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Masonry arch bridges: condition appraisal and remedial treatment

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Summary

Masonry arch bridges have proved to be reliable, enduring structures and remain a vital part of the road, rail and waterway infrastructure in the UK and other countries. However they are facing a number of challenges associated with their extended period in service and the changing requirements of modern transport systems. In order to ensure the continued efficient use of these assets in the future it is necessary to manage and maintain them carefully, with due regard to, and an adequate understanding of, their special characteristics and needs. In a number of important ways these are distinct from those of modern structures and the effective stewardship of masonry arch bridges requires some specialist knowledge and a particular approach. The report provides information and guidance which will assist those responsible for this task in achieving their aims.

The guidance provides infrastructure owners, consulting engineers, contractors and maintenance managers with guidance on the management, condition appraisal, maintenance and repair of masonry (stone and brick) arch bridges. It is based on a detailed review of published literature and infrastructure owner's procedures, consultation with experts and practitioners within the field and includes case studies demonstrating good practice.

The purpose of the book is to:

- present good practice (2005)
- provide a guide for routine management
- recommend assessment, maintenance and repair strategies to give value for money
- facilitate knowledge sharing.

The guidance is divided into five chapters, each including information and guidance on particular aspects of masonry and brick arch bridges, followed by appendices with detailed information for practitioners.

Chapter 1: Introduction and general background information on the document, including advice on how and where to find information.

Chapter 2: Construction and behaviour of arch bridges and an overview of the basic principles of arch bridge history, construction and materials, behaviour and performance which is intended to be particularly useful to readers with less experience in this type of structure.

Chapter 3: Asset management and condition appraisal of masonry arch bridges, including information and guidance on bridge inspection, investigation and structural assessment.

Chapter 4: Selection, planning and implementation of maintenance, repair and strengthening works on masonry arch bridges, including health and safety, environmental and heritage considerations.

Chapter 5: Summary of recommendations for good practice, discussion of future research and development needs, and a list of references used in the guidance.

Appendix 1: Case studies which illustrate particular aspects of the practical implementation of topics discussed in the main body of the guidance.

Appendices 2 to 6: Additional information on topics covered in the main body of the guidance.

Acknowledgements

Steering group

This book has been produced at the request of the Bridge Owners' Forum by CIRIA as CIRIA Research Project 692. The detailed research for this project was carried out by Mott MacDonald in partnership with the University of Salford, Birse Rail Ltd and KW Ltd.

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Steering group

Following CIRIA's usual practice, the research project was guided by a steering group which comprised:

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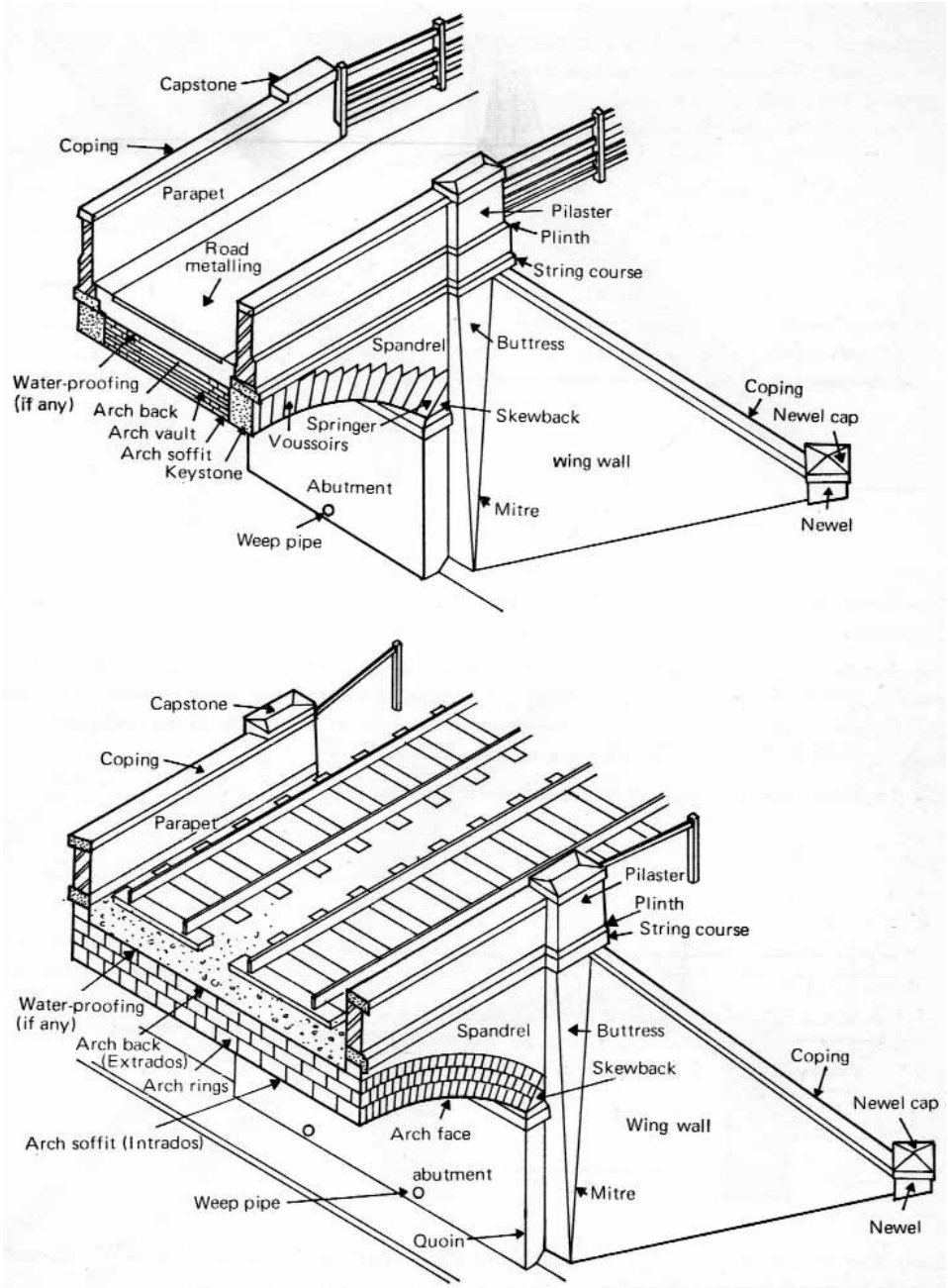
Glossary

Note on the use of the term – Masonry

Although sometimes used specifically to refer exclusively to building stone, here the word "masonry" will be used in the broader sense ie to refer generally to both brick and stone construction. When referring to brick or stone in particular, specific terms will be used, eg "stonework", "stone arch bridge", "brickwork" and "brick arch bridge".



Abutment	a body, usually of masonry, which provides the resistance to the vertical forces and the thrust of the arch.
Adobe	regularly shaped body made of dried clay, usually incorporating straw to give it cohesion.
Antifunicular geometry	for a given set of loads, this is the geometry that results in an equilibrium state free from bending stresses ie simply under axial section forces
Appraisal	includes the range of activities involved with the evaluation of a bridge's condition and performance ie the gathering of existing data, inspection, investigation and structural assessment.
Archivolt	a projecting moulding which follows the curve of an arch above the extrados, for example the arch ring on the façade, or the shape of the arch curve.
Arch	a curved structural member capable of supporting vertical loads across an opening and transferring these loads to piers or abutments.
Arch barrel (or barrel)	the load-bearing part of the arch. It contains a single thickness of voussoir tones or several rings of brickwork or coursed random rubble.
Ashlar	type of masonry consisting of regularly shaped blocks of stone square-dressed to given dimensions and laid in courses with thin joints.
Aspect ratio	the ratio of the span (longitudinal axis) of a bridge to its width (its transverse axis).
Assessment	here used specifically to imply the evaluation of a bridge's structural capacity and performance, typically by one of a number of prescribed methods and possibly making use of proprietary software applications.
Autogenous healing	the "self healing" of fine cracks in mortars by the precipitation of dissolved calcium ions as calcium carbonate; a slow and gradual process which may occur in wet conditions where there is adequate free lime (and thus particularly in lime-rich mortars).
Backfill (or backing/ fill/infill)	material (usually low quality fill) used to give support behind a structure. For a masonry arch bridge, backfill material is placed in the spandrels between the arch barrel and the road surface and retained laterally by the spandrel walls and/or wingwalls. It normally consists of granular material eg gravel or building debris, which may have been excavated for the foundations or is waste from the construction.
Backing	see **Backfill**.
Barrel	see **Arch barrel**.
Bastion	a section of solid masonry projecting from a wall to provide additional structural stability.
Bedding mortar	the mortar between masonry units which forms a part of the structural masonry, as distinct from the pointing mortar, which is that used for the outer finish of the joints; in original construction, these are normally identical.

Bedding plane	a plane of stratification in natural sedimentary stone.
Bed joint	a joint between masonry courses.
Bond	an arrangement of masonry units so that the vertical joints of one course do not coincide with those immediately above and below.
Bond types	refers to the relative arrangement of masonry units, particularly the arrangement of header and stretcher units, the main types being: (1) Header bond: units laid so that their ends only (short dimension) appear on the face of the element, (2) Stretcher bond: units laid so that their long side only appears on the face of the element, (3) English bond: with alternate courses composed of headers or stretchers only, (4) Flemish bond: with alternate headers or stretchers appearing in each course. The most common type used in UK bridge arch barrels is stretcher bond, in which there is no connection between rings.
Brick	a masonry unit comprising a shaped and kiln-fired block of clay or shale which can be used as an element for the fabric of a bridge.
Bridge engineer	a person responsible for the technical and engineering processes of bridge management eg carrying out or making decisions regarding condition appraisal, bridge capacity and serviceability, performance restrictions and requirements for maintenance, repair and strengthening.
Bridge strike	an incident in which a road, rail or waterborne vehicle, or its load, impacts on any part of a bridge structure.
Calcining	The heating of calcite or limestone ($CaCO_3$) to its temperature of dissociation so that its carbon dioxide is driven off, leaving "quicklime" (CaO) which can be reacted with water ("slaking") to produce lime putty.
Centring	temporary structure on which an arch is supported during construction, normally made from timbers.
Clamp	a large stack of moulded dry clay bricks with crushed fuel, which is then fired.
Common brick	a type of brick whose characteristics suit it to general use eg where there are no special requirements for appearance, strength and durability.
Condition appraisal	see **Appraisal**.
Conservation	work carried out to with the aim of maintaining or restoring the important features of a bridge, in particular the visible parts of its structure.
Coping	a cap or covering to the top of a wall, which may comprise single or multiple units, the primary function being to channel water away from the building.
Course	a continuous layer of brick or stone masonry units.
Corbel	horizontal outward masonry projection (in brickwork usually constructed of headers) to provide an outstand from the normal line of masonry.

Corbelling	structural form preceding the construction of true arches, in which the masonry units of successive horizontal courses project progressively further inward from the bottom course up, to create a "stepped" structure capable of spanning an open space.
Elliptical arch	indicating a "flattened" semicircular arch, used to keep height reasonable, to reduce approach gradients, and to increase the width of gauge clearance below.
Engineering brick	a dense, strong and durable brick, often used for construction or just for facing of engineering structures.
Extrados	in an arch or vault is the top surface of the arch barrel ie the outer (convex) curve of an arch.
Facing brick	a brick with suitable colour and durability for use in the exposed face of a masonry element.
Fatigue	the reduction of the failure load by the repeated application of loads.
Fill	see **Backfill**.
Gauging	the addition of cement to lime and sand mixes to impart an element of hydraulicity (ability to set by chemical reaction with water) to the set of a mortar (see also **Hydraulic lime**).
Haunch	the lower section of the arch barrel towards the springing
Header	a masonry unit laid with its longer dimension normal to the face of a wall or arch barrel, used to interconnects adjacent *rings* of brickwork. See also **bond types.**
Hinge	a more or less local situation in which, due to the formation of tensile openings, the structure can rotate as if it were an articulation.
Historic bridge	one that has some recognised historical value, through rarity or in terms of social, cultural or engineering heritage.
Hydraulic/ semi-hydraulic hydraulic lime	a non-hydraulic lime is a more or less pure calcium/non-hydroxide substance, used as cement, which can only achieve a set through reaction with atmospheric carbon-dioxide. Hydraulic or semi-hydraulic limes also contain calcium silicates or calcium aluminates, and their set is to a greater or lesser degree assisted by chemical reaction with water (see also **Natural hydraulic lime**).
Impost	the upper element of an abutment or pier which supports an arch barrel or other superstructure.
Infill	see **Backfill**.
Inspection	refers to a visually-based examination of the bridge and associated structures, which may be supported by other simple methods of evaluation or measurement
Intrados	in an arch or vault is the inner surface of the arch barrel ie the inner (concave) curve of the barrel.
Investigation	refers to an enquiry into one or more specific aspects of a bridge's structure, its environment, performance or behaviour, typically using techniques of measurement, testing or sampling of relevant parameters which go beyond the normal scope of visual inspection.

Keystone	the highest and last-placed stones in an arch. In the arch barrel of a bridge there are a series of keystones at the crown, across its width, which are often left projecting on side elevations.
Leaching	a deteriorative process where moisture movement through or over the surface of a material causes the removal of soluble components from it; the "leachates" may crystallise out of solution elsewhere or be redeposited at surfaces where evaporation occurs causing distinctive staining and discolouration, and gradual build-up of mineral deposits.
Lime mortar	a lime mortar is produced by combining slaked lime, sand and water and relies at least in part upon gradual reaction with atmospheric carbon dioxide ("carbonation") to harden and develop strength. Pure limes (also known as "fat" or "non-hydraulic" limes) produce a mortar that is typically weaker and more porous and permeable than limes with a degree of hydraulic (water-dependent) set or those which have been gauged with Portland cement.
Maintenance	all the operations necessary to maintain it in a serviceable condition until the end of its life, comprising *routine maintenance* (routine work carried out with the aim of preventing or controlling deterioration, including inspection and monitoring activities) and *essential maintenance* (rehabilitation works required to address specific inadequacies in function and performance eg strengthening).
Masonry	the work of a mason, strictly referring to work in stone, but commonly used to refer generally to work in either brick or building stone, as it is here.
Masonry cement	a blend of Portland-type cement (typically comprising around 75 per cent) with the remainder being fillers, admixtures and sometimes other binders, often used for general purpose applications.
Mortar	mix of one or more inorganic binders, aggregates, water and sometimes additions and/or admixtures for bedding ,jointing and pointing of masonry.
Multi-ring arch	an **Arch** with more than one *ring*. Rings can be separated fully by mortar joints, or can be structurally connected by masonry units laid as *headers* between rings.
Natural hydraulic lime	a lime produced by burning of more or less impure limestones with reduction to powder by slaking (the addition of water) with or without grinding. They have the property of setting and hardening under water, although the presence of atmospheric carbon dioxide can contribute to the hardening process.
Open-spandrel arch	one that has apertures between the bridge deck/roadway and the arch ring, which can have the benefits of minimising dead weight loading and reducing hydraulic pressure on bridges crossing rivers whose levels rise in spate.
Parabolic arch	a very strong arch shape defined by the intersection of a cone and a plane parallel to the plane tangent of the cone. For uniform loads a parabola is theoretically an ideal arch shape because the line of thrust coincides with the centre-line of the arch ring.

Parapet	usually a vertical continuation of the spandrel wall; an upward extension of a spandrel wall above road surface level to protect those on and below the bridge.
Pattress plate	Load-spreading plate fitted at ends of *tie-bars* to restrain spandrels.
Performance	operation and/or functionality of a bridge or bridge element, in relation to the requirements of owners/operators/users.
Pier	has two definitions: (a) an intermediate support between adjoining bridge spans, or (b) a thickened section located at intervals along a masonry wall to strengthen it.
Pointing	the filling and finishing of mortar on the outer part of a joint where the bedding mortar has been raked back from the masonry face or left recessed from it in construction.
Polycentric arch	an arch shape with more than one centre ie one that is not defined as part of a single circle or curve.
Pozzolan	a cement additive comprising silica in reactive form, which can impart hydraulic set; can be either naturally occurring (eg volcanic ash) or artificially produced (eg brick dust or pulverised fuel ash, PFA).
Puddled clay	a thoroughly mixed combination of pure clay with a proportion of water, forming a plastic material which can be used in construction to prevent the passage of water – particularly for lining canals, aqueducts and as a waterproof backing to arches.
Pulverised fuel ash (PFA)	a waste product of coal fired power stations consisting of tiny spherules of reactive silica, sometimes used as a component in mortars and grouts.
Rehabilitation	work that involves bringing features of a deteriorated bridge back into a satisfactorily functional state.
Relieving arch	one built over a lintel, flat arch or smaller arch to divert loads, thus relieving the lower member from excessive loading.
Ring	a layer of transverse single masonry elements that form slender units which make up an *arch barrel*. In brickwork, multiple adjacent rings are commonly used to produce a *multi-ring arch*.
Ring separation	loss of bonding between adjacent rings (not necessarily a gap) in a *multi-ring arch*.
Rise	vertical height of arch from springing level to the crown of the *intrados*.
Risk	a summation of the likelihood and consequences of an undesirable incidence.
Roadway or road surface	the upper surface of the bridge on which vehicular traffic runs, used here also to include the equivalent surface of bridges carrying rail traffic or waterways.
Roman cement	a quick-setting naturally hydraulic cement produced by calcination of limestone containing clay materials (principally silica and alumina) in a coal or coke-fired kiln. Used from about 1800 onwards, it was so named because its red/brown colour and hardness resembled mortars of the Roman period, although rather misleading since this type of cement was not in use in Roman times.

Rubble masonry	the term describes many different types of masonry, the main types being random rubble (irregularly shaped stone elements, typically as it comes from the quarry) either coursed or uncoursed, and squared rubble (more regularly shaped stone), either coursed or uncoursed.
Saddle	a concrete slab cast over an arch to strengthen it or distribute loads upon it.
Scour	the removal of material from around structural supports by flowing water.
Segmental arch	arch whose intrados comprises a segment of a circle which is smaller than a semicircle.
Semicircular arch	arch with an intrados the shape of a semicircle (ie a 180° arc) so that the rise is half the span.
Shallow arch	arch in which the rise is smaller than a quarter of the span.
Skew arch	arch where the longitudinal and transverse axes are not at right angles.
Skewback	The inclined surface of the course of masonry located at the extremity of an arch which transmits the stresses of the arch to an abutment or pier; surface of an inclined springing.
Slaking	see **calcining**.
Snap-through	mechanism in which sufficient rotations take place at a hinge so as to produce instability and local failure, prior to the formation of a global hinge failure mechanism. This type of local failure can occur in highly confined arches and precipitates the global collapse of the structure.
Soffit	the underside of an element – in masonry arch bridges, equivalent to the intrados.
Soldier	masonry unit laid with its longer dimension upright and parallel with the face of the wall ie bedded on its smaller face.
Spalling	loss of material from the face of a masonry unit, either through “flaking” or delamination.
Span	the distance between the supports of an individual arch along its longitudinal axis.
Spandrel	the area overlying the arch barrel under the road surface (or equivalent), occupied by the spandrel walls, fill material or voids, and occasionally hidden elements such as internal spandrel walls.
Spandrel wall	masonry wall that sits on the edge of the arch barrel and that limits the extent of, and retains, the backfill. Sometimes “internal” spandrel walls may be present at other locations on the arch.
Spandrel separation	usually refers to lateral separation, in which the spandrel wall moves horizontally due to the action of applied loads, sometimes over the extrados of the arch and sometimes by forming a crack through the arch barrel close to its outer face. However, it could also be tangential separation, in which a crack tangential to arch forms at the contact between the arch and the spandrel walls.
Spreader beam	load spreading strip over the length of the span and fitted at ends of tie-bars to restrain the spandrels.

Springing	plane from which an arch springs ie the junction between the vertical face of the abutment and the arch barrel.
Square spanning	non-skewed arches.
Stretcher	a masonry unit laid with its longer dimension parallel to the face of the wall or *arch barrel*. See also **bond types**.
Stock brick	originally meaning a soft mud brick that is hand made using a stock mould, later coming to mean a large number (stock) of bricks all manufactured in the one locality eg London stock brick.
Thrust line	the locus of the positions of the centroid of the compressive force within the arch. The point on a given section where if you transfer the stresses, there is no bending moment but only axial force.
Tie-bar	a structural tensile element used to provide restraint, typically comprising steel rods installed transversely through a bridge, and attached to *pattress plates*, to provide restraint to the spandrel walls.
Unit	an individual stone or brick that is laid, normally in mortar, to form masonry.
Vault	either (a) the arched ceiling over a void, or (b) any space covered by arches.
Voussoir	a wedged-shaped masonry unit used to make an arch or vault (voussoirs can be flat or irregular in rubble construction).
Voussoir arch	arch with one ring only ie not a multi-ring arch.
Width	the transverse dimension of a bridge, perpendicular to its span.
Wing wall	a wall at the abutment of a bridge, which extends beyond the bridge to retain the earth behind the abutment.

Acronyms and abbreviations

ALARP	as low as reasonably practicable
BMS	bridge management system
BR	British Rail (now Network Rail)
BRR	British Rail Research
BW	British Waterways
CBA	cost-benefit assessment
CEEQUAL	the Civil Engineering Environmental Quality Awards Scheme (<www.ceequal.com>)
CL	calcium lime
DE	discrete element (method of structural analysis)
DEFRA	the Department for Environment, Food and Rural Affairs
FE	finite element (method of structural analysis)
HA	Highways Agency
HL	hydraulic lime
KEL	knife edge loading
LU	London Underground
MEXE	Military Engineering Experimental Establishment
NHL	natural hydraulic lime
NR	Network Rail
PAL	provisional axle loading
PFA	pulverised fuel ash
QRA	quantitative risk assessment
SAC	special area for conservation (EC designation relating to environmental conservation)
SNCO	statutory nature conservation organisation
SPA	special protection area (EC designation relating to conservation of wild birds)
SSSI	site of special scientific interest
UDL	uniformly distributed loading
WLC	whole-life costing

1 Introduction and background

1.1 Background

Safe and efficient transport is fundamental to the freedom, wellbeing and prosperity of society. By their nature, bridges are essential elements in the road, rail and waterway transport networks of the UK and are vital to their operation. Restrictions to the operation of bridges or their closure can have effects beyond the immediate local disruption, including undesirable health and safety, economic, environmental and political consequences.

In the UK the present transportation network is the result of development that has taken place over hundreds of years, and bridges form a valuable part of our historical legacy. Although the oldest bridges still in existence date from medieval times, a significant proportion of the UK's current bridge stock was constructed between 1760 and 1900 as first the canal, then the railway, and finally the road networks were subject to rapid development and expansion. The great majority of these bridges were constructed in the form of arches, either from stone or brickwork, depending on the availability of local materials, skills and experience. Few such bridges were constructed after 1925 when iron, steel and, later, reinforced concrete became the engineering materials of choice and the UK trunk road and motorway systems were developed. A high proportion of the bridges on the waterway, rail and local road network comprise masonry arches that have now been in service for at least 100 years and frequently much longer. Masonry arch bridges are not only a vital part of our transport infrastructure but also make an important contribution to our cultural and engineering heritage.

Today the transport network in the UK, as in many other countries, is under constant pressure to expand and increase capacity, with attendant economic and environmental costs. In this climate it is vitally important that the existing infrastructure is used efficiently and to its full capacity. This can only be achieved by careful management of existing bridge assets. Changes in the requirements of the transport system and the gradual deterioration of existing structures in service mean that there is a growing need to maintain, repair, widen and strengthen masonry arch bridges over the coming decades. The success of this will be dependent on accurately determining the needs of bridges and understanding how best to undertake and allocate resources for their maintenance, repair and renewal.

Masonry arch bridges can be viewed as among the most sustainable structures ever to have been built. Many have already been in service for hundreds of years without significant repair or strengthening works – exceeding the design life requirements of modern structures. By contrast, many of the steel and concrete bridges built in the last century have required considerable expenditure on maintenance and repair or even replacement within the first 30–40 years of service. A recent review of funding required for bridge and retaining wall maintenance carried out by the Bridges Group of the County Surveyors Society (CSS, 2000) which involved several methods of assessment, suggested that the annual maintenance cost of masonry arch bridges appeared to be much lower than for other bridge types, and half that of steel bridges with reinforced concrete supports. Other studies have produced similar results (Bouabaz, 1990; CSS, 1999).

The aim of this document is to gather existing knowledge from the UK and abroad and to provide examples of good (and poor) practice in the management of masonry arch bridges. It is hoped that the advice and information included here will benefit those involved with the preservation of such bridges, suggest improvements in their inspection and assessment, and assist in the budgeting, selection, planning and execution of maintenance and repair works. While intended primarily for the UK market, the methods and advice included are generally applicable in other countries.

1.2 Purpose and scope of work

This guidance provides guidelines on good practice for the appraisal, maintenance, repair and strengthening of masonry arch bridges, as well as advice on issues such as inspection, investigation and monitoring, bridge management, conservation, health and safety and environmental issues.

The purpose of the guidance is to:

- present good practice (as of 2005)
- provide a guide for routine management
- recommend assessment, maintenance and repair strategies to give best value for money
- facilitate knowledge sharing.

1.3 Application

This guidance is intended for:

- clients who are infrastructure owners
- those responsible for the management and care of bridge assets
- engineers who are responsible for assessing, maintaining, repairing and strengthening bridges.

There are around 40 000 masonry arch bridges in the UK, representing an estimated 40–50 per cent of the total bridge stock. The main UK arch bridge owners are railway authorities, highway authorities and navigable waterway authorities.

1.4 Issues of special importance for masonry arch bridges

Topics of particular importance in the management of older masonry arch bridges include:

- the need to investigate and evaluate the existing structure, its performance and materials, taking into account issues such as complex structural behaviour, lack of design to modern codes, the presence of defects and the original variability and in-service deterioration of materials
- the importance of a thorough knowledge of this particular bridge form in order to make good assessments of their condition, and understanding the significance of observed features
- the necessity of regular maintenance to ensure continued performance and serviceability while minimising unnecessary repair expenditure, closures and traffic restrictions

- the impacts of changes in usage and in traffic loading regimes
- consideration of the effectiveness of repairs and alterations and their likely influence on the long-term performance and maintenance of the structure
- the importance of careful selection and planning of works so as to minimise disruption to the normal operation of the bridge
- the particular access, safety and environmental issues, their associated requirements and cost implications, when carrying out works
- consideration of the historic or aesthetic value of the bridge and the need to respect and preserve the existing structure by carrying out repairs and alterations sympathetically
- lack of recent experience in, and modern guidance for, building new masonry arch bridges.

This guidance aims to provide guidance in each of these areas. For a quick reference guide in dealing with these issues, see the table below in Section 1.5.

1.5 How to use this guidance

This guidance is divided into five chapters each comprising of advice and guidance on particular aspects of masonry and brick arch bridges, followed by appendices which include supporting information. It is intended that the main sections of the book can be read to provide further information on each topic, and that readers requiring additional detail for application are referred to the appendices or to other available sources of information where appropriate.

1.	**Introduction** General background information; principal bridge asset owners; how to use this guide.
2.	**Construction and behaviour** Basic principles of arch bridges; their history; construction and materials; behaviour and performance.
3.	**Management, condition appraisal and assessment** Asset management; bridge condition appraisal; structural assessment.
4.	**Selecting and carrying out bridge works** Health and safety, environmental and heritage considerations; maintenance, repair and strengthening techniques; selection and execution of works.
5.	**Summary of recommendations and future needs** Overall summary of recommendations; discussion of future research and development needs; list of references.

Section A1 includes a number of case studies intended to illustrate the practical application of some of the concepts discussed in this publication.

The construction, materials and structural behaviour of masonry arches is not a topic widely taught in modern engineering courses,and it is not greatly understood by many modern engineers. Chapter 2 of the guidance is intended to provide the reader with a basic level of understanding. The guidance is written so that more experienced readers with a greater depth of knowledge of masonry arch bridges can omit Chapter 2 and concentrate on those chapters of the document most relevant or useful to them. Frequent cross-references are included where the reader may require further explanation or clarification of points not fully covered in that chapter, but a certain amount of repetition has been included to enable readers to “dip into” sections of the document without excessive cross-referencing.

Table 1.1 provides a quick guide to finding relevant information on a number of the principal topics included in the publication.

Table 1.1 *Where to find guidance in this book*

General topic	Where to find guidance in this book	
	Issue	*Section*
Understanding the history of bridges, how they were built and the materials used	History and construction of bridges	2.1
	Bridge structural elements	2.2
	Bridge materials	2.3
Structural behaviour and causes signs of loss of performance and deterioration	Structural behaviour	2.4
	Structural problems	2.5
	Materials deterioration	2.5.3
Ensuring serviceability through a maintenance and repair programme	Maintenance management (general)	3.4
	Maintenance requirements	3.4.1
	Bridge management systems	3.4.2
Inspection, investigation and monitoring	Sources of information	3.6.1
	Bridge inspection (general)	3.7
	Inspection frequencies	3.7.1
	Investigation techniques	3.8.2
	Materials sampling and testing	3.8.3
	Monitoring techniques	3.8.4
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