of evidence by the Royal Society for the Prevention of Accidents
Written evidence by the Institution of Industrial Safety Officers
G C Works/1/ Contract
Paper on scheme of training for safety officers in construction
The Institution of Industrial Safety Officers. Examination papers 1969–1973
Paper on Institution of Industrial Safety Officers' articles of membership
Institution of Industrial Safety Officers' examination: Press article
The Advisory Committee on Falsework. Published copy of Interim Report
Merrison Committee Report, Appendix 1. Loading and general design requirements, etc.
Merrison Committee Report, Appendix 2, Materials and Workmanship
IED Membership grading indicator
Distribution list
Final Report: Investigation into collapse of falsework, Arroyo Seco Bridge Road, State of California, Business and Transportation Agency Dept. of Public Works Division of Highways
ICE Conditions of Contract, 5th edition. Press report

Written evidence on the Responsibilities of the Consulting Engineer in relation to falsework by the Association of Consulting Engineers
Design and method of erection of Steel Box Girder Bridges. DOE letter to councils
Independent checking of erection proposals and temporary works. Details for major highways structures on trunk roads and motorways. DOE Technical Memo B 1/74
Press report on bridge design checks
Press report on publication of Interim Report
Technical papers prepared from evidence by a member
Technical papers prepared from evidence by a member – Inspection of falsework
Technical papers prepared from evidence by a member – Lateral stability
A Report on the Collapse of falsework at the Welshpool Road Overpass, 1966 by Main Roads Department of Western Australia
Inquiry on the Collapse of the 2nd Narrows Bridge 1958 by the British Columbia Royal Commission
The ICE Conditions of Contract
Verbatim evidence. Committee's deliberations on evidence on Arroyo Seco collapse
Falsework high strength friction gripbolts. G Maunsell & Partners
Submission of evidence: E W H Gifford & Partners (Southampton), Consulting Engineers
Verbatim evidence by the Institution of Industrial Safety Officers
Falsework for Arroyo Seco Bridge, Pasadena, California, 1972: Preliminary Report
Construction Industry Training Board: Outline proposals for supervisors' training courses in falsework
Press notice on construction safety training
CITB training proposals: Technical press comment
Shortage of civil engineers: Technical press comment
Verbatim transcript of evidence from National Federation of Building Trades Employers
Verbatim transcript of evidence from Association of Consulting Engineers
Written evidence from the Amalgamated Union of Engineering Workers (Construction Section)
Interim report: press notices
Collapse of 2nd Narrows Bridge 1958. Summary of the Report of the Royal Commission Inquiry, British Columbia
Interim Report: DE and DOE Press notices
Interim Report: Technical press review
Proposed format for Final Report
The DIN standard on falsework
The Bridge Falsework Standards and Procedure, Bridge Dept., State of California, 1973
Written evidence from Institution of Structural Engineers
Memorandum of evidence by W & C French Ltd. (Construction)
Memorandum of evidence by Costain Civil Engineering Ltd.
Memorandum of evidence by British Railways Board, Chief Civil Engineer
Memorandum of evidence by SGB, Building Equipment Division
Falsework collapses. Paper by HM Construction Engineering Inspector of Factories
Verbatim transcript. Committee's continued deliberations on Arroyo Seco collapse
Report of study/visit to United States and Canada
Third draft of Falsework for construction purposes by Canadian Standards Association

The Investigation of the Skyline Plaza Collapse, Fairfax County, Virginia, June 1973. Report prepared for OSHA, Washington, DC
Report on the Heron Road Bridge failure, Ontario, Canada 1966 by H G Acres & Co. Ltd., Consulting Engineers, Toronto, Canada
Summary of the Final Report of the Investigation into collapse of Falsework, Arroyo Seco Bridge, State of California
Summary of a Report on the Collapse of Falsework, Welshpool Road Overpass. Main Roads Department of Western Australia
Summary of the Investigation of the Skyline Plaza Collapse in Fairfax County Virginia, USA. June 1973
Falsework collapse of multi-storey car park in Kuwait. Technical press report
Control of temporary works in Germany. Report by C J Wilshere
Reconstruction of Loddon Bridge. Technical press note
Bavarian bridge collapse. Technical press comment
Training in England and France. Technical press comment
Focus on contractors insurance. Technical press comment
Inst. R A Contract – "A breath of fresh air". Technical press comment
Collapse of falsework at cement silo. Technical press comment
Verbatim minutes of evidence from the Concrete Society
Verbatim minutes of evidence from the Institution of Structural Engineers
Verbatim minutes of evidence from the Institution of Structural Engineers (Edited)
Verbatim minutes of evidence. Chief Civil Engineer's Dept., British Railways Board
Supplementary written evidence. Chief Civil Engineer's Dept., British Railways Board
Application of Committee's Interim Report. Technical press comment
Memorandum of written evidence. The Institution of Civil Engineers
Need to improve conditions on site. Press comment
Dangers of training too many engineers. Technical press comment
Failure of falsework. Technical press comment
Observations on Interim Report. John Laing Research and Development Ltd.
Collected summary of verbatim minutes
Safety in the erection of frame structures. Letter from University of Surrey
Spate of large-scale mishaps in the building industry result of "throw away" society. Press notice
Training of civil engineers and safety education. Technical press comment
Conditions of employment and effect on training. Technical press comment
Memorandum of evidence. Wren Associates, Dublin
Memorandum of evidence. E W H Gifford and Partners, Southampton
Summary of the Report on the Heron Road Bridge failure. Supervising Coroner of Ontario
Comment on Interim Report. John Laing Construction Ltd.
Final Report of Advisory Committee. Draft plan
Falsework in the USA. Paper by Dr S Champion
Contractual procedures and falsework. Technical press comment
Article for engineers to take over from architects. Technical press comment
Contract practice – relationship of architect and contractor. Technical press comment
Standard form of building contract
Conditions of contract for civil engineering work. British Railways Board
Construction Industry Insurance. Technical press article
Apprenticeship and training today in the construction industry. Article in Technical press
Verbatim transcript of evidence. Federation of Civil Engineering Contractors

Report on the JAC on Safety and Health in the Construction Industries – Safety of Scaffolding
Building Contract. Institute of Registered Architects
Structural checks in design. Letter from architect
Construction safety and falsework design by G B Wins and R F Leggett, National Research Council of Canada
Falsework collapse of Koblenz Bridge. Part transcript of expert's report
Measuring bending moments. Article in technical press
Verbatim evidence of the Institution of Civil Engineers
Professional indemnity insurance. Press report
Information supplied by proprietary suppliers. Paper from Institution of Structural Engineers/Concrete Society
Comments on Interim Report by Mr Peter Hancock, Architect, Lesotho
"Codes of Practice take on new role". Technical press article
OSHA and the contracting industry in America. Technical press comment
Engineers: Status and standards. Technical press article
Distribution list
CITB revised Training Syllabus in Falsework
Exposition of Committee's 3% Rule
Elastic Analysis of Frameworks with Elastic Connections by Edgar Lightfoot and Andrew P le Mesurier. Technical paper
The strength of Scaffold Towers under vertical loading by H S Harung, Edgar Lightfoot and D M Duggan. Paper
Professional responsibility. Technical press article
Role of the Temporary Works Co-ordinator. Paper by Dr S Champion
Summary of evidence on Birling Road Overbridge collapse
Summary of evidence on collapse of falsework over River Loddon
Summary of verbatim evidence of the Institution of Civil Engineers
What is the responsibility of the Structural Engineer Technical press paper
The Report of the CIRIA Study Committee on Structural Safety
Verbatim evidence of the British Insurance Association
Recent developments in falsework in the United Kingdom. HM Factory Inspectors' Report – Construction Engineering Branch
Construction industry insurance. Discussion on paper to ISE
Rig for failure tests on Scaffold Towers. Paper by Edgar Lightfoot and D M Duggan
Instability of Space Frames having elastically-connected and offset members. Paper by Edgar Lightfoot and Andrew P le Mesurier
Verbatim minutes of the Royal Institute of British Architects
Record of the Technical Institute of Building and Public Works, Paris – Recommendations for the execution of falsework
Summary of evidence of the British Insurance Association
Brief for the falsework designer. Paper by C J Wilshere
Summary of evidence from the British Railways Board
Members' commentary on 3% rule
Chairman's paper on 3% rule
The increasing responsibility of the Structural Engineer. Article by H C Husband
Independent checking procedures. Memorandum by C J Wilshere
CIRIA Report on load factors and adjustable steel props
Propsed format of Final Report
Summary of evidence of Royal Institute of British Architects
Aero Dynamic Wind Tunnel tests applied to Buildings. Technical Press
Verbatim minutes of evidence from CIRIA and the Transport and Road Research Laboratory
Sponsorship in the Construction Industry. Technical Press
Commentary on Tasman Bridge Design. Technical Press

Statistical extract from DOE publication on the Construction Industry
Extract from paper on Ultimate Load Design of Concrete Structures
The training of civil engineers. Recommendations of the Chilver Committee
Centres offering training for safety officers
BSI Draft for public comment "Standard methods of test for falsework equipment – Part I – Floor Centres"
Verbatim minutes of evidence from CIRIA – edited
Verbatim transcript of final evidence from HM Inspectors of Factories, Construction Engineering Section
Research proposals on Falsework. W I J Price, Transport and Road Research Laboratory
Verbatim minutes of evidence. Edited. W I J Price on Research
Joint Report on Formwork

Appendix 5 Proposed outline syllabus for senior staffs' appreciation course in falsework

Duration Three days. The course ends at 16.30 hours on the third day.

Intended for Senior Engineers, Site Agents and Temporary Works Co-ordinators.

Objectives To give senior staff a better understanding of recommended acceptable practices in relation to erecting, inspecting, maintaining and striking falsework.

Syllabus *Theoretical instruction will cover:*

(a) Current falsework report
(b) Current British Standards and Codes of Practice
(c) Current Statutory Regulations
(d) Types of falsework
  (i) Light duty
  (ii) Medium duty
  (iii) Heavy duty
  (iv) Very heavy duty
(e) Checking typical falsework, drawings, schedules and specifications
(f) Falsework components ties and anchorages
(g) Principles of falsework design, covering concrete pressures and loading
(h) Ground bearing pressures
(i) Methods of erecting and striking falsework
(j) Planning and co-ordinating, erection, inspection, maintenance and striking of falsework
(k) Common failures in falsework
(l) Falsework – manager's responsibility
(m) Safe working practices in relation to erecting and striking falsework
(n) Re-use of materials i.e, timber ply etc.

Practical training will cover:

(a) Inspecting, checking and rectifying erected falsework
(b) Planning erection and striking of falsework for specific projects; drawings, schedules and specifications will be supplied
(c) Designing simple falsework soffitts

Course test Theoretical multiple choice test paper

Theoretical instruction	19 hours	*Test*	½ hour
Practical instruction	2½ hours	*Trainees per course*	9
Joining/leaving course	½ hour	*Venue*	Bircham Newton

Proposed outline syllabus for safety officers' appreciation course in falsework

Duration Three days. The course ends at 16.30 hours on the third day.

Intended for Safety officers.

Objectives To give safety officers a better understanding of acceptable safe practices in relation to erecting, inspecting and striking falsework

Syllabus *Theoretical instruction will cover:*

(a) Current falsework report
(b) Current British Standards and Codes of Practice
(c) Current Statutory Regulations
(d) Types of falsework:
  (i) Light duty
  (ii) Medium duty
  (iii) Heavy duty
  (iv) Very heavy duty
(e) Checking typical falsework drawings, schedules and specifications
(f) Falsework components, ties and anchorages
(g) Appreciation of concrete pressures and loadings
(h) Methods of placing and compacting concrete
(i) Appreciation of ground bearing pressures
(j) Safe methods of erecting and striking falsework, including slinging
(k) Common failures in falsework
(l) Re-use of materials i.e. timber and plywood
(m) Sequence of checking falsework
(n) Maintenance and storage of equipment

Practical training will cover:

(a) Erecting simple falsework systems i.e. shoreload, 'U' system scaffolding etc.
(b) Inspecting, checking and rectifying erected falsework
(c) Striking sections of falsework

Course test Theoretical multiple choice test paper

Theoretical instruction	13 hours	*Test*	½ hour
Practical instruction	8½ hours	*Trainees per course*	9
Joining/leaving course	½ hour	*Venue*	Bircham Newton

Proposed outline syllabus for first line supervisors' course in falsework

Duration Ten days. The course ends at mid-day on the tenth day.

Intended for First line supervisors i.e. agents, engineers, foremen and supervisors. Courses may be modified to meet specific needs of groups of trainees.

Objectives To give trainees a better understanding of recommended acceptable practices in relation to the erection, inspection, maintenance and striking of falsework.

Syllabus Theoretical instruction will cover:

(a) Current Statutory Regulations
(b) Current Codes of Practice
(c) Current British Standards
(d) Current falsework report
(e) Drawing office practice
(f) Reading falsework drawings, schedules and specifications
(g) Types of falsework:
  (i) Light duty
  (ii) Medium duty
  (iii) Heavy duty
  (iv) Very heavy duty
(h) Formwork/falsework, ties & anchorages
(i) Introduction to concrete pressures and loadings
(j) Introduction to ground bearing pressures
(k) Falsework foundations
(l) Planning sequence of erection and striking falsework
(m) Placing and compacting concrete
(n) Methods of erecting and striking light to heavy duty falsework
(o) Methods of checking and rectifying faults in falsework
(p) Care and maintenance of falsework components
(q) Safe working practices in relation to handling, erection, and striking falsework.
(r) Re-use of materials i.e, timber, ply etc.

Practical training will cover:
Erecting, inspecting and striking the following designed systems:

(a) Props, panels, and spans to drop beams and slabs
(b) Light duty system scaffolding, spans, timber bearers and plywood decking
(c) System falsework, spans and supports for waffle and through type floors
(d) Shoreload or similar systems to support heavy duty slabs and drop beams
(e) Trishores and D.S.L. 500 girders or "H" 33 girder construction
(f) Scaffold tubes and fittings, timber bearers and plywood decking for heavy duty slabs

Course test: *Theoretical* – Multiple choice test paper
Practical – Checking erected falsework with built in faults

Practical instruction	43 hours	*Test*	2½ hours
Theoretical instruction	24 hours	*Trainees per course*	9
Joining/leaving course	½ hour	*Venue*	Bircham Newton

Index

Printed for Her Majesty's Stationery Office by J. Looker Ltd., 82 High Street, Poole, Dorset.
D/d. 289249 K60 12/75.

HER MAJESTY'S STATIONERY OFFICE
Government Bookshops
49 High Holborn, London WC1V 6HB
13a Castle Street, Edinburgh EH2 3AR
41 The Hayes, Cardiff CF1 1JW
Brazennose Street, Manchester M60 8AS
Southey House, Wine Street, Bristol BS1 2BQ
258 Broad Street, Birmingham B1 2HE
80 Chichester Street, Belfast BT1 4JY
Government Publications are also available through booksellers

ISBN 0 11 880347 6