
**VOLUME 1 HIGHWAY STRUCTURES:
APPROVAL PROCEDURES
AND GENERAL DESIGN**

SECTION 3 GENERAL DESIGN

PART 11

BA 41/98

**THE DESIGN AND APPEARANCE OF
BRIDGES**

SUMMARY

This Advice Note gives guidelines for the scope of work expected from those designing bridges, and basic principles of design with which bridge designers should be conversant.

INSTRUCTIONS FOR USE

1. Remove BA 41/94, which is superseded by BA 41/98, and archive as appropriate.
2. Insert BA 41/98 into correct place.
3. Archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from The Stationery Office Ltd.



THE HIGHWAYS AGENCY



THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT



**THE WELSH OFFICE
Y SWYDDFA GYMREIG**



**THE DEPARTMENT OF THE ENVIRONMENT FOR
NORTHERN IRELAND**

The Design and Appearance of Bridges

Summary:

This Advice Note gives guidelines for the scope of work expected from those designing bridges, and basic principles of design with which bridge designers should be conversant.

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

SUPERSEDED

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

SUPERSEDED

**VOLUME 1 HIGHWAY STRUCTURES:
APPROVAL PROCEDURES
AND GENERAL DESIGN**

SECTION 3 GENERAL DESIGN

PART 11

BA 41/98

**THE DESIGN AND APPEARANCE OF
BRIDGES**

Contents

Chapter

1. Introduction
2. Major Factors
3. Approach to Design
4. General Principles
5. The Whole and the Parts
6. Surfaces and Weathering
7. Aids to Design
8. Special Problems
9. Conclusion
10. Bibliography
11. Enquiries

1. INTRODUCTION

General

1.1 This Advice Note gives guidelines for the scope of work expected from those designing bridges, and basic principles of design with which bridge designers should be conversant. Account has been taken of the views of the Royal Fine Art Commission for Scotland and many experienced and award winning bridge engineers.

Further Advice

1.2 More specific and extensive advice on the appearance of bridges and other highway structures is now contained in a separate publication designed to be read in conjunction with this Advice Note. It should be noted that together these documents present the principles which Overseeing Organisations regard as being the minimum standards of aesthetic design.

The new document entitled *The Appearance of Bridges and Other Highway Structures* (ISBN 0 11 551804 5) deals in more detail with the design of bridges, retaining walls, culverts, tunnels and ancillary buildings. It is a publication that abundantly illustrates both the growing importance of designing highway structures for the environment and the advances in construction technology since the Ministry of Transport publication *The Appearance of Bridges* was first published in 1964.

The importance of the appearance of bridges

1.3 Bridges are some of the largest and most visible man-made objects and it is important that they should be good in appearance as well as in other ways. The RFAC and RFACS have always been concerned about the appearance of the bridges submitted to them, and since 1925 Ministers of Transport, as the client in England, have periodically issued advice to engineers on how to improve appearance. This document continues and reaffirms that advice. While it is not possible to lay down hard and fast rules for appearance in the same way as for more technical matters, this note may be seen as part of an effort to raise the consciousness of engineers about the importance of an integrated approach to bridge design, in which appearance takes its rightful place alongside function, structure/construction and economy.

1.4 Good design requires good designers. To be a good bridge designer it is necessary to be a good engineer, but it is not sufficient. A talent for, and

understanding of, design are also required, and unless a design team includes at least one good designer, the results are most unlikely to be good. An understanding of good design is also required on the part of the client and contractor.

1.5 Bridges are forms seen in light. They are engineering but they are also architecture, just as at their best Gothic cathedrals are. Vitruvius makes no distinctions between engineering and architecture and deals not only with what we now consider to be architecture and town planning but with civil engineering, military engineering, artillery and clocks. Mediaeval cathedral designers mixed up aesthetic and structural design rules with no distinction between them. By splitting subjects into smaller and smaller subdivisions, people have gained enormously in depth of understanding of them, but have lost as much or more than has been gained. What has been lost is a view of the whole, and design, especially bridge design, is about the whole. Synthesis is what is needed, not putting bits of knowledge together to create a camel where a horse was wanted, but a synthesis in which the understanding of the parts is absorbed into an integrated whole.

Engineers and architects

1.6 There are at least two ways not to design a bridge:

- to decide what it should look like and then work out how to make it stand up and how to build it;
- to work out the most economical structural/constructional solution and then decide how to make it look nice.

1.7 The first is the architect's pitfall, the second the engineer's. In each case, by the time the decision has been made it is almost certainly too late to get it right. All the important issues have to be kept in mind from the start.

1.8 A small minority of civil engineers become bridge designers, and their academic training generally deals with appearance within the process of bridge design at a very elementary level. Architects learn through integrated design with particular emphasis on appearance all through their training and in practice are constantly aware of the aesthetic implications of their decisions. Therefore they can make a valuable

contribution to bridge design, especially on sensitive sites and on major structures. Although architects do not normally have the technical background to design bridges, their experience in integrated design can help improve the appearance of bridges. Therefore it can be of benefit for a bridge design team to have an architect as adviser.

1.9 In England and Wales, advice on when and where to appoint an architect, and on architects suitable for the particular project with its specific problems and individual location can be obtained from the Architect/Planner to the Highways Agency. Artists can also have a visual input to the appearance of bridges, usually working together with an architect.

1.10 To work effectively together it is necessary for engineers and architects to have some common understanding, some area of overlap in aims, knowledge and sympathy. Each must understand something of the other's discipline, and both need a certain humility. Often the best way in which an engineer can develop his aesthetic appreciation and approaches to dealing with aesthetic problems is by working with architects over many years, not necessarily only on bridges. It can also help to look at bridges and buildings to see how aesthetic problems have been resolved, or not, as well as apparently minor but visually important considerations, such as the way the nature of light and shadow affects the way we see things, and so on.

Designing bridges

1.11 A bridge is an entity, a thing in itself. It should be a unity in which structure, construction, materials, appearance, use and everything else come together; a unity in which all its parts relate to the whole and to each other.

1.12 A bridge is also part of the environment. The environment has many aspects, one of which is the immediate physical location, the site. The site holds the most important clues to what the bridge should be like, or perhaps what it should not be like, and these clues are both technical and aesthetic. The second set of clues is the sensible and economical ways of building it, which may be known or in some cases may be invented. The function of the bridge and its relation to the route which it serves also play primary parts. Most of the effort during the design process is going to be technical, but all the time it is necessary to keep the aesthetic and environmental implications in mind. It is necessary to concentrate on particular aspects for purposes of analysis, but analysis is only a tool for design. Unless the wider view of the whole is kept in sight, it is not worthy of being called design.



Figure 1. Bray Viaduct

The best design is the best balance of the many conflicting requirements, but there is no way of knowing whether there is a still better one except by finding it. Design is an iterative process. The process is mostly rational and can be judged rationally. However the unconscious is better at making sideways jumps than the conscious mind. If the designers have been sufficiently immersed in the facts and their conflicts, sometimes an idea which resolves most of the conflicts in a new way will suddenly emerge, and this is one of the most satisfying experiences a designer can have.

Scope

1.13 This Advice Note covers basic principles for the approach to design and for the appearance of road bridges. It also has relevance to other highway structures such as tunnels and retaining walls.

Implementation

1.14 This Advice Note should be used forthwith on all road schemes incorporating the construction of new bridges or the major alteration of existing bridges. The advice should be incorporated in tender documents for consultants, in Design and Build and DBFO tender documents, and in briefs for design competitions.

2. MAJOR FACTORS

Preamble

2.1 There are several major factors which influence the design of a bridge, such as the site, the function of the bridge, type of structure and materials, methods of construction and economics. These are by no means the only factors but they are usually the main ones and they interact, and conflict, with each other.

The site

2.2 The site in all its aspects is always unique and gives the most important clues to the design. The geotechnics of a site, which includes its history and geology, is absolutely fundamental to the kind of bridge which is practical or even practicable. It may determine what foundation positions might be possible and often what span ranges are economic. The character of the site as landscape is equally important and needs to be studied and recorded from different viewpoints. The nature of the site as a place for construction is also a significant factor, especially the access to the various parts of it and the space which is available for working

design of a bridge in relation to the landscape:

- the first is to treat the bridge as an object in itself,
- the second is to make the bridge fit into the landscape as unobtrusively as possible.

2.5 The first is the Palladian approach where the landscape acts as a background to show off the villa or the bridge. This is not to say that the landscape is ignored, but that it is regarded as a setting for the object to be placed in it. The second approach is generally more suitable in attractive rural settings, for bridges which are not so large or so dominant in location that any attempt at unobtrusiveness is doomed to failure. In every case the bridge should be tailored to its site. In rural situations particularly, the “transparency” of the bridge can be very important. Unlike a building the landscape can usually be seen through the openings of the bridge and it is often important to exploit this as much as possible, so that the bridge becomes a frame for the landscape, rather than an intrusion on it. Fitting



Figure 2. Proportions. The bridge in the upper picture has spans roughly proportional to the height above ground. The lower picture shows a conventional arrangement with equal inner spans and shorter end spans. The upper version is more elegant, but observers rarely can say why.

and storage. The visibility of the bridge, where it is seen from and at what speed may also affect what it should look like.

2.3 Apart from the physical and aesthetic aspects of the site there may be others which the designer should be aware of: historic, political perhaps, and there are of course environmental issues other than the visual ones, and many ways in which a bridge can affect people using it and in its vicinity. These may produce requirements conflicting with each other. It is important therefore that, at the route planning stage, the needs of the bridge are considered.

2.4 There are two extreme ways of treating the

the bridge to the landscape also means that the topography is taken into account. There will be a difference between a bridge in a valley with steeply sloping sides and one crossing a flood plain. The site will also affect the relative importance of the view of the bridge as seen by road users and that seen by local people living or walking nearby.

Function

2.6 The function of a bridge, which is after all the primary reason for its existence, will also have a strong influence on its character. It will determine its width, the loading and other standards which affect the dimensions of the structure, what restrictions are imposed on the alignment, the kinds of parapet which can be used and so on. Railway bridges can be markedly different from road bridges; footbridges, pipe bridges, aqueducts all have their own characteristics which can and should affect the appearance.

Structure

2.7 In a sense, a bridge is its structure, and the form of the structure is what gives the bridge much of its fundamental character. It is intimately connected with materials and the methods of construction as well as with safety and durability. Generally a bridge should honestly show its structure and materials and achieve its aesthetic effect by refinement of form and details. Forms which reflect the flow of forces, such as arches and suspension bridges are generally liked and can be dramatic, and details which reflect the flow are generally to be preferred to those which do not. This is equally as valid for modern structures as it was for historic ones.

Construction

2.8 In some cases the method of construction may have a definitive influence on the form. Since bridges are often built on difficult sites and in difficult conditions it is particularly necessary for the designer to be aware of different methods of construction and he may have to invent, or rediscover, a suitable form. (This is becoming increasingly the case with new bridges over live motorways, as for motorway widening). A good knowledge of engineering history is very useful as is a thorough acquaintance with practice in many countries. Sometimes methods which have been used for a particular material can give ideas for use in other materials. Where a designer is uncertain about some aspect of construction it is usually possible to consult a contractor, but it should be remembered that contractors differ in their views about the difficulties and merits of different methods. It is important to have a balance between aesthetic considerations and other considerations, such as ease of construction and disturbance to the traffic flow or the environment. No one aspect should dominate design.

2.9 During construction the contractor can make a positive, and sometimes a negative, contribution to the appearance through the quality of his work and ideas. Sometimes a contractor puts forward an alternative proposal or idea for construction which he thinks will save him money. This may have no effect on the appearance or even offer the opportunity of positively improving it, but sometimes it will have an adverse effect and should be resisted. Matters of this kind sometimes have far reaching consequences which are not always easy to foresee either in terms of the effect on the appearance or of cost to the Employer and should always be referred through the client to the member of the design team responsible for appearance.

Maintenance

2.10 Bridges should be designed so that they can be properly inspected and maintained. Where this requires such things as doorways and walkways these should be properly integrated into the overall design and not treated as afterthoughts. Where permanent inspection and maintenance gantries are required they should be considered when the bridge is being designed and, if possible, provision should be made for parking them unobtrusively when not in use. They should, of course, be designed to be as neat and unobtrusive as possible, particularly on very long bridges where they may be in use much of the time.

2.11 Bridges should also be maintained in a way which respects the original design. Thoughtless and insensitive modifications to the structure or additions of ironmongery or signs can be very damaging to the character of a bridge.

Economics of good design

2.12 *"It is unwise to pay too much. But it's worse to pay too little ... There is hardly anything in the world that someone can't make a little worse and sell a little cheaper - and people who consider price alone are this man's lawful prey."* - Ruskin.

The above quotation should be borne in mind. Cheapness is not the same as value for money, and value for money is what is sought, with due regard for whole life costings.

2.13 A commonly held but erroneous view is that a bridge which is attractive in appearance must be more expensive than one which is not. This is not necessarily so. In fact a good looking bridge is likely to have had more thought devoted to all aspects of its design; it will probably be a more fully integrated design and therefore could even cost less to build. It may well have cost more to design, but this is a small part of the total cost, and should be taken into account when the situation requires a sensitive design. There are sometimes situations where to do justice to a bridge and its site it is necessary to spend some extra money, and this is an important part of the environmental mitigation of schemes. Unless designer and client are willing to make and accept a case for the necessary spending, where it is really justified, it is unlikely that they will have attractive bridges in those cases where it is not, because the first essential to getting an attractive bridge is the feeling, on the part of the client and the designer, that it really matters.

2.14 On many important sites, it would not be possible to build the road scheme unless the bridge were of high enough design quality, with its necessary cost. In general elegant bridges are not produced by a greatly expanded budget. Better results are usually obtained by designing with economy and simplicity. Simplicity, which is not the same as crudity, is usually a virtue in bridge design. Crudity is easy, simplicity just looks easy and takes time and effort at every level of design. What seems obvious and inevitable in the finished bridge was neither at the start of design.

Figure 3a. Maillart's Salginatobel Bridge is extremely simple and produced the lowest tender in a design/construct competition.



Although there is an approach viaduct and a bridge proper, it is impossible to see the bridge except as a single object, so strong is the feeling of unity.

Note that the unusual line of the intrados tends to improve the clarity of expression of the arch vault as a whole. See paragraph 2.4.

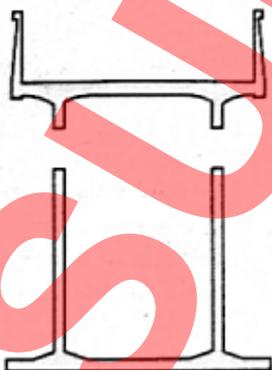


Figure 3b. Cross section

The overhang of the deck causes the shadow line on the elevation. The shadow stops either side of the crown, where the projecting flange of the arch is connected to the deck.

3. APPROACH TO DESIGN

Collecting the facts

3.1 The design of a bridge is implicit in the fact relating to it, but there is always more than one possible design. It is therefore necessary to start from the facts, but to keep an open mind and to explore the options. Not all of these will be apparent at an early stage, and the best ones may not become obvious until a good deal of work has been done. Good design requires time and immersion in the facts and in the apparent conflicts between the requirements. It is normal good practice to study alternative solutions, with preliminary analysis and cost estimates to provide data for comparing solutions. One not so obvious but very important purpose of this is to provide this time and immersion for those who are designing the bridge. It is wrong to just use the first solution which comes to mind; other solutions should also be pursued to find the best one. Even if eventually the first solution proves to be the best it is necessary for both designer and client to be certain the right choice is made.

3.2 The facts which are collected are predominantly technical, but technical facts often have aesthetic aspects or implications. There are also aesthetic and cultural facts to be collected, especially about the site. A good bridge design is always a holistic response to the site.

Approach to the process of design

3.3 The approach can be briefly summarised as follows.

- At all stages remember that a bridge is a unity, that the site and the bridge are also a unity, that technical or aesthetic decisions cannot be taken in isolation from each other, and that there is always interaction between them.
- Start without any preconceptions about the final solution; if there is an architect he/she should be involved as early as possible.
- Find out everything that is necessary, or that can be discovered about the situation, and still without preconceptions: this will provide the essential facts and to some extent give the criteria for judging different schemes.
- Make a list of all schemes which might be possible and start to explore them, by examining variables such as span lengths, abutment positions and so on,

starting with the simplest and apparently cheapest solutions to provide a datum. It will often be useful at this stage to have a model of the site on which the more promising possibilities can be examined, especially where the topography is not straightforward.

- Carry out analysis, cost estimates, model studies at whatever level of detail is appropriate at each stage as the design proceeds from the overall idea to its working out in detail.

The design process, as has often been said, is highly iterative with many loops.

Teamwork

3.4 A bridge is rarely designed by one person. A team is generally more powerful than an individual, and all should be involved as much as possible in the search for ideas and from the earliest stages. Dynamic interaction, even disagreements between team members of different disciplines can sometimes produce new ideas as individuals are forced to re-examine their preconceptions. Disagreements sometimes resolve themselves when a clear solution emerges, but there has to be someone leading the team who is capable of taking an overview and making a decision, and unless this person is a real designer, or is able to appreciate what is real design, the results will often not be good.

3.5 It is particularly important that the highway design and bridge design are well co-ordinated. This works both ways. The bridge must relate properly to the road and decisions which fix the route and the land requirements should not be made without consulting the bridge designer (where there are significant bridge structures).

3.6 The team should include the client, the structural and highway engineers, the architect (when one is to be appointed), the landscape architect, mechanical and electrical engineer, and construction methods engineer as appropriate.

4. GENERAL PRINCIPLES

Bridges and buildings

4.1 Design is a matter of producing order out of a chaos of facts and circumstances, and this ordering process naturally includes the appearance. In architecture certain ideas and principles are used, whose application to bridges is more restricted by circumstances. For example the height of the deck is usually more or less decided by the conditions which affect the layout of the route, and physical conditions often restrict pier locations. However a knowledge of and feeling for ideas about aesthetic order are still helpful; it is better to know what to aim for. In any case these principles should be helpful tools and not straitjackets.

4.2 What is the nature of a bridge and how do aesthetic principles apply to it? From an aesthetic point of view, bridges are much simpler objects than buildings and are more obviously governed by physical laws and the way they are built. Bridges are essentially three dimensional objects organised about the deck, which is linear in concept and usually roughly, but almost never precisely, horizontal. It is the main functional element which everything else is there to serve or support.

4.3 Buildings contain space. It flows through bridges. Buildings are largely based on horizontal planes, which almost never occur in a bridge. Nevertheless general architectural principles of proportion and scale, unity and variety, relation of parts to the whole and to each other, apply to bridges just as they do to buildings.

Scale and proportion

4.4 Scale is about the relative sizes of things in their contexts. It could refer to the relation between a bridge and its landscape or townscape, the relation between parts and the whole bridge or between different parts and their elements. It can also refer to the size of a bridge relative to people. Bridges are often large in scale, and sometimes a bridge seen from a distance, but not relative to something of known size, appears to be much smaller than it really is. When seen close to, there is a shock of surprise at how big it is.

4.5 Proportion usually concerns numerical relationships between dimensions: span and clear height above ground, clear height and deck depth, between successive spans and so on. Systems of proportion are attempts to produce orderly relationships between proportions.

4.6 Scale and proportion are more easily understood in use than by definition. Definitions do not matter, the only thing that matters is to see and feel these relationships.

Unity and variety

4.7 Unity is achieved by having an overall governing idea or unifying element and by consistency or compatibility of character of the various parts and details (Figure 3). Thus unity is usually more applicable to individual bridges than is variety. Variety is perhaps relevant when considering a number of bridges, as well as unity. For example, in the case of bridges seen in succession along a stretch of motorway, which ought mostly to be as unobtrusive as possible, similar shapes of parts and similar details could be used to give unity, while the usual variations due to different sites, road types, skews, curvatures and other individual requirements make the bridges recognisable as individuals, which is not just an aesthetic preference but is also important to the road user. For example, if most of the bridges have open side spans with bank seats there will probably be a few which, because of road geometry or other reasons, must have solid abutments instead. An interesting variation can also come about if one larger or more prominent bridge has to be substantially different, although it may still be good to have related forms or details to provide a link with the others.

Articulation and other matters

4.8 Articulation is not used here in the sense of the arrangement of expansion joints and restraints or releases in the structure, but as the visual expression of the way in which elements of the structure meet each other. For example where a deck is supported on a bearing over a pier, the gap with the bearing in it quite properly expresses the way the structure works and may legitimately be emphasised as something quite different from a monolithic connection. Articulation can also be used to emphasize the shapes and identities of surfaces rather than the solidity of the solids they define, whereas solidity can be emphasised by running one surface smoothly into another, as with well rounded corners, for instance, or a cross section defined by a mathematically continuous curve.



Figure 4. Basically rectangular piers showing the effects of various ways of treating the corners
 (a) Simple rectangle.
 (b) Chamfered corners:
 - reduced bulk in diagonal views,
 - reduced sides,
 - loss of definition of sides.
 (c) Rounded corners:
 - increased appearance of solidity,
 - complete loss of definition of sides.
 (d) Articulated junctions of sides:
 - reduced solidity,
 - increased definition of sides.

also be considered as opportunities to give texture to the surface.

Honesty and simplicity

4.11 Honesty is the best policy in bridges as elsewhere. Materials and structures should generally look like what they are. However, if it is not possible to find an honest solution, a designer who knows what he is doing may be able to hide an offending detail or employ an effective deception as a last resort.

4.12 Simplicity is generally a virtue which designers should think carefully about departing from. Real simplicity is usually the result of considerable effort; the more inevitable it looks the less inevitable it probably was.



Figure 5. Effect of deep beam close to ground reduced by:
 - brightly lit area further from ground,
 - surface broken, so depth of beam seems less,
 - recession of shaded areas.

Light and shade

4.13 Bridges are forms seen in light and by means of light. Differences of light intensity reveal shapes, and the appearance can be modified by shaping the structure so that one part shades another.

4.14 Apart from reflected light, which is of less intensity, the amount of light on a surface depends on its orientation and attitude relative to the sky.

Vertical surfaces are better lit than soffits, and a sloping soffit which can be seen in elevation looks darker than a vertical face. This is partly why a deck using a trapezoidal box structure with fairly shallow side slopes appears more recessive than a rectangular box of similar depth; another reason is that it is virtually impossible to read the actual depth.

4.15 The most strongly lit part of the deck of a modern bridge with an edge cantilever is the face of the cantilever, which casts shadows on the surfaces beneath it.

4.9 Details which are required for functional, structural or constructional reasons may be used in a positive way if their shaping or arrangement is properly ordered. Every necessary detail when properly considered may become a visual asset, rather than something to be hidden, particularly repeating details which are laid out using modules related to the main structural elements (Figure 7). Everything should be organised as far as possible on a modular basis and everything should look as if it was meant to be there and not as if it had happened by accident. This applies to visible constructional details such as construction joints or the pattern of shutter bolts as much as anything. This means that the designer has to draw them to determine them or lay down ground rules for the contractor's designer and make sure the result is acceptable. Difficult elements, such as anchorages at the edge of the deck of a cable stayed bridge, if simply and neatly designed may be an opportunity to provide a rhythm at the edge without spoiling its horizontal flow. There will of course also be cases where details are better hidden.

4.10 Surface finishes which are used to prevent water runs from streaking concrete surfaces might



Figure 6. The effect of a light fascia over beams shaded by a substantial cantilever. This is less marked when the sky is overcast.

4.16 Small projections from a vertical surface reveal their presence by shadows in the same way that the mouldings on a classical building are read. Vertical edges on projections can also reveal themselves in this way, depending on the direction from which the strongest light is coming. Surface textures such as vertical ribbing presumably depend on this for their effect. A ribbed surface looks different from a plain surface from distances where it is impossible to see the ribs as such. Where the bridge crosses water, the underside will sometimes be lightened by reflection from the water. Sunlight reflected from waves or ripples produces particularly attractive effects.

Colour and tone

4.17 Colour and tone modify the way we see things. For example a light toned concrete bridge shows up strongly against a background of dark foliage where a steel bridge painted a dark tone would be less conspicuous. Light grey makes fine elements like balustrades less noticeable against a typical grey sky and dark lamp posts disappear against dark foliage. (Of course the sky is not always grey and some foliage changes with the seasons.) A dark beam, whether through paint or shadow, appears further recessed against a light edge cantilever than would a light one.



Figure 7. The scuppers in the parapet of the Salginatobel Bridge are there to allow water from the deck to drain away. They also add interest to the bridge when seen close to, and reduce the apparent scale. There may be more scuppers than function strictly requires.

5. THE WHOLE AND THE PARTS

The whole

5.1 A bridge is first of all a whole, not just an assemblage of parts, so that everything should be related and all the parts compatible with each other and serving the whole. A quite common defect of large modern bridges, built since metal and concrete became the main materials of construction, is the incompatibility of approach viaducts with the main bridge.

5.2 An awkward effect is produced by an abrupt change of structure within a length of viaduct to accommodate a change in circumstance, where structures of different sizes or types are juxtaposed without any transition element.

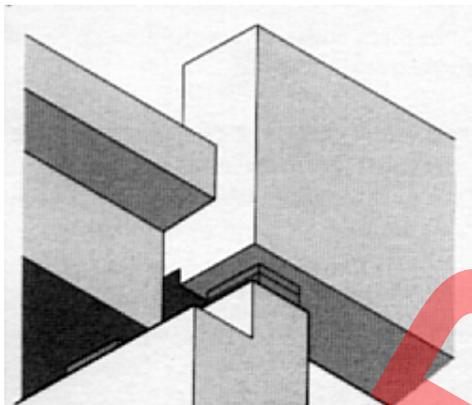


Figure 8. Not only is a junction like this unpleasant in itself, it also destroys the visual continuity of the deck. If it is absolutely impossible to avoid the change in structure, the two decks should be visually separated by another element. On a much larger scale the brick towers, which separate the outer cantilevers of the Forth railway bridge from the constant depth trusses of the approach spans, provide just what is needed.

5.3 Too many different angles in a structure produce a disorganised effect¹, and trusses require particular care, particularly when used in cable stayed bridges.

The parts

5.4 What follows is not intended to be a comprehensive list of parts in all types of bridge, but a brief commentary on the main ones usually met with. It will be covered more comprehensively in a new edition of the *Appearance of Bridges* to be included in DMRB Vol 1 Section 4.

¹ as Leonhardt has pointed out.

• Decks

5.5 Usually a bridge deck is visually the main organising element which links everything else together and emphasises the continuity of the route. Most modern highway bridge decks have edge cantilevers overhanging the main structure and this is usually, but not always, an advantage. It helps to reduce the width of the main soffit; it also breaks up the visible depth of the deck, and the recession of the main structure and the shadow cast on it by the cantilever reduce the apparent depth still further.

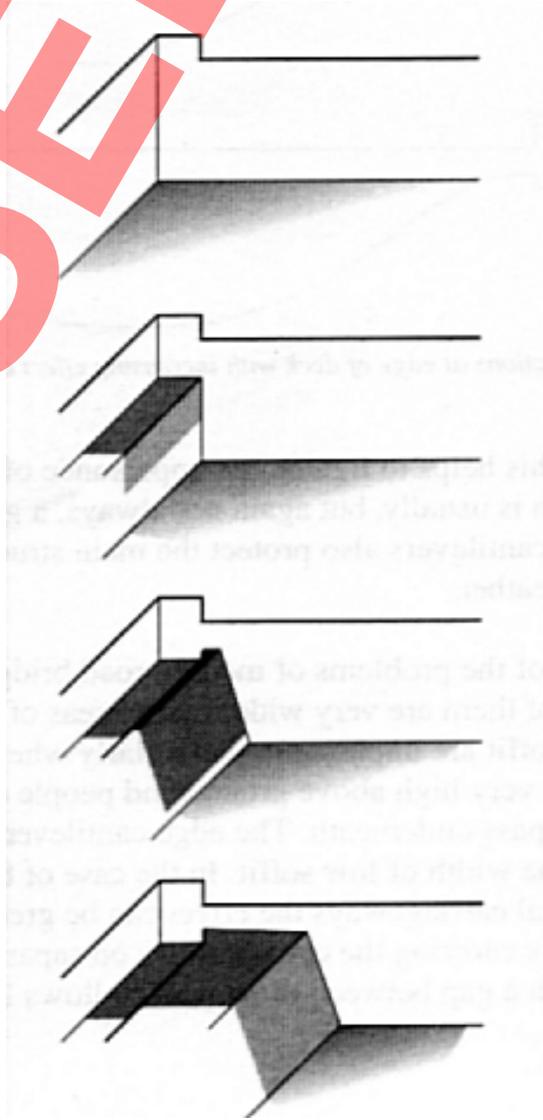


Figure 9. Shadows at edges of decks.

5.6 By suitable shaping of the structure the depth can be made almost impossible to read, except in silhouette.

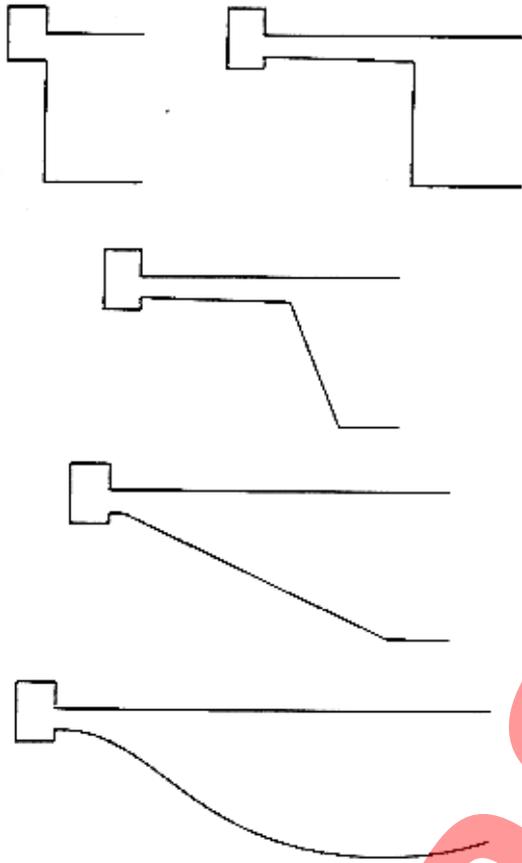


Figure 10. Sections at edge of deck with increasing effect of recession.

5.7 All this helps to lighten the appearance of the deck, which is usually, but again not always, a good thing. The cantilevers also protect the main structure from the weather.

5.8 One of the problems of modern road bridges is that many of them are very wide. Large areas of unbroken soffit are unpleasant, particularly where the soffit is not very high above ground and people on foot or in boats pass underneath. The edge cantilevers help to reduce the width of low soffit. In the case of bridges carrying dual carriageways the effect can be greatly improved by carrying the carriageways on separate bridges with a gap between them which allows light to penetrate².

² Safety precautions may be required at the central gap to prevent people climbing over or to catch them if they do. Gaps between bridge decks that range from 100 mm to 2000 mm must be suitably protected and in a manner that avoids them having the appearance of central reserves.

5.9 Where this is not possible a main structure consisting of separate beams or boxes may help to some extent.

5.10 It is also important that the deck should run through as cleanly as possible. Sudden changes of depth or width should be avoided. If they are absolutely unavoidable, steps should be taken to minimise the effect, possibly by means of transition or a strong dividing element.

• Piers

5.11 Generally piers should be simple and there should be good reasons for departing from the simplest possible shape. If there are different kinds of piers on a bridge they should be related to each other in some way. The form and placing of piers in relation to the deck should be judged. Two examples of this are:

- i thin piers under a very thick deck can look ridiculous;
- ii where the deck is of constant depth the piers are often inset from the edge and this emphasizes the visual flow of the deck and reduces the significance of the piers and their spacing; if this inset arrangement is used where the deck is haunched or curved in elevation, it produces an unfortunate effect of unsupported thrust at the edge of the structure.

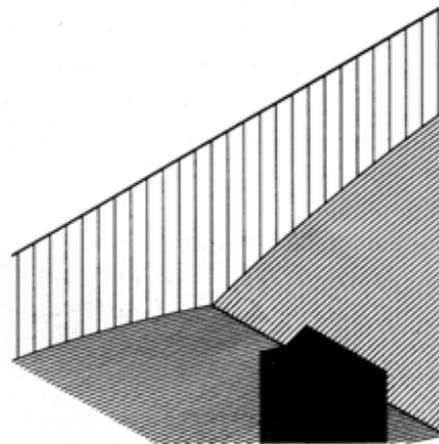


Figure 11. Unsupported thrust effect of inset pier at haunch.

5.12 Pier shapes should be carefully considered, not only in relation to each other but also in relation to the shape of the deck. There will also be situations where something in the surroundings demands a special response.

5.13 Piers whose cross section is a rectangle with semicircles at the ends are never as satisfactory as those which have a cross section defined by a continuous

curve, such as an ellipse. However rectangles with rounded corners often seem to be satisfactory, perhaps because they are approximations to a type of continuous curve³.

• *Abutments and bank seats*

5.14 Abutments provide a visual end stop to the bridge. For rural bridges it is often preferable to have bank seats which are much less visually obtrusive and avoid the problems associated with large visible areas of concrete, but this is not always possible. From a road user's point of view closed abutments provide more contained and focused views, which can be an advantage in certain situations, although perhaps not as a general rule. The proportions of the opening then become particularly significant.

• *Parapets*

5.15 Parapets have several functions or requirements:

- i. containing people or vehicles or other objects,
- ii. giving a sense of security to users of the bridge,
- iii. providing a visual edge to the deck as seen from off the bridge,
- iv. allowing users to see the landscape.

Too often only the first of these is remembered, both during design and when preparing and interpreting standards.

5.16 One of the more useful, but little used, forms of parapet is the type which consists of a concrete upstand with one or more metal rails above it. This can provide a better sense of security than one which is all metal, and a better outlook than one which is all concrete. Another factor is that a parapet which is at least partly of concrete provides a thicker element as the cornice of the bridge. The parapet is the most brightly lit part of the deck as seen from off the bridge and it is useful to be able to vary the size of this element depending on the scale of the bridge.

5.17 High containment parapets are difficult to handle visually and need to be carefully considered, especially where they do not run the full length of the bridge. Where the proportions are right it may be possible to express the continuity of the bridge fascia by means of a shadow line and possibly a change of texture.

³ As highway engineers know, continuous curves are much more satisfactory visually than combinations of straight lines and circles.



Figure 12. Treatment of a high containment parapet to emphasise the continuity of the deck. A step in the face of the parapet to create a shadow line, and a different surface, which should not be overdone.

5.18 Sight lines between rails for car occupants can be investigated graphically.

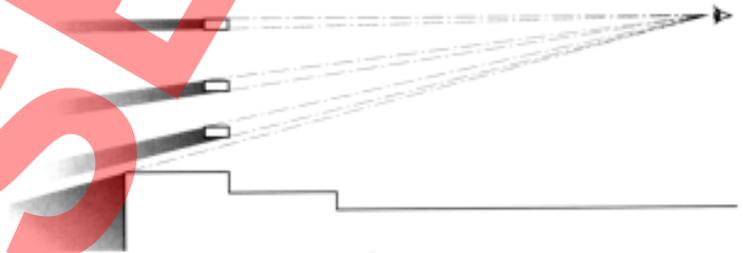


Figure 13. Sight lines through parapet.

5.19 In exceptional circumstances, where the functions of vehicle containment and pedestrian balustrading can be separated, the possibility of non-standard pedestrian balustrades can be explored.

• *Wind shields*

5.20 Where wind shielding is required, not only should the aerodynamic effects on the structure and traffic be considered, but also the effects on the appearance of the bridge and the view from vehicles crossing the bridge. When wind shields are being considered and tested, all these aspects should be studied. Graphical methods can be used to study the combined effect of the elements interposed between occupants of vehicles and the surrounding landscape, i.e. wind shields, safety fences and parapets, but are no substitute for experiencing the real thing. This is a case where computer videos may be useful, but with the same proviso.

• *Embankments*

5.21 Although not strictly a part of the bridge, the shaping of an abutting embankment should be carefully considered. Simple models with sand can be helpful in relating the embankment to the shape of the bridge.

Hachures (tadpoles) on a plan often gloss over the issues and are not adequate as instructions to the contractor; an accurate representation can only be given by contours.

5.22 The extent and shape of the earthworks have a great effect on the bridge design and on the general landscape context, and their detailed design should be developed between the bridge designer and the landscape architect.

5.23 *The Good Roads Guide (DMRB)* should be referred to for the interaction between bridges and landscape. The effect of trees both when mature and when just planted should be considered. Large trees can enhance a bridge or hide it, and in special circumstances the planting of large mature trees can soften the environmental impact of a large bridge abutment when first built.

5.24 Paving under the bridge should also be carefully considered and not used except where functionally necessary. Solid concrete slabs look like part of the bridge structure and stop the flow of the soft landscaping under the bridge. In rural areas honeycombed slabs, with the largest possible voids, allow vegetation to grow wherever there is enough light and water and often make a more satisfactory continuation of the landscape under the bridge.

SUPERSEDED

6. SURFACES AND WEATHERING

General

6.1 An important factor in the appearance of surfaces is the way in which they weather. It can be very instructive to return to a bridge from time to time to see how it is weathering.

Weathering of concrete

6.2 All materials weather, even brick and stone if badly chosen or not properly detailed can weather badly. Combinations of different materials sometimes cause problems, again even traditional materials. However, concrete surfaces need the most attention because concrete can weather very badly, particularly large unrelieved concrete surfaces such as retaining walls which are, in any case, often rather unattractive.

6.3 The main agent of the most unpleasant effects of weathering is water, which redistributes dirt; either washing the surface by picking up particles or dirtying it by depositing them, depending on the velocity of flow and the size of the particles. With edge cantilevers and properly detailed drips, the main structure of the deck should be well protected from water runs coming from above. Elsewhere the effects can be mitigated by controlling the flow of water.

Design and detailing for weathering

• Drips

6.4 The designer should consider the way water can flow over the surfaces and try to control it as much as possible. In doing this it is necessary to think in three dimensions. It is quite common to see drawings of cross sections with drips detailed on them where no thought has been given to what happens to the water in the other dimension. Since the drips will inevitably be sloping in this dimension, water can run, or be blown, along them until it finds somewhere it can run down, like a pier or abutment, or perhaps finds a place where it can run across the soffit, streaking it as it goes. If this cannot be avoided, a vertical groove in the face of the pier or abutment will help to contain the streaking.

6.5 If there are joints in a fascia (as commonly with prestressed decks) water may eventually come through, possibly bypassing the drip which should be there to protect the main structure from water runs. A drip in the soffit of the slab behind the fascia will protect the structure, not only from water which gets through the joint in the fascia, but also from water flowing over the edge of the deck before the fascia is

constructed, which may be carrying particles of rust or other debris from materials stacked on the deck. Weathering steel has particular problems, and water which has run over it should never be allowed to touch concrete.

• Expansion joints and details

6.6 Care is necessary at all levels of design, particularly in the placing of expansion joints, which will leak sooner or later, and in making sure that the details are correctly drawn and constructed.

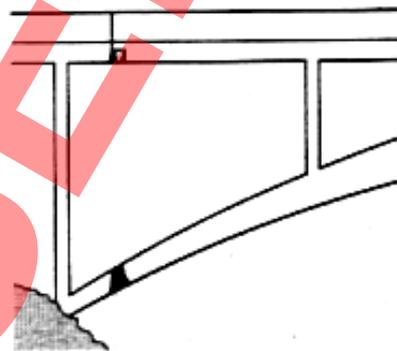


Figure 14. Leaking joints in the deck have caused the arch to be stained by dirty water.



Figure 15. Streaking due to a mistake in detailing. The top of the fascia/parapet plinth was detailed without an inward fall. Correctly detailed bridges with similar parapets on the same contract are not streaked.

6.7 Expansion joints should be avoided as far as possible, to avoid problems of durability as well as of weathering. They are much easier to cope with at abutments than over piers or in the span. The effects of the flow of water when they leak should always be considered and drips at the joints should be co-ordinated with the longitudinal ones if possible.

• *Vertical surfaces*

6.8 The parts which are most vulnerable are the fascia, piers and abutments; it is for these, particularly in urban areas, that special finishes might be considered.

6.9 A projection from a vertical surface prevents water washing over the surface immediately below it. A projection of limited length will have a darker unwashed area under it, contrasting with the rest of the surface. Conversely, if only a small part of a surface is washed this could show up as a lighter streak, unless the water is carrying and depositing dirt, when it will be a dark one.

• *Concrete Surfaces*

6.10 Smooth concrete surfaces, particularly when vertical and even more so when sloping, often weather very badly, whether well constructed or not. No matter how uniform the surface appears to be, water flows down in irregular paths causing random streaks. Rough surfaces behave rather better, for example when tooled or cast against sawn board formwork. Some proprietary form liners may also produce surfaces which avoid streaking, but many of these have a pattern which repeats in consecutive panels to produce a wallpaper effect which seems singularly inappropriate. Surfaces with closely spaced vertical ribs or grooves have

worked well. The grooves channel the water so that it cannot spread out to cause streaks.

6.11 A form of concrete surface which has behaved well on walls in an extremely dirty atmosphere is shown in Figure 16a.



Figure 16b. Seventeen years after completion. Less uniform dirt, but still acceptable.

The surface of the precast fascia is a fine vertical ribbing. The wall was cast against moulded g.r.p. formwork panels. The panels are modular, with several different patterns which can be assembled in different combinations.

The surface imitates fractured rock and is not appropriate for use near the real thing. When clean it seems a bit overdone and suitable for dirty towns rather than for the clean countryside.



Figure 16a. Ribbed and moulded surfaces in a very dirty atmosphere. Nine years after completion. The mark on the fascia to the left is the shadow of the post. The whole surface is extremely dirty, but uniformly so.

7. AIDS TO DESIGN

General

7.1 In order to design a bridge it is always useful, and sometimes necessary, to be able to see it as a three dimensional object in relation to the landscape, also as a thing in itself, and perhaps to be able to study some of the details in three dimensions. Some of the tools which have been used for this are:

- drawings representing three dimensions on two,
- photo montages,
- models.

Three dimensional drawings

7.2 Perspectives can be drawn by a human being or a computer. They can be useful but they can also be misleading, particularly when inaccurately and seductively drawn. Rough sketches can be useful during the development of a design. Isometric or axonometric drawings can be helpful in seeing how things fit together in three dimensions but do not give satisfactory impressions of what they look like.

Photo montages

7.3 Very sophisticated representations can be achieved by using computer techniques to superimpose a perspective of a bridge on a photograph of the site. These are primarily for presentation purposes and are not likely to be useful during design, whereas a relatively crude montage, made by sticking strips of paper or tape to a photograph, may give an idea of how a particular form will sit in the landscape.

Models

7.4 Computer models, especially drive through videos, are much less useful to the designer than even the simplest physical model. It cannot be stressed too strongly how useful physical models can be to the bridge designer during the design process. This does not refer to the sophisticated model used for presentation, but to models of varying degrees of crudity which can be used to study visual relationships and shapes. These are by far the most useful tools for the designer. Models can be used to study the relation of the bridge to the site, the bridge structure itself as a whole, or perhaps one or two spans of a viaduct, shapes of piers and abutments and their relation to the deck, or the shapes of particular details.



Figure 17. A model made in the drawing office from cardboard to see the visual effect of the deck cross section. It also showed that the proposed column shape was not satisfactory in relation to the deck. The model has unfortunately not been lit so as to show realistic shadows in the photograph.

7.5 It is often useful to have a contour model of the site available at an early stage of design, on which various possibilities can be examined. It does not need to be a very realistic model, in fact it is probably better if it is not. The contours can be built up from sheets of suitable material and significant features such as rivers, possibly groups of trees, existing structures and so on can be represented in basic outline.

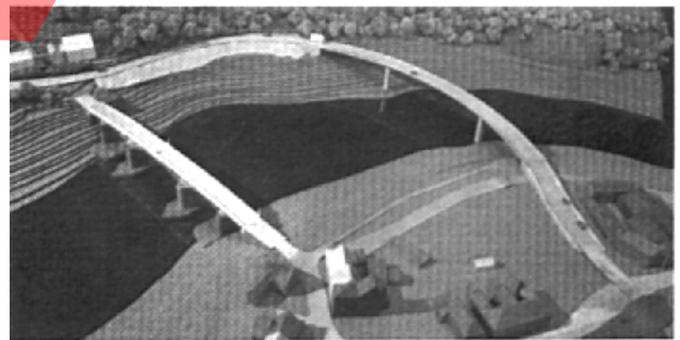


Figure 18. A landscape model used to examine possible schemes for a new bridge in relation to the land/townscape and existing structures. The model can show high and low tide levels, as this greatly affects the appearance.

7.6 Models have to be designed, and ingenuity is required in deciding on the most suitable scales, materials and degree of crudity (and hence economy) which will suit the purpose in hand. They are particularly useful for studying the relationship between existing bridges and the various possibilities for new ones which are to be built next to them.

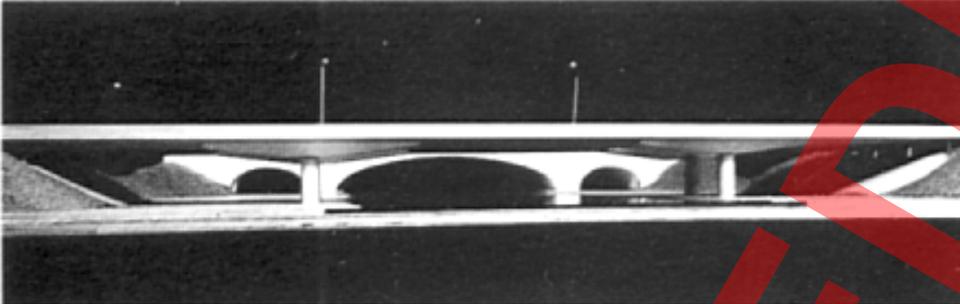


Figure 19. Cardboard, timber, sand and perspex used to examine schemes for a new bridge next to an existing one. The outline of a man drawn to scale on a slip of paper can be used to give scale to the bridges.

8. SPECIAL PROBLEMS

Bridges next to existing bridges

8.1 When a new bridge is to be placed next to an existing one, it should respect the presence of the other, especially if it is worthy of respect. It is usually, although not invariably, better to put a frankly modern bridge beside an existing one. The piers of the new bridge should be aligned with older piers if at all possible; this does not mean that every pier of the older bridge should have a corresponding new one. If the older bridge is arched, the new one should avoid cutting across the profile of the arch opening(s).



20a & b. The bridge designed by Sir Edwin Lutyens to take the A3 over the Pilgrim's Way near Compton in Surrey, seen in relation to a more modern bridge which carries the realigned A3. Notice how Lutyens has used the device of stepping the arch at each end of the tunnel, to increase the apparent size of the arch in elevation and to reduce the tunnel effect.

8.2 There should be a gap between the two bridges, preferably of a least 2 m, and more if it can be managed. This must be settled with the highway designers at the alignment planning stage.

Bridge widening

8.3 Most bridges are difficult to widen in a way which is aesthetically acceptable, unless they have been designed for it in the first place. Therefore the best advice that can be given about bridge widening is to avoid it, unless it can be done in such a way that the character of the bridge is maintained. Concrete slabs sitting on and cantilevering beyond masonry arches generally destroy the character of the existing bridge. If it must be done, the cantilever should be kept short, the historic parapet should be moved to the cantilever edge and vertical elements such as cut waters should continue up past the deck.

8.4 Wherever it is possible, and is reasonably cost effective, it is better to plan the highway so as to be able to provide a second bridge or a complete replacement. If this is not possible the extension should be designed to fit with the existing bridge as well as possible. This will usually mean maintaining the original materials and character as well as possible but sometimes a very light and transparent addition to a massive looking bridge might be successful if it is well handled. A new pedestrian bridge can often avoid the need for widening historic bridges.

Alignment

8.5 Once upon a time roads were aligned to fit the bridges. Now this is no longer necessary, but things may have gone too far in the other direction. Engineers enjoy technical challenges, but should remember that there are other issues involved. A collaboration between the highway and bridge engineers can avoid excessive skew over broad bridges, steep superelevation, the need for pedestrian steps and ramps, and the poor appearance and increase in costs which may occur. The best solutions both aesthetically and economically come from collaboration.

New materials

8.6 When new materials or methods are used, there is often a settling down period before forms and details emerge which are appropriate aesthetically as well as technically. Every effort should be made to make this transition period as short as possible. New materials should be used rationally,

with respect for their individual properties, and honestly but not crudely, expressed.

Bridge enclosures

8.7 Bridge enclosures of g.r.p. or other materials should also be expressed honestly as cladding. Waterloo bridge is faced with stone, which is used in such a way that it is quite clearly a cladding and not a structural material, at least to those who understand stonework. Bridges to be enclosed should be designed from the start with enclosure in mind.

Problems with prefabricated beams

8.8 Bridges whose decks are curved in plan but supported by straight beams are generally unsatisfactory in appearance, unless the radius of curvature is so great that changes of line between successive spans are extremely small. The same applies to beams where a curve in plan is approximated by a series of straights in each span. It does not apply to the elevations of deck-stiffened arches, such as those by Maillart and Menn, where the polygonal arch is the logical expression of the thrust line, at least to the eye of an engineer.

8.9 Plate girder bridges which are not going to be enclosed, should have any permanent bracing exposed services or walkways neatly detailed. Unsightly temporary bracing should be removed.

SUPERSEDED

9. CONCLUSION

Conclusion

9.1 Major heresies often contain important truths which have been taken too far. Engineers often start with the idea that designing a technically sound structure will result in a good looking bridge; and more particularly that a design which is refined to use the least material will produce an elegant bridge. In bridges where the form follows laws of nature, such as suspension bridges, there is a good deal of truth in this, at least as far as the basic form goes, but there is still scope for spoiling it in detail. A bridge is not a piece of abstract art, it is a structure which has to satisfy a need, get built and be durable, maintainable and economical, and the design has to start with this. At the same time it also has to fit into its environment and be elegant. These things have to be achieved at the same time with the same structure, and they do not happen without a great deal of thought and work. They will not be achieved unless there is a sensitive designer involved.

9.2 To do this, employers and clients should choose a method of procurement which allows account to be taken of the importance of appearance relevant to the particular project in its specific location. It is important for everyone to understand the value of having bridges which are a pleasure to see and to use and which fit happily into their surroundings as well as being safe, durable and economical.

Aphorisms

9.3 Design is a process of producing order out of a chaos of facts and circumstance; this includes aesthetic order as a reflection of practical order. The same object has to be good looking at the same time as it fulfils all the other requirements. It is mostly a rational process, but sensitivity and intuition have to be there to achieve success.

9.4 The design of a bridge has various levels. Firstly, the bridge in its environment, including the site and the route; secondly, the bridge as a thing in itself, thirdly, the parts, and finally details of the parts. All these have to be addressed and the conflicts between them resolved.

9.5 Sometimes the right solution is to have the most inconspicuous bridge possible, for example the general run of motorway overbridges, but even then particular circumstances can be exploited to produce an occasional dynamic bridge to relieve the problem of motorway monotony. There is always scope for doing

an inconspicuous bridge as neatly as possible. Details are very important.

9.6 Many technical decisions are also decisions about the appearance.

9.7 Unity depends on an overall idea and consistency of form and detail.

9.8 Models are exceptionally useful tools for studying problems of appearance. Architects are usually well aware of this, as are some engineers. Engineers should get into the habit of using them at all stages and all levels of detail.

10. BIBLIOGRAPHY

1. Highways Agency : *The Appearance of Bridges and Other Highway Structures*. The Stationery Office, 1996. ISBN 011 551804 5
2. The Royal Fine Art Commission: *Bridge Design - The Royal Fine Art Commission Seminar*: HMSO 1993.
3. Max Bill: *Robert Maillart*: Verlag für Architektur, Erlenbach-Zurich, 1949.
4. D.P. Billington: *Robert Maillart's Bridges: The Art of Engineering*: Princeton University Press, 1979.
5. Fritz Leonhardt: *Brücken/Bridges*: Architectural Press, 1982.
6. C. Menn: *Prestressed Concrete Bridges*: Birkhäuser, 1990.
7. F.D.K. Ching: *Architecture: Form, Space and Order*: Van Nostrand Reinhold, 1979.
8. C. Tunnard and B. Pushkarev: *Man-Made America*: Yale University Press, 1963.
9. F. Hawes: *The Weathering of Concrete Buildings*: Cement and Concrete Association, 1986.
10. Vitruvius: *De Architectura*: edited and translated by F. Granger, Loeb Classical Library, Harvard, U.P. and Heinemann, 1931.
11. J. Heyman: *How to Design a Cathedral*: Proc. Inst. C.E., Civ. Eng., Feb 1992.

11. ENQUIRIES

Approval of this document for publication is given by the undersigned:

The Divisional Director
Civil Engineering
The Highways Agency
St Christopher House
Southwark Street
London
SE1 0TE

A PICKETT
Divisional Director
Civil Engineering

The Deputy Chief Engineer
The Scottish Office Development Department
National Roads Directorate
Victoria Quay
Edinburgh
EH6 6QQ

N MACKENZIE
Deputy Chief Engineer

The Director of Highways
Welsh Office
Y Swyddfa Gymreig
Crown Buildings
Cathays Park
Cardiff
CF1 3NQ

K J THOMAS
Director of Highways

The Assistant Technical Director
Department of the Environment for
Northern Ireland
Clarence Court
10-18 Adelaide Street
Belfast
BT2 8GB

D O'HAGAN
Assistant Technical Director

All technical enquiries or comments on this document should be sent in writing as appropriate to the above.