HR Wallingford

HYDRAULIC ASPECTS OF BRIDGES :
ASSESSMENT OF THE RISK OF SCOUR

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ABSTRACT

This report presents advice and guidelines which will enable British Rail to assess hydraulic aspects of bridges over water. Possible causes of failure are discussed, and guidelines are presented to assess individual structures with respect to scour. The guidelines are based on bridge geometry and river and catchment characteristics. Features of the bridge and river are discussed and quantified where this is feasible. Recommendations are made concerning relevant data which should be recorded and maintained for each bridge. The guidelines have been designed to allow a bridge to be inspected and assessed in a short time and without special equipment.

The report incorporates numerous changes to the original procedure contained in Handbook 47 dated May 1989. The revised procedure is expected to be more accurate over a wider range of circumstances than the original. The main changes incorporated into this procedure are as follows:

1. An addition chapter (Chapter 8) has been added to assist in the inspection and assesssment of parts of a bridge for which appropriate numerical calculation methods are not available. Chapter 7 (numerical assessment) is now used only for parts of the bridge for which the calculation methods are applicable. Guidance is given to identify whether Chapter 7 or Chapter 8 should be used for each part, or element, of the bridge (Section 1.1).

2. An improved method of accounting for the effects of flood plain constriction has been included, and assessments of flood plain and channel constriction have been combined (Section 7.3.1).

3. Modified advice on calculations of foundation depth has been included (Section 7.4).

4. An optional correction has been included to account for 'residual' scour which may be present at the site, even at low flow conditions (Section 7.5.3).

5. A new procedure has been included to account for local scour at groups of closely spaced columns (Section 7.3.5).

6. The overall marking and classification system has been modified (Sections 7.5.3, 7.6).

7. Additional advice and discussion has been included eg. types of failure (Section 2), flood frequency (Section 7.1), structural aspects of foundations (Section 7.4.1).

8. Increased use has been made of figures and diagrams.

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1 INTRODUCTION

All bridges and structures associated with waterways are potentially at risk of failure from hydraulic causes. British Rail is responsible for a large number of such structures, many of which were built in the nineteenth century.

In 1988, BR asked Hydraulics Research to prepare guidelines to assess the level of potential risk of individual structures. The guidelines enabled BR to assess the frequency and level of inspection that is appropriate for each individual structure. In addition, the guidelines identified high priority structures requiring prompt, more detailed inspection.

HR Wallingford were later asked to produce a revised version of the procedure, in order to improve the assessment procedure and enable its use over a wider range of circumstances. This report describes the revised procedure.

An approach has been adopted in this work to categorise structures based on priority but this should not encourage complacency and the belief that particular structures are 'safe'. In reality there will always be a non-zero probability of failure. Nor should the risk associated with a particular structure be regarded as something fixed in time. Changes may take place, particularly with regard to the river, which may significantly change the factors influencing the hydraulics of the structure. Thus, for example, changes in the alignment of a river channel may radically affect the risk of failure due to scour.

This report is concerned with erosion to the river bed and banks which may affect the safety of a bridge. It does not address questions of structural weakness. In some cases additional analysis may be required in order to establish, for a particular foundation, the critical bed level below which the foundation becomes structurally unsafe.

The major cause of bridge failure is undermining of pier and abutment foundations following scouring or erosion of the channel bed. Scour at bridges is a highly complex process and cannot be precisely predicted. In this report we have highlighted the main and most easily measurable parameters which could affect the risk of scour, and have, with the help of published research findings, established how scour is affected by each parameter. The combined effect of all the parameters will give an indication of the severity of scour, but it is difficult to accurately predict the maximum scour depth at the bridge. In assessing the risk of failure, the depth and structural condition of the bridge foundations is as important as the depth of scour, but may not be known with certainty. A bridge with potential for deep scour relative to its foundations will be at higher risk than one which causes little scour and has good deep foundations. In this report, the two quantities of scour depth and foundation depth are assessed and compared. This comparison provides the basis for categorisation of piers and abutments within the main river channel with respect to their risk of failure due to scour.

For some parts of a bridge, such as abutments founded on the flood plain, it is more difficult to assess the risk of scour and so these parts of the bridge are assessed by inspection and noting features which indicate scour risk. This is carried out with the aid of a checklist of features which can be observed.

The handbook provides an initial assessment of the potential risk of failure due to scour. It is, by its nature, a general method which cannot take into account all the local and particular circumstances. If the assessment indicates a high priority rating then this suggests that a more detailed examination of the structure and the hydraulics should be carried out. This should concentrate on:

- the reasons for the Handbook assessment leading to a high priority rating
- detailed consideration of the hydraulics associated with the structure
- the need for any remedial work
- the need for monitoring flow conditions and scour

The survey guidelines have been prepared with the aim of requiring data which can be obtained from observation, simple site measurements and a small amount of desk work. For the initial survey, for example, neither a boat nor a theodolite is needed, and estimates of flood magnitudes and flow velocities are not necessary. In some cases, the report advises the use of additional data where this is available, in order to provide a more accurate assessment.

Possible causes of bridge failure are discussed in Section 2. Section 3 includes a discussion of factors which can change hydraulic conditions at a bridge site, such as construction of a structure nearby, or dredging. Section 4 discusses special factors affecting bridges over tidal waterways. Section 5 contains recommendations for obtaining data which may be relevant to hydraulic conditions at a bridge. Section 6 presents information on the characteristics of rivers and catchments which may be relevant to the safety of the bridge.

Sections 7 and 8 present guidelines for making a preliminary assessment of the risk of scour at a bridge. This enables bridges to be placed in one of six categories, based on the priority for further investigation.

1.1 Outline of assessment procedure

A bridge which crosses a river will generally comprise several different elements which are subject to hydraulic action. For example, a crossing may comprise of earth approach embankments on the flood plain, abutments which are either founded on the flood plain or in the main channel, and piers which are founded on the flood plain or in the main channel. The risk to different elements may vary in scale and severity.

Furthermore, methods for calculating scour vary depending on the type of element and its location - in some cases reliable methods are not available.

Table 1 identifies elements of a river crossing which may be subject to scour due to flowing water. Examples of these elements are shown in Figures 1 to 8. Table 1 also gives the most likely causes of scour and erosion problems. For example, a pier in the main channel is most likely to be at risk from local scour at the pier and general scour due, for example, to a narrowing or constriction of the channel at the bridge site. The column containing main worsening factors in Table 1 shows factors of the bridge and river most likely to exacerbate the primary risks.

In addition to the primary risks, parts of a bridge crossing may be vulnerable to secondary risks which are generally less severe. Secondary risks for each bridge element are shown in Table 1.

For assessment purposes, bridge elements are assigned to one of two categories as follows:

Category 1	Category 2
• Bridge pier in main river channel	• Bridge pier on flood plain near to main river channel
• Abutment projecting into main river channel	• Abutment on flood plain near to main river channel

- Bridge pier on flood plain set well back from main river channel

- Abutment on flood plan set well back from main river channel

- Flood relief arch on flood plain

- Earth embankment approach embankment

The primary risks associated with 'Category 1' elements can be assessed numerically, as methods exist for predicting general and local scour. However, methods do not exist to calculate scour and erosion at bridges showing 'Category 2' elements with sufficient accuracy, so these elements are assessed by observing and recording the presence or absence of features which affect scour.

The following steps illustrate the general procedure to be followed:

1. Identify the elements of a bridge subject to hydraulic action.

2. Collect all relevant available data regarding bridge and upstream and downstream channel. Site inspection is necessary in most cases to assess existing conditions at the bridge. Measure main

dimensions of the bridge if not available. Chapter 5 outlines the data requirements.

3. Review the history of the bridge and river, with reference to Chapter 3, to ascertain the likely effects of changes to the river and bridge, and be aware of special factors which may influence the safety of the bridge.

4. Calculate the type of river score, TR, based on river type, bank stability, flashiness of river. Chapter 6 outlines the classification of river and catchment characteristics.

5. Decide into which category, 1 or 2, each element of the bridge should fall based on information given in Chapters 1 and 2.

6. For each category 1 element of the bridge, calculate scores for each feature. Determine foundation depth, calculate scour depth, calculate priority rating as explained in Chapter 7.

7. Modify priority rating, if appropriate, for each category of bridge, Section 7.7.

8. For each category 2 element, use procedure in Chapter 8 to assess features.

9. Decide on any further action, Chapter 9, depending on priority rating of bridge.

2 TYPES OF FAILURE DUE TO HYDRAULIC CAUSES

Several possible causes of failure are discussed in this section. Failure is most likely to occur at high flows, when the river is in flood. Scour is the most frequent cause of failure and is the chief subject of this report.

2.1 Failure due to scour

Most rivers have beds and banks of more or less mobile material. During a flood, the bed level may fall as bed material is transported by the moving water. A bridge across the river can result in additional lowering of the bed level at the bridge. Two possible causes of this extra erosion, or scour, are a general increase in flow velocity due to a constriction of the channel, and a local disturbance of the flow due to a bridge pier or abutment. These two types of scour are called general and local scour. General scour may affect the whole width of the river, while local scour occurs adjacent to piers or abutments. Where both types of scour occur, the total depth of scour is the sum of general and local scour. In addition scour may be increased on navigable waterways, by the action of vessels causing rapid displacement of water and high local flow rates. Local scour at a bridge pier is normally greatest near the upstream nose of the pier. Due to the local geometry and flow or the nature of the sediment, however, there may be exceptions where the local scour is greater in other areas adjoining the pier.

Many features of the bridge and river affect depth of scour, and the complex nature of the problem means that accurate prediction of scour is not possible except in very simple cases. We can however identify the most important features and predict trends of how scour depends on each feature, and assess the expected severity of scour for a given bridge by combining the effects of the significant features. This forms the basis assessment methods in this report.

The depth of the foundations is important in determining the risk to a bridge from a given degree of scour. Deep foundations subjected to severe scour may be safer than a shallow spread footing in only moderate scour.

A bridge constructed on spread foundations will be at risk from scour when the adjacent scour reaches the level of the base of a footing. However if the substructure member is subject to lateral loads which are partially or wholly resisted by passive pressure then the foundation may be at risk before scour reaches the footing level. These lateral forces may be increased by hydrodynamic effects.

Scour adjacent to piled foundations may result in a loss of skin friction and reduction in load bearing capacity of the piles, even if they have not been undermined.

Structural analysis of the bridge foundations may be required to accurately assess the critical bed level below which the foundations become unsafe.

There are a significant number of bridges where the flow is affected by tidal action. Depending upon the location of the bridge, the discharges can be predominantly fluvial, predominantly tidal or both tidal and fluvial components can be significant. In all cases the flow is in at least two significantly different directions at different times and the flow patterns may vary significantly. Therefore a pier which may be well aligned and subject to little scour during the flood tide may be poorly aligned and subject to additional scour during the ebb tide.

2.2 Failure due to bank erosion

Most natural rivers tend to change their course with time. A mechanism by which this occurs is bank erosion. A structure such as a pier or abutment located on a flood plain may be placed at risk if the main channel moves sufficiently close to the structure to cause loss of support or undermining. Bank erosion may occur very slowly in time, or may be very rapid, particularly during times of flood. The rate of bank erosion depends partly on the character of the river: a river with a steep gradient and high flow velocities will in general be more active and prone to bank erosion than a river with a fairly flat slope and lower velocities.

2.3 Failure of approach embankments

Overtopping of the approach railway and/or turbulent flow adjacent to the approach embankments can lead to erosion and scour to the side slopes and toes of the embankments. This may lead to instability of the approach embankments and possible loss of the railway. Loss of fill material around and behind the wing walls can lead to instability and failure of the wing walls.

2.4 Failure due to hydraulic forces on piers

Water flowing past a bridge pier exerts a force on the pier. This force can be resolved into two components one along the axis of the pier, which is referred to as the drag force and one normal to the pier, which is referred to as the lift force.

The applied forces depend upon the depth of flow and the length of the pier, with a marked dependence upon the flow velocity. If the flow is aligned with the pier the lift force is zero but as the angle of attack increases the lift force increases rapidly. The ability of a pier to withstand drag forces will depend upon the structure of the bridge and the foundation details and may be reduced during a flood if significant scour around the base of a pier takes place. A method for evaluating these forces is given in Farraday and Charlton (1983). The application of this method requires a detailed knowledge of the flow velocity and direction and so is outside the scope of this report.

Debris which is caught on piers can result in increased hydraulic forces by increasing the effective pier width, while floating debris which collides with piers can cause dynamic loading. Both types of loading will probably be most severe when the river is in flood. If it is necessary to consider the effects of hydraulic and hydrodynamic loading, then it is recommended that specialist advise is sought.

2.5 Failure due to hydraulic forces on the bridge deck

If the water level reaches the soffit level of a bridge, or the springing in the case of an arch, the flowing water will exert a force on the bridge deck. The drag on the deck may be calculated in a similar way to drag on a pier, and is again very dependent on the flow velocity. A force applied to the deck of the bridge is potentially more dangerous due to the large overturning moment about the pier foundations. If it is known that historic flood levels have approached the bridge deck, it may be appropriate to carry out a site-specific study to assess future flood levels, flow velocities and hydraulic forces and the resistance of the bridge to these forces. Estimates should also be made of possible dynamic loads imposed by collision of floating debris. These types of study are outside the scope of this report. For further information consult Farraday and Charlton (1983) or seek specialist advice.

2.6 Failure due to debris

Build up of trash and debris against bridge components can significantly affect the hydraulic performance of bridges. Difficulties are normally associated with small, single-span bridges which tend to be more easily blocked than large multi-span structures. For such single span bridges the blockage can be extensive, reaching up to 90% of the bridge opening. This may result in large increases in water level and flooding upstream. Debris may restrict the flow leading to significant scour around piers or abutments threatening the safety of the structure.

Debris may also result in additional 'drag' and 'lift' forces on piers, and impact forces may result from debris colliding with piers.

2.7 Failure due to Ice Forces

For inland river structures the critical mode of ice action is most likely to be the impact of large sheets of ice with piers or piles as ice break up occurs. Ice may also result in additional scour due to blockage of the waterway. Ice problems are unlikely to occur in most parts of the UK. If it is thought that ice problems may occur then specialist advice should be sought.

3 MODIFICATIONS TO THE RIVER OR CATCHMENT

3.1 Introduction

Most rivers naturally change their geometry with time. Rates of change depend on geological as well as hydraulic factors, but the stability of the river which is discussed in Section 6.2 is an important factor. A very stable channel, such as a canal, will change very slowly if at all, whereas many less stable meandering rivers will steadily change their course as meanders migrate downstream.

In addition to these natural changes, modification of the hydraulic properties of the catchment or river tends to cause changes. The sensitivity of the river to these modifications depends partly on its stability. In this section several types of modification are discussed. The indirect nature of their effects and the complexity of river systems means that firm general guidelines cannot be given. Recent modifications may be more dangerous than older ones - the bridge is less likely to have been tested by a major flood if new conditions have been imposed recently.

Section 3.2 discusses modifications which may have a direct effect on flow conditions at the bridge. In addition, it is very important that factors affecting the river regime remote from the bridge are monitored since those may have a significant impact on the potential scour as a result of altering the characteristics of the river. One of the hydraulic aspects which can lead to scour and hence to bridge failure is a change in channel pattern. The river can shift laterally after a flood or after engineering works upstream of downstream of the bridge. This can cause scour problems at unprotected parts of the bridge. By altering the angle of attack of the flow relative to the structure, existing scour may also be increased.

3.2 Modifications in the neighbourhood of the bridge

- Structures constructed later than the bridge.

Another bridge built upstream can affect the hydraulic conditions at the railway bridge. Increased turbulence and less uniform approach velocity can both result in deeper scour depths at the railway bridge. The upstream structure may alter the flow direction and cause erosion of abutments and deeper scour at the bridge piers. This effect is illustrated in Figure 9.

- Bank protection measures in the neighbourhood of the bridge.

Work may have been carried out to protect the banks and stabilise the course of the river. The presence of bank protection measures which post date the bridge may indicate that the river has in the past actively eroded its banks and may have changed its course and its cross sectional geometry. Both types of change can reduce the safety of an adjacent bridge.

3.3 Modifications to the river

If water and/or sediment flows in a river are altered, the equilibrium state of the river may change. The plan geometry, cross section and discharges at the bridge site may be affected. The bridge may be subjected to worse erosion and scour and higher water levels.

It is not possible to give guidelines on whether changes due to river works are likely to improve or worsen the bridge's safety, as the river geometry depends on complex interaction between discharge and sediment movement. In general, an unstable river will be more liable to change than a stable river.

Changes in flow can be caused by a change in the river upstream of a bridge. Rivers works can cause these flow changes, if they are carried out since the construction of the bridge. Some river works which could cause these effects are identified below:

- construction of flood embankments;
- construction of flood detention basins;
- construction or removal of bridges;
- construction or removal of bank protection or river training works;
- changes in water abstraction patterns;
- schemes for water transfer between river basins.

Approach velocities may be increased by: the construction of flood banks, which eliminate flood plain storage and increase flows; the construction or removal of another bridge, which may alter flow velocities and directions, and by the construction or removal of bank protection or river training works. The above effects are illustrated in Figure 9.

Other river works can cause changes in bed level:

- channel improvement schemes such as dredging for navigation or gravel abstraction, weed clearance, realignment;
- reservoir impoundment;
- construction or removal of weirs.

The above effects are illustrated in Figure 10.

3.4 Modifications to the catchment

Changes to catchment characteristics can affect rates of water and sediment supply to a river, which can result in changes in discharge, water levels and channel geometry. Changes to a catchment which have occurred since the bridge was constructed can therefore affect the safety of the bridge.

Some examples of catchment changes which may be significant are given below:

- Urbanisation;
- De-forestation;

- Change in land drainage;
- Change in groundwater regime.

Recent modifications either to the structure or the river should be recorded and their potential impact on the hydraulics of the bridge considered. When modifications are proposed their potential impact should be assessed (see Section 5.1, paragraphs d) and e)).

4 BRIDGES ON ESTUARIES

The bulk of this work has considered bridges on rivers where the flow is uni-directional. There are, however, a significant number of bridges where the flow is affected by tides. Because of the large range of conditions that may prevail at such bridges it is not possible to characterise them in the same way that has been done for non-tidal rivers. In this section we discuss general points to be considered and also suggest how markings in some of the other sections could be modified to take account of tidal effects. We must stress, however, that this is not complete or exhaustive and that in cases of concern further investigations should be made and specialist advice sought.

Most of the assessment for river bridges can be applied to bridges on estuaries with the exception of Section 6.3.1 which is based on the slope of the catchment. It is suggested that in tidally dominated rivers this is replaced by an assessment of the tidal velocity, as described in 6.3.2. If both fluvial floods and tides may be significant then the worst score of 6.3.1 and 6.3.2 should be taken. It should be appreciated, however, that in these cases specialist advice may have to be sought.

In assessing the shape and alignment of bridge piers it should be remembered that there will be two prominent flow directions.

In view of the complexities of tidal estuaries the final assessment can only be regarded as an indication of the risk associated with the structure. In any cases of doubt expert advice should be sought.

4.1 Tidal discharge

One of the important hydraulic factors is the magnitude of the discharges through the bridge. Depending upon the location of the bridge the discharges can be predominantly fluvial, predominantly tidal or both tidal and fluvial components can be significant. The tidal discharge depends upon the tidal area upstream and upon the tidal range at the bridge site. If the tidal area upstream is large or if the tidal range at the site is large problems are more likely to arise.

4.2 Reversing flow

In tidal dominated areas at different times the flow is in at least two significantly different directions. This should be reflected in the design of piers and abutments. Thus there will be requirement to streamline both ends of a pier. It should be remembered that flood and ebb flow patterns may vary significantly from one another; one is not to be regarded as the reverse of the other. A pier which may be well aligned for the flood flows may be poorly aligned for ebb flows. Indeed, flow in channels which dominate in the flood may not be as significant on the ebb.

In general the strongest ebb currents run at the surface and the strongest flood currents at the bed, and this differential flow, accentuated in plan in a wide estuary, may give different flood and ebb channels. Worst conditions are likely during ebb tide with a high freshwater discharge.

4.3 Sediments

Estuaries are frequently, but not always, characterised by fine sediments consisting of silts and clays. When first deposited such sediments may have very low densities, in extreme cases they can 'flow' under gravity. Such sediments may be easily re-eroded and even in position will not provide any significant support for foundations. In these situations care must be taken in interpreting information from echo sounders and similar devices.

4.4 Channel pattern

Within an estuary there is usually a pattern of low flow channels. Depending upon the nature of the estuary and its sediments this pattern may change from time to time. Thus while at the moment one pier may be in a deep channel and another located on a sand bank the situation might reverse within a few weeks or months. In such circumstances unless there is strong evidence that the channel pattern is fixed the foundations of all the piers should be sufficient to withstand the conditions where the flow is presently the deepest and fastest.

4.5 Dredging

A number of estuaries are periodically dredged either for navigation or for flood prevention. Such dredging, if it is close to a structure may have a direct impact on the stability of foundations. Even dredging at some distance, may have an indirect affect by altering the flow pattern. If dredging is to take place within 1km of the structure it would be advisable to ask the dredging authority for information about the quantity and location of dredging. The dredging authority will probably monitor bed levels in the dredged area for their own purposes and it may be possible to arrange for them to extend such monitoring work to the neighbourhood of the structure to ensure that significant changes do not take place unnoticed.

Development of the estuary on the landward side of a bridge may affect the flow conditions at the bridge. If the total volume is reduced, for example, by the construction of a barrage the flows are likely to be reduced. If the tidal volume is increased, for example, by dredging then flows are likely to be increased.

5 DATA REQUIREMENTS AND RECOMMENDATIONS

We recommend that a file of all relevant information is maintained for bridges which have been assessed using this procedure. In addition to providing useful data about the bridge and river for future reference, some of the information will be very valuable at a later date in assessing whether and how quickly important features are changing with time.

5.1 Data requirements

Details of many of the relevant features will be recorded during the assessment procedure, and this section describes the additional information which should be obtained for future reference. The information is particularly important for bridges which are shown by the assessment procedure to be potentially vulnerable.

a) Photographs taken at the time of inspection.

Though of limited immediate value, these can provide valuable evidence of whether changes have or have not taken place. A minimum of one photograph of the river should be taken looking upstream and one looking downstream from the bridge, if possible. The positions from which the photographs were taken should be recorded and where possible the photographs should include suitable references, such as trees or other permanent features near to the river banks. These photographs should be kept and compared with similar shots taken during subsequent inspections to assess if any changes are taking place, and if so how quickly.

Photographs should also be taken of the bridge and of piers, abutments and any embankments which are near to the river. Again, these can be used later to indicate any visible deterioration which may have taken place.

b) Photographs, notes and observations of flows through the bridge during flood can provide valuable information

These observations can give indications of, for example, the amount of flow through relief arches and culverts, flow velocities at different parts of the bridge, and angle of attack of flow during flood and the water level.

The NRA may be able to supply estimates of the magnitude and severity (return period) of the flood. This can be valuable if further hydraulic studies of the bridge are carried out.

c) Aerial photographs and Ordnance Survey maps

Aerial photographs can very readily give a very good impression of the nature and stability of the river channel and its relationship to any structure. The perspective provided by such photographs can provide an overall appreciation of a structure and its surroundings which may not be obtainable by viewing from the ground. Good air cover of most of the country is now available. Possible sources of air photographs are:

The Royal Commission on the Historical Monuments of England

The Central Register of Air Photography for Wales, - contact

Air Photographs Officer
Cartographic Services (PS 8), Welsh Office
Room G-003, Crown Offices
Cathays Park, Cardiff, CF1 3NQ

Aerial photographs dating back to about 1940 are available from RAF Broughton and Cambridge University.

The Ordnance Survey, Southampton, can supply maps to 1" to the mile scale (or, for recent editions, 1:50,000 scale) for a number of series dating back to 1897. 1:25,000 sheets are also available.

The National Map Centre (Caxton Street, London SW1) can supply latest editions only of large scale plans. These are generally 1:2,500 scale for rural areas and 1:1,250 scale for urban areas. 6" to the mile (approx 1:10,000 maps are also available, again from the latest series only.

The British Map Library, part of the British Library at Great Russell Street, London, keeps archives of a number of series, including 25" to the mile dating back to 1871, and 6" to the mile dating back to 1882. Maps may be viewed and traced at the library, and a copying service is available.

A scale of at least 1:10,000 would be preferred for plotting changes to channel plan form for most British rivers.

d) Alterations to the bridge

Structural alterations or repairs to the bridge may affect its hydraulic performance. Details should be obtained of any repairs which are proposed, and an assessment made of whether the temporary or permanent works will significantly affect the hydraulic behaviour of the bridge. If worse scour or greater forces on the piers or deck are expected as a result of alterations, more detailed hydraulic investigations may be advisable. Particular attention should be paid to alterations which increase the width of piers and abutments, or cause additional channel constriction. Both of these changes can result in increased scour.

e) Alterations to the river upstream or downstream of the bridge.

Consideration should be given to proposed river engineering works which might affect the flow at the bridge. Examples are new structures or earthworks which can alter the approach flow and scour at a bridge, and flood protection work such as flood embankments or channel clearance which can change the regime, or stable form, of the river. Detailed studies may be required to assess the effects of changes to the river on the safety of the bridge. Records of river conditions before the works should be kept and the river should be monitored after the works and compared with the records.

f) The range of water levels, particularly high water and the frequency of occurrence. This data may be collected during or immediately following floods. The presence of nearby flow gauging stations should be determined. This is often available from the local National Rivers Authority office.

Gauging stations on the river will provide information on the range of discharge and, in particular on flood discharges. If the NRA office is approached after a flood event on a gauged river, they should be able to provide an indication of the severity of the event in terms of return period.

g) General geological data is available from the British Geological Survey. They retain some borehole data. Other data may be available from local authorities who have undertaken site investigation work in the area.

The occurrence of rock as the bed or founding material does not guarantee the absence of a scour problem. The following data should be collected:

i) The depth of the rock and its variation over the site.

ii) The extent and character of the weathered zone.

iii) The structure of the rock, including bedding planes, faults, fissures which affect its erodibility.

Advice should be sought on the susceptibility of the rock to scour.

h) The structural form of the bridge.

i) Original design calculations.

j) As-built drawings.

In most cases, basic information relating to the dimensions and form of construction of each bridge are already available. It appears however that details of the foundation and founding depth are often unknown. For an accurate assessment of the risk of scour, this information should be obtained.

6 RIVER AND CATCHMENT CHARACTERISTICS

6.1 Introduction

The aim of this section is to assess the degree of hazard which is inherent in the river at the bridge site. This inherent hazard depends on the type of river and the characteristics of the catchment which it drains. Two features are considered to be particularly important and are assessed in the following sections.

(a) The stability of the river. Many rivers change their plan form and cross sectional properties with time. The stability of the river is an assessment of how quickly these changes are likely to occur and how responsive the river will be to changes which are imposed on it. This feature is therefore important in determining the required frequency of inspection of a structure. In Section 6.2 the stability is assessed by identifying the river-type and by examining bank erosion characteristics.

(b) Severity of extreme floods. Most bridge failures due to hydraulic causes occur during rare, high flow events. In Section 6.3 the expected magnitude of a rare flood relative to the magnitude of a more frequent flood of longer duration is expressed in terms of the catchment's slope.

6.2 The stability of the river

6.2.1 Classification of the type of river

In this section, guidelines are given for classifying the type of river in terms of its stability. Most rivers can be placed in one of three categories: stable, dynamically-stable and unstable.

Stable channels have inert beds and banks with no significant scour or erosion. Their plan form and cross sectional geometry changes very slowly, if at all, with time, and even interference with the flow in the channel causes only local changes in channel geometry.

Dynamically-stable channels continually scour and deposit bed and bank material during times of moderate or high flows. Their cross sectional shape does not change progressively, but their plan form does change as the channel migrates. Interference to the flow in the river causes changes in channel geometry for some distance upstream and downstream. A meandering river is usually dynamically stable.

Unstable channels are less common in Britain than the other types. They are characterised by very high rates of erosion and bed material transport during floods, and the main channel can shift to follow a different course during a flood. Rivers which are braided, that is, consisting of more than one channel separated by bars or islands which are mobile during floods, are usually unstable.

The table below lists some types of channels, together with an indication of their expected stability. With the help of this table, categorize the type of river, and obtain an appropriate score.

Additional information which may be used is the history of the river and its tendency to change with time. If no change in course occurs, the classification is probably 'stable'. If changes occur gradually, the river is probably dynamically stable. If changes are rapid and frequent, the river is probably unstable.

Type of watercourse	Stream slope	Plan form (for most cases)	Bed material (for most cases)	Score	Remarks
Canal	mild slope	straight or gently meandering	silt or sand	1	Stable
Channel in rock or entrenched in valley	any slope	-	bed rock	1	Stable
Controlled river	mild/ moderate		silts/ sands gravels	2	Stable
River	flat	straight/ meandered	silts/ sands	3	Dynamically Stable
River	hilly (moderate slopes)	straight/ meandered	sands/ gravels	5	Dynamically stable
River	steep	straight/ meandered	sand/ gravel/ cobbles	6	Dynamically Stable
River	steep	straight/ braided	sands/ gravels/ cobbles	7	
Tidal	-	any plan form	silts/ muds	7	Unstable

6.2.2 Bank stability

The condition of the river banks both upstream and downstream of the bridge can give important clues to the stability of the river. Banks which are rapidly eroding indicate that the river is active and its course is changing.

Banks should be examined upstream and downstream of the bridge. If artificial protection such as sheet pile walls is provided, and the protection is in good condition with no signs of deterioration, then the banks should be classified as 'stable' and a score of 0 is obtained. Where natural banks exist, note any of the following features which are visible signs of instability. Pay particular attention to outsides of bends which are often sites of active erosion.

Visible signs of bank instability:

- Loose, cohesionless bank material exposed with no vegetation cover;
- Banks showing signs of recent degredation, such as slumping or undermining;
- Tree roots exposed by erosion of soil;
- Trees, fences etc now within main river channel due to erosion of banks;
- Towpaths lost or cut off due to erosion

Note the presence of any of these features. Obtain a score by adding the number of factors present.

For example, if all of the features are present, obtain a score of 5, indicating a high degree of instability.

Enter score for bank stability on data sheet:
(From 0 to 5)

6.3 Severity of extreme events

Most bridge failures due to hydraulic causes occur during rare, high flow events. This section assesses the likely severity of (a) 6.3.1 the flashiness of the catchment on river bridges or (b) 6.3.2 tidal conditions in estuaries.

6.3.1 Flashiness of river catchment

The flashiness of a catchment expresses the relative magnitudes of an instantaneous flood and a flood of longer duration but with the same return period. Flashiness can be represented by the channel slope.

From suitable contour maps of the catchments, for example OS maps, calculate the slope of the channel in the catchment upstream of the bridge. The slope is defined as the average slope between points 10% and 85% of the length of the main river measured upstream from the bridge. The slope is thus the difference in height between these two points divided by the distance between them measured along the river. Obtain a score for catchment flashiness from the table below:

Slope m/km	Score
≤0.1	1
0.1-1.7	2
1.7-3.3	3
3.3-6.7	4
6.7-14	5
14 -30	6
≥30	7

Enter score on data sheet for either 6.3.1 or 6.3.2, whichever is applicable

6.3.2 Tidal conditions

If no measurement or records of tidal velocity are available then the velocity can be estimated by

$$v = \frac{\pi V}{T A}$$

where V is the volume of water upstream of the bridge location between low and high water levels at Spring tide (m^3)

A is the cross-sectional area of the waterway opening below mean sea level (m^2)

T is the tidal period, that is, the time interval between successive low or successive high tides (s)

Tidal velocity (m/s)	Score
≤ 0.5	1
0.5 - 0.8	2
0.8 - 1.1	3
1.1 - 1.5	4
1.5 - 2.0	5
2.0 - 2.5	6
≥ 2.5	7

Enter score on data sheet for either 6.3.1 or 6.3.2 whichever is applicable

6.4 Overall assessment of river and catchment characteristics

Rivers are complex systems which do not lend themselves to neat classification, and runoff depends on many factors, some of which are probabilistic. The results from this section must therefore be treated with caution.

The scores from Sections 6.2 and 6.3 should be combined as described below.

The scores for Sections 6.2.1, 6.2.2 and (6.3.1 or 6.3.2) should be added together. The result should be divided by 17 and then 1.12 should be subtracted.

$$\frac{1}{17}\ \text{(Sum of scores from sections 6.2.1, 6.2.2 and 6.3.1 or 6.3.2)} - 1.12$$

The result, which is a measure of the type of river should lie in the range -1 to 0. This number, denoted by TR, will be used in Section 7.6.

7 THE RISK OF SCOUR : Category 1 elements

7.1 Introduction

The table in Section 1.1 shows the different types of bridge elements and the categories into which they fall. This table should be checked before proceeding with Chapter 7. If the bridge element falls into Category 2 proceed to Chapter 8.

Elements in Category 1 are bridge piers or abutments which lie within or project into the main river channel. They are assessed by combining the effects of features of the bridge and river which could be significant in determining the risk of failure of the bridge due to scour.

Each feature is given a score, and the scores are combined to give a 'risk number' which reflects the potential risk to the bridge. The theory behind this procedure is described in Appendices A and B.

In certain circumstances, eg if the bridge is founded on bedrock, it may not be necessary to carry out the full assessment described in this section. Refer to Sections 7.7.2, 7.7.3 and 7.7.4 for examples where a full assessment is unnecessary.

This assessment is designed to provide a method for surveying the hydraulics of bridges. It has been impossible to include all aspects of the hydraulics of bridge structures. For example, if a bridge is immediately downstream of a bend then the geometry of the river may lead to the formation of large eddies in the neighbourhood of the bridge. This can have a dramatic effect on both the magnitude and direction of the velocities of flow. If it is suspected that any bridge is peculiar in nature because of the presence or absence of any feature then this should be noted and further advice sought.

The history of scour at a bridge may give further indication of the susceptibility to future scour problems.

There may be significant differences between the various elements of the bridge. Thus if a bridge has a number of piers then the size and shape of the piers or the depth of foundations may differ significantly. Thus a number of markings may be obtained for one structure. The appropriate action to be taken should then be based on the worst score obtained.

A new bridge would normally be designed to withstand a flood of specified magnitude. The magnitude is normally expressed in terms of return period. If a given discharge is exceeded, on average, once every T years then that discharge is said to have a T year return period. Calculation of design discharge in rivers is a specialist topic which is outside the scope of this report. If the design discharge is known, then methods are available for calculating water levels and flow velocities. These are also outside the scope of this report.

In order to compare risk at a number of bridges, it would, strictly, be necessary to calculate flow conditions at all of the bridges, for the same return period flows. This would be a major task. By making some simplifying assumptions, the procedure in this report avoids the need to calculate flow conditions for particular return periods.

Where the procedure refers to 'flood conditions' this should be taken to mean conditions during a historically high flood. This could, for example, be a flood with a selected high return period (eg 50 or 100 years), or alternatively this could be the highest recorded flood.

7.2 Measurement of main dimensions

7.2.1 Channel width W_u and depth Y_u (eg Figs 11-14)

W_u is the bank to bank channel width, measured upstream of the bridge. Y_u is the mean channel depth upstream of the bridge. On smaller rivers, the typical bank to bank channel width upstream of the bridge can be measured directly. Where this is not practicable, estimate the width as accurately as possible. Large scale maps may also be used in some cases. If the width varies significantly then take the average width in the reach up to a distance of 10 channel widths upstream of the bridge.

The mean depth of the channel from the bed to the bank tops, Y_u, should also be determined. Y_u is defined more precisely as the cross sectional area of flow in the main channel divided by the channel width W_u. In most cases it will not be possible to measure this depth directly without taking soundings from a boat, though in some cases information may be available from previous survey work. Assuming direct soundings cannot be carried out, it is recommended that, if the water is shallow and the bed can be seen, the bank full depth is estimated directly by estimating the sum of the mean water depth and the height from the water surface to the bank tops.

The mean depth of channel from the bed of the river to the bank tops is relatively easy to determine. It would be better to use the mean depth of flow under flood conditions though this is more difficult to determine unless an approximate estimate of water levels under flood conditions is available. If, however, information on flood levels is available the mean depth of flow should be substituted for the mean depth of the channel.

If no visual estimate can be made of water depth, which will often be the case for larger rivers, then the following formula may be used:

$$Y_u = 0.185\ W_u^{0.7}$$

This formula may give an indication of the approximate bank full depth, but applies only to alluvial rivers whose dimensions are not controlled by features such as rock, bank protection or highly cohesive banks or beds. Other factors such as bank vegetation may also affect the width/depth relationship. The above formula should be used only when no other method for estimating channel depth can be used.

7.2.2 Channel width W_B and depth Y_B at the bridge

W_B is the width of the main channel under the bridge, defined as the distance from bank to bank, minus the width of bridge piers.

Y_B is the mean channel depth at the bridge. This is defined as the cross sectional area of flow in the main channel divided by the channel width W_B.

Note that the same reference level (i.e either bank top level or, if known, flood water level) should be used for assessing both Y_u and Y_B.

7.2.3 Flood plain width W_o and flood plain flow depth Y_o (eg Fig 13)

The amount of flow which approaches the bridge on the flood plain will influence scour conditions at the bridge. The most accurate estimate will be obtained if the width of flow on the flood plain, and the average depth of flow on the flood plain, can be estimated.

Y_o is the average depth of flow over the flood plain, at a typical cross section approximately 10 river widths upstream of the bridge. This is equivalent to the cross sectional area of flood plain flow divided by the total water surface width of the flood plain W_o. Guidelines for estimating Y_o and W_o are given below.

In order to estimate the flood plain flow depth Y_o, the following methods maybe used.

i) Hydraulic analysis of the river under design flood conditions enables Y_o to be calculated. Detailed description of the method is beyond the scope of this report. This method should give a reasonably accurate estimate of the water level, and hence average flow depth over the flood plain.

ii) Water levels observed during high flood events may be estimated to obtain mean flood plain flow depth. It is useful to sketch the cross section upstream of the bridge, including flood plain ground levels, in order to estimate average flow depth.

iii) The extent of flooding, together with informationon ground levels, may be used to estimate flood plain flow depths. The extent of flooding from high floods may have been recorded or observed.

iv) Anecdotal information or flood records, such as 'flood levels reach underside of bridge' or 'flood levels reaching track level or approach embankment' should be used, if available, to estimate flood water levels.

Note that high values of Y_o will tend to result in higher estimates of scour.

If no estimate of Y_o can be made, then it is recommended that the ratio Y_o/Y_u is set to 0.3. If it is known that flooding does not occur, then Y_o/Y_u should be set to 0 (Section 7.3.1).

The flood plain width W_o is the combined width of the right and left flood plains, measured perpendicular to the main flow direction.

In order to estimate W_o the following methods should be used. It should be noted that W_o is the water surface width of the flooded cross section, minus the channel width W_u, measured at a typical location within approximately 10 channel widths upstream of the bridge.

i) The geometry of the river valley may indicate the extent of the flood plains. For example, relatively level, flood prone areas may be bounded by steeper slopes or flood embankments, giving a clear indication of the extent of flood water.

ii) Hydraulic analysis of the river under design flood conditions enables W_o to be calculated, Detailed description is beyond the scope of this document, and signficantly more data may be required, but this more detailed analysis will lead to more accurate results.

If no estimate of W_o can be made, it is recommended that the ratio W_o/W_u is set to 5. If it is known that flooding does not occur, then W_o should be recorded as zero.

In view of the uncertainties in establishing flood plain flow depth and width, sensitivity tests can be carried out to assess the affect on the final 'priority rating' of a range of flood plain depths and widths.

7.2.4 Pier width W_p and length L_p

The effective width of each pier should be measured and estimated. Use the following notes for guidance:

- For the simplest case of a single, uniform pier extending to below the general scoured bed level, the pier width W_p is defined as the width of the pier, measured perpendicular to the long axis of the pier if the pier is elongated.

- If the pier has an enlarged footing or base, part of which lie above the general scoured bed level, then the effective pier width W_p is taken to be the width of the enlarged footing or base.

- If an abutment projects into the main river channel by a width W_a, then its effective width is W_p. W_p is calculated from the width of projection of the abutment W_a:

  $$W_p = 2W_a$$

  W_a is the width of projection of the abutment into the main river channel. If the abutment and river bank are both vertical, then W_a is simply the distance from the line of the river bank to the face of the abutment. If the face of the abutment or river bank are not vertical, then W_a is the average projection of the abutment from the river bank.

- If the abutment has an enlarged footing or base, part of which lies above the general scoured bed level, then the abutment width W_a should be assumed to be equal to the projection of the footing from the river bank, W_f. If the river bank or face of the footing are not vertical, then W_f is the average projection of the footing from the river bank.

- If the pier consists of a group of two or more circular columns, with centre-centre spacing of less than 5 W_p, then measure or estimate the separation of the columns. If the columns are aligned approximately with the flow direction, then measure or estimate the centre-centre separation C_1. If the columns are aligned approximately perpendicular to the flow direction, then measure or estimate the centre-centre separation C_2. The pier width W_p is the width of an individual column within the group (Fig 20).

- If a group of columns is founded on a single base or footing which is partly above the general scoured bed level, then the effective pier width W_p is equal to the width of the base or footing.

The length of the pier, L_p, is measured along the long axis of the pier. For a circular pier, L_p = W_p. For the case of two adjacent elongated piers, with one positioned downstream of the other, the measurement L_p depends on the gap between the piers. If the gap is greater than 3 W_p, then L_p is the length of an individual pier. If the gap is less than 3 W_p, then L_p is the sum of the length of the individual piers.

7.3 Assessment of features significant in scour

7.3.1 Constriction of channel and flood plain

A constriction in the width of a channel, for example by bridge abutments or piers, tends to result in a decrease in bed level within the constriction. This reduction in bed level is known as general scour due to channel constriction, and depends on the ratio of the channel width at the constriction, W_B, to the channel width upstream W_U. These dimensions are estimated in Sections 7.2.1 and 7.2.2.

Approach embankments which cross a flood plain will force flood water through the bridge opening, resulting in higher flows in the main channel under the bridge and a general lowering of the river bed level at the bridge site. This is known as general scour due to flood plain constriction, and depends on the extent to which embankments obstruct or block the flood plain flow (Figs 11-13).

General scour due to flood plain constriction depends on the depth of flow over the flood plain Y_o, the width of flow over the flood plain W_o, and the depth and width of the main river channel upstream of the bridge, Y_u and W_u (Fig 14). These dimensions were estimated in Sections 7.2.1 and 7.2.3.

Calculate the ratios $\frac{W_U}{W_B}$, $\frac{Y_o}{Y_u}$ and $\frac{W_o}{W_u}$. Enter values on calculations sheet.

Based on the values of these ratios, use Figures 15 to 18 to obtain a value of d_{g1}/Y_u. Interpolate between lines if necessary, and interpolate between figures if necessary. Alternatively, the following equation may be used:

$$\frac{d_{g1}}{Y_u} = [1 + 0.7 \left(\frac{W_o}{W_u}\right) \left(\frac{Y_o}{Y_u}\right)^{5/3}]^{6/7} \left(\frac{W_U}{W_B}\right)^{0.64} -1$$

Enter the value of $\frac{d_{g1}}{Y_u}$ in the space provided on the calculation sheet.

7.3.2 Additional scour due to river bends

In this section, the risk that a pier or abutment is exposed to deeper than average depth of scour due to a bend in the river is assessed. The assessment should be based upon whether there are any significant bends and their severity. The relevant reach of the river includes the bridge site and extends approximately 5 channel widths upstream of the bridge. If this stretch of river is straight it should be marked accordingly. If this section of river contains a bend then its severity should be assessed and marked.

If the channel is straight within this reach the location of the deepest scour may shift across the width of the channel unpredictably. A curved channel will tend to adopt a triangular cross sectional shape, with the deepest point towards the outside of the bend (Fig 19).

For each abutment which lies in the river channel, obtain a score from the following table:

	Location of abutment	
Bend sharpness	Inside of bend	Outside of bend
Straight	4	4
slight	3	5
moderate	2	6
severe	1	7

For each pier which is in the river channel, obtain a score from the following table:

	Location of pier within channel		
Sharpness of bend	Inner 1/3 of bend	Central 1/3	Outer 1/3 of bend
Straight	4	4	4
slight	3	4	5
moderate	2	5	6
severe	1	6	7

Enter the highest of the scores for the pier/abutment on data sheet:

7.3.3 Relative flow depth

Local scour at a pier is reduced if the flow depth is shallow compared with the pier width. This is most likely for wide piers or where flows will normally be relatively shallow.

The maximum flow depth at the pier should be calculated. If the pier or abutment is in the river channel, the maximum depth is the general scoured depth, which is calculated below Table 1 in Section 7.5.1. As the assessment of relative flow depth requires information derived in Section 7.5.1 its assessment is delayed until then.

7.3.4 Angle of attack and pier thinness

A pier which is not well aligned with the oncoming flow can result in greatly increased scour depths. For a given angle of attack, a pier which is slender will be more severely affected than one which is square or circular in plan.

Estimate the angle of attack, which is the angle between the long axis of the pier and the approach current, using the following information:

- Observe the direction of current at the surface, from floating debris etc, just before it reaches the pier. Estimate the maximum angle between this approach current and the pier.

- Estimate the angle between the main channel direction immediately upstream of the bridge, and the bridge pier.

- The angle of attack at high flows may be different to that at low flows. If the river floods, the flood plain flow may be deflected by the railway approach embankments, increasing the angle of attack. Take account also of any abutments or works upstream of the bridge which may deflect the current at high flows to increase the angle of attack.

Estimate the thinness of the pier, defined as

$$\text{thinness} = \frac{\text{pier length}}{\text{pier width}} = \frac{L_p}{W_p}$$

L_p and W_p were estimated in Section 7.2.4

Find a score for angle of attack and pier thinness from the following table.

Interpolate if necessary:

	Thinness							
		1	2	4	6	8	12	16
Angle of Attack (degrees)	0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	5	1.0	1.1	1.2	1.3	1.4	1.6	1.9
	10	1.0	1.2	1.4	1.6	1.7	2.0	2.5
	20	1.0	1.4	1.8	2.0	2.2	2.7	3.5
	30	1.0	1.5	2.0	2.3	2.7	3.4	4.2
	45	1.0	1.5	2.3	2.8	3.2	4.1	5.1
	60	1.0	1.6	2.5	3.1	3.7	4.8	5.8

Enter for angle of attack and pier thinness on data sheet:

7.3.5 Group of Columns

If a pier consists of a group of circular columns, with a centre-centre spacing of less than 5 W_p, then the effects of the columns may interact to increase the depth of scour.

If a pier does not consist of columns, then the following calculations should be omitted, and a score of '1' should be entered for 'group of columns' on the sheet.

Use the following measurements depending on the arrangement of the columns:

C_1: Centre-centre distance of columns which are arranged approximately parallel to the flow direction.

C_2: Centre-centre distance of columns which are arranged approximately perpendicular to the flow direction

W_p: width of a column within the group.

Note that if four or more columns are arranged in a rectangular or square layout, then values for C_1 and C_2 will be obtained.

(If column widths are not all equal, W_p should be the width of the widest column)

α: Angle of attack of flow

(See Fig 20 for definitions of C_1, C_2 and α)

Calculate the following as appropriate:

C_1/W_p and/or C_2/W_p

Use Fig 20 to obtain scores using the values of C_1/W_p and α, and/or C_2/W_p and $(90-\alpha)$ as appropriate. If more than one score is obtained, choose the maximum score.

Enter score for group of columns on the calculation sheet:

7.3.6 Pier nose shape

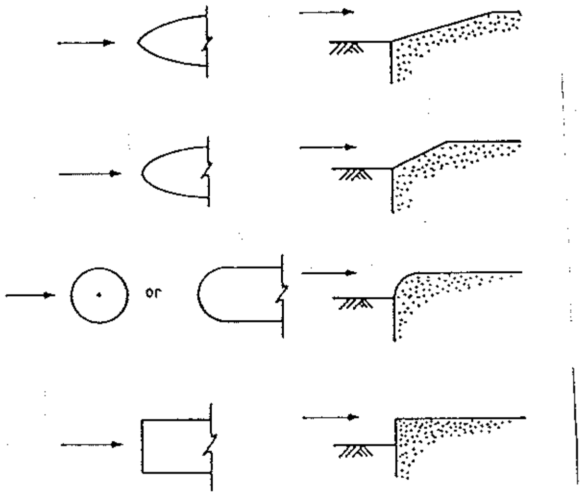
The plan shape of the upstream end of the pier has a small influence on scour. If the pier is not well aligned, however, the shape of the pier ceases to significantly affect the scour.

Match the upstream end of the pier or abutment, or both ends if tidal conditions prevail, to one of the following drawings, and obtain a score for pier nose or abutment shape.

Nose shape in plan Score

Pier Abutment

Angle of attack > 5° (see 7.3.5) 4



1

2

4

7

Enter the highest score of pier nose or abutment shape on data sheet :

7.3.7 Assessment of bed sediment size and grading

Probe the bed of the river, and, where possible, take samples of the bed material at several locations upstream and downstream of the bridge, and beneath the bridge. A layer of fine material (silt) may have been deposited on the bed if the flow velocity is low at the time of inspection. If gravel or sand is found beneath a layer of silt, ignore the silt and sample the underlying gravel or sand.

Examine the sampled bed material, and put ticks in the following table corresponding to material which is present in significant proportions.

Table for assessing bed sediment size and grading:

Description	clay	silt	sand	gravel	
				fine-medium	coarse
Particle size (mm)	<0.002	0.002-0.06	0.06-2	2-20	>20
Tick if present					

Assess the grading of the bed material using the following table, and obtain a score for bed material grading:

Number of ticks in above table	Bed material grading	Score
1	narrow	7
2		5
3		3
4		2
5	wide	1

Enter score for bed material grading on data sheet:

7.3.8 Blockage due to trapped debris

Scour may increase significantly if debris such as vegetation becomes trapped on a pier, blocking part of the waterway opening.

If the bridge has one or more piers in the river channel or has a single span of less than 10m, obtain a score for the effect of trapped debris from the following table:

Catchment vegetation					
		heavily forested	wooded	fertile, bank vegetation	few trees and bushes
catchment topography	steep	7	5	4	2
	hilly	6	4	3	2
	moderate	5	3	3	1
	flat	4	2	2	1

If debris is present which is causing a significant blockage to the flow through the bridge, then score 7. If the bridge has a history of debris blockage, then score 7.

Enter score for trapped debris on data sheet:

7.4 Foundations

7.4.1 Introduction

This section presents guidance for assessing the foundation depth. The depth of foundations is important as it partly determines the ability of the bridge to withstand scour.

Spread foundations are most susceptible to scour. Safety is increased if the foundation is on bearing piles or surrounded by a sheet pile curtain which extends below the base of the foundations.

Pile foundations are inherently safer than spread foundations, but excessive scouring can result in loss of skin friction or pile stability. Old piles may have lost strength due to deterioration.

The type of bed material on which the pier or abutment is founded is important in determining the integrity of the foundation if it is subjected to scouring forces.

The critical foundation level is the level to which the bed level can fall without endangering the bridge. If the bed level falls below the critical foundation level, then it is assumed that the foundation is in danger of failing. For the case of spread foundations, the critical level may be the level of the underside of the base. For abutments, the critical level may be higher than the underside of the base, if bed material acts to resist lateral forces on the abutment due to pressure from the embankment.

The critical level for pile foundations depends on the type of pile (skin friction, end bearing or both) and its stability. The critical level will often be higher than the base of the piles, but more detailed analysis would be required to determine this accurately.

In many cases, piers are founded on an enlarged base which is underpinned by columns. Here again, more detailed analysis would be needed to accurately determine the critical level.

The 'foundation depth' is measured from the river bed to the critical foundation level.

7.4.2 Measurement of foundation depth

The foundation depth is taken to be the vertical distance between the bed of the river and the critical foundation level. The measurement of the level of the bed of the river should be taken in the region surrounding the pier up to a distance of 2Wp away from the centre of the pier (Fig 21). The minimum bed level within this region should be taken.

Case (a) in Figure 21 shows a depression in the bed around a pier and d_f is measured at a point close to the pier.

Case (b) in Figure 21 shows that there has been significant scour away from the pier and in this case d_f is measured from the minimum bed level within an area of radius 2Wp from the centre of the pier. In this case (b) the measurement position is at a distance 2Wp from centre-line of the pier and the depth of foundation d_f is negative ie the bed level at measurement position is lower than the lowest part on the foundation.

Based on the estimates of critical foundation level and river bed level, obtain a best estimate for the foundation depth d_f.

Enter foundation depth d_f (m) on data sheet:

7.5 Calculation of scour depth d_t

7.5.1 Calculation of depth of general scour

In this section a value for general scour depth is calculated using the value of $\frac{d_{g1}}{Y_u}$ calculated in Section 7.3.1.

The following calculation determines $\frac{d_g}{Y_u}$ which is dependent upon $\frac{d_{g1}}{Y_u}$ and factors which relate scour due to bends and bed material grading. Enter the scores from appropriate sections into Table I:

Table I

Section	Description	Score S	Calculation	Result	Factor
7.3.2	Scour due to bends		0.25S+0.25		B
7.3.7	Bed material grading		0.05S+0.65		BMG

To determine $\frac{d_g}{Y_u}$, find $\frac{d_{g1}}{Y_u}$ from Section 7.3.1.

To $\dfrac{d_{g1}}{Y_u}$

1) Add 1
2) Multiply by B and BMG
3) Subtract BMG

the result gives a value for $\dfrac{d_g}{Y_u}$

The value of Y_u is known (Section 7.2.1)

Multiply d_g/Y_u by Y_u to obtain value for d_g

Enter d_g on data sheet:

7.5.2 Calculation of depth of local scour

Calculate the depth of flow at the bridge including the effect of general scour, Y_m:

$Y_m = Y_u + d_g$

Obtain a score for relative flow depth from the following table.

Y_m/W_p	Score
≤ 0.2	1
$> 0.2, \leq 0.5$	2
$> 0.5, \leq 0.8$	3
$> 0.8, \leq 1.2$	4
$> 1.2, \leq 1.6$	5
$> 1.6, \leq 2.3$	6
> 2.3	7

Enter score for relative flow depth on data sheet:

Enter scores from appropriate sections into Table II.

Table II

Section	Description	Score S	Calculation	Result
7.3.3	Relative flow depth		0.11xS+0.23 =	
7.3.4	Angle of attack and pier thinness		1.0xS =	
7.3.5	Group of columns		1.0xS =	
7.3.6	Pier nose shape		0.1xS + 0.6 =	
7.3.7	Bed material grading		0.05xS+0.65 =	
7.3.8	Trapped debris		0.08xS+0.92 =	
				Product FL=

Calculate local scour d_l = 1.5 x FL x Wp

7.5.3 Calculation of total depth of scour

Obtain an initial estimate of total scour d_t from

$d_t = d_l + d_g$

The following paragraphs describe a correction which may be applied to the calculation of scour d_t. The correction accounts for the fact that in some cases, scour which has occurred during a flood may not have completely 'filled in' during low-flow periods. The following correction accounts for this. Note that this is optional, but should be used if sufficient bed level data is available.

Figure 22 show the measurement of d_f being made from a point of minimum bed level within a radius of 2Wp from the centre of the pier. But the calculation of total scour d_t is, strictly, the difference between the bed level at the bridge during flood and the bed level in a typical channel section upstream of the bridge. Therefore in order to make an accurate comparison of scour depth and foundation depth, a correction may be applied to the calculated scour depth.

At some bridges, general and local scour may already exist at the time of inspection, as shown in Figure 22. During a flood the general and local scour will increase, lowering the bed level and then possibly fill in again during lower flow conditions.

The total calculated scour depth, d_t, is greater than in the actual case due to the existing scour of depth AF. Therefore d_t should be adjusted by subtracting the adjustment factor AF.

This will ensure that a valid comparison of d_t and depth of foundation d_f can now be made.

The value AF is the difference between the minimum bed level at a typical cross section upstream of the bridge, (preferably beyond any channel constriction associated with the bridge) and the bed level from which the foundation depth was measured. Note that this correction can only be applied if sufficient knowledge of bed levels is available, eg from divers' reports or echo sounding surveys. If insufficient information is available, then AF should be assumed to be zero.

It is possible that the bed level in the upstream channel will be lower than the bed level under the bridge if dredging etc has taken place, in which case AF should be assumed to be zero.

Enter adjustment factor AF(m) on data sheet:

Calculate revised scour depth

$d_t = d_t - AF$

7.5.4 Foundation depth

The foundation depth d_f (m) is calculated in Section 7.4.2.

7.6 Assessment of risk due to scour

The scour depth d_t (m) and foundation depth d_f (m) are now combined to give a preliminary priority rating for the bridge. The priority rating is then modified to account for other factors such as the river type, and load bearing material.

Use the graph on Figure 23 to obtain the preliminary priority rating, based on values of d_t and d_f obtained above. Interpolate between curves where necessary. Alternatively, the following formula may be used:

preliminary priority rating =

$$15 + \ln [(d_t - d_f)/d_f + 1].$$

Note that this is valid only when the foundation depth d_f is greater than 0.

7.7 Amendment of priority rating

A number of additional features may be present which influence the risk of failure. The preliminary priority rating should be ammended to account for these, as described in the following sections.

7.7.1 River type

The value TR was obtained in Section 6.4. TR can lie from -1.0 to 0.0. The priority rating is modified to account for river stability. Value TR is added to the preliminary priority rating:

priority rating = preliminary priority rating + TR

The priority rating may therefore be either reduced or remain the same as a result of the correction for river type.

7.7.2 Load bearing material

The type of bed material on which the pier or abutment is founded is important in determining the integrity of the foundation if it is subjected to scouring forces. The above assessment of scour assumes that the material on which the pier or abutment is founded (the load bearing material) is the same as the material on the surface of the river bed. If the load bearing material is more resistant to scour, then the risk from scour will be reduced.

In the extreme case, a pier may be founded on bedrock which is highly resistant to scour, while the bed material visible in the river is sand or gravel which may be eroded in flood.

As another example, a pier may be founded in cohesive clay with significant resistance to scour which could effectively limit the rate and degree of scouring.

The material between the river bed and the foundation level may consist of several strata of differing strengths, eg a sand and gravel layer overlying more stiff clay which has a higher resistance to scour. The effective resistance to scour is in this case very complex, depending on the strengths of the different strata, and their levels relative to scour and foundation depths.

The following guidelines should be used to account for the type of load bearing material.

* If the load bearing material is not known, then the priority rating from Section 7.7.1 is unchanged.

* If a pier or abutment is founded on rock which is highly resistant to erosion, and scouring of any erodible material down to the rock layer would not jeopardise the strength or stability of the foundation, then the bridge pier/abutment should be classified as 'low priority'

* If a pier or abutment is founded on clay classified as stiff or very stiff, then reduce the priority rating (obtained from Section 7.7.1) by 1.0.

7.7.3 <u>Invert on the river bed below the bridge</u>

This can be an effective measure against both general and local scour at a bridge site. The material of the invert should be sufficient to resist scour. Inverts are most commonly constructed from concrete, masonry or brick. The following points should be noted.

i) The invert should cover a sufficient extent of the bed around the pier to protect it from scour. For narrow rivers, an invert should extend across the width of the river. For wide rivers, separate inverts may be provided for each pier. Inverts should cover at least the extent of any constriction in the waterway upstream and downstream of the bridge. An invert which does not fulfil these requirements may be vulnerable to general scour.

ii) The upstream edge of the invert should be toed in to the bed to a sufficient depth, to prevent scour from undermining the invert.

iii) The invert should not project above the bed, for this would encourage local scour at the upstream edge of the invert. This is particularly important during floods, when the bed level may fall.

iv) No scouring should be visible at the upstream or downstream edges of the invert.

If a satisfactory invert exists, then elements of the bridge protected by the invert should be classified as 'low priority'.

7.7.4 Stone scour protection measures

Quantities of loose bed protection such as large stones or grout base may have been placed locally around piers or abutments, with the aim of increasing the resistance of the bed to scour. Unless the site was pre-excavated and the stone carefully placed in the excavation to lie below the bed level, the effect of this measure may be to increase scour depths, particularly if the available waterway area was reduced or the pier width increased. Material which has been dumped on the bed and banks, particularly at a constricted crossing, will reduce the flow area, and may increase both general and local scour depths.

If the scour protection is known to have been designed and constructed to an adequate design standard, then protected elements should be classified as 'low priority'.

8 ASSESSMENT OF 'CATEGORY 2' ELEMENTS

8.1 Introduction

This section applies to parts of a bridge for which no appropriate methods exist for calculating scour or erosion depths. In these cases therefore, the bridge elements are assessed by observing and recording features which are known to affect the susceptibility to scour. The terms labelled 'a)' indicate lowest risk, 'b)' a higher risk, etc.

8.2 Bridge pier or abutment founded on flood plain near to the main channel

This section applies to piers or abutments founded on the flood plain, near to the main channel. As a guideline, this applies to elements located within a distance equivalent to 10% to 20% of the channel width from the river bank (eg Figs 3 and 4), although the appropriate distance from the river bank depends on factors such as the rate of bank erosion, and details of structure.

The main risk in this case is undermining of the foundation or loss of support due to lateral shifting of the river channel. This can result from bank erosion during floods. The risk depends on many factors including the rate of bank erosion, the severity of the flood, the type of soil, and the degree of bank protection.

The pier or abutment may also be at risk from local scour.

The following are designed to characterise the nature of the river within approximately one to two kilometres upstream and downstream of the bridge.

Unstable rivers tend to be more prone to rapid lateral shift in river course. (For guidance on river classification, see Section 6.2):

River (1):
a) Stable
b) Dynamically stable
c) Unstable

The channel pattern gives an indication of the tendency of the river to change course:

River (2): a) Straight
b) Meandering
c) Braided

Steep rivers tend to be more prone to sudden changes in course. (For guidance, see Section 6.3.1 which includes measurement of the river slope upstream of the bridge):

River (3): a) Flat (eg less than 0.2m/km)
b) Moderate (eg between 0.2m/km and 3.0m/km)
c) Steep (eg greater than 3.0m/km)

Canals and controlled rivers tend to be more stable than natural waterways:

River (4): a) Canal
b) Controlled river (ie river where flows are significantly controlled by measures such as wiers)
c) Natural river

The risk is increased if the river has a history of erosion problems:

River (5): a) No known bank erosion or channel shifting
b) History of gradual erosion and slow channel shifting
c) History of rapid bank erosion and rapid channel shifting

The following apply to the river in the vicinity of the pier:

Protected river banks in the vicinity of the bridge reduce the risk of channel shifting:

Bridge site (1):	a)	River banks stabilised by natural vegetation or artificial measures eg sheet piling, riprap, etc.
	b)	River banks not protected from erosion.

Visible river bank erosion indicates that the river course may be shifting:

Bridge site (2):	a)	No signs of bank erosion visible
	b)	Localised bank erosion visible
	c)	Widespread active bank erosion visible

A channel will normally shift laterally towards the outside of a bend, so a pier here will be at higher risk:

Bridge site (3):	a)	Bridge pier on inside of bend
	b)	Bridge on straight reach of river
	c)	Bridge pier on outside of moderate bend
	d)	Bridge pier on outside of sharp bend

A pier very close to the main river channel will be more susceptible to a smaller shift in the river course:

Bridge site (4):	a)	Pier located close to river the bank ie between a distance of 10% and 20% of the river width from the river bank

b) Pier located very close to river bank ie within a distance equivalent to 10% of the channel width from the river channel

Shallow foundations will tend to be undermined or to loose support if the channel shifts towards the pier:

Bridge site (5):
a) Pier foundations deep relative to bed level in river near to pier location eg pile foundation
b) Pier foundations shallow relative to bed level in river near to pier location eg spread foundation

Drawings or maps may show that the alignment of the river relative to the bridge has changed with time, which may indicate a worsening in hydraulic conditions:

Bridge site (6):
a) No evidence that the alignment of the river has changed since construction of the bridge
b) Evidence that the alignment of the river has changed since construction of the bridge

Visible signs of erosion around the pier or abutment may indicate active scour during floods:

Bridge site (7):
a) No signs of erosion around pier or around base of abutment
b) Signs of erosion around pier or around base of abutment

8.3 Bridge pier or abutment founded on flood plain set well back from main river channel

This section applies to piers or abutments founded on the flood plain, set well back from the main channel. As a guideline, this applies to elements located further than a distance equivalent to 10% to 20% of the channel width from the river bank (eg Figs 5 and 6). The appropriate distance depends on factors such as the rate of bank erosion and details of the structure.

In this case, the pier or abutment is founded on the flood plain, and set back from the riverbank a sufficient distance so that the risk of undermining due to movement of the river channel is remote. The main risk is now local scour caused by flow over the flood plain. Flood plain flow is generally relatively shallow and has lower velocity than flow in the main channel, and the risk of scour tends to be lower. It is therefore unlikely that these elements will fall into the 'high priority' category.

High velocity flows over the flood plain due to steep valley gradient will tend to increase scour at obstructions such as a pier or abutment. (For guidance, see Section 6.3.1 which includes measurement of the river slope upstream of the bridge):

River (1):

a) Flat (eq less than 0.2m/km)

b) Moderate (eg between 0.2m/km and 3.0m/km)

c) Steep (eg greater than 3.0m/km)

A flood plain upstream of the bridge which offers little resistance to the flow will tend to increase flow velocities and hence the tendency to scour:

River (2):
- a) Flood offers high resistance to flow due to hedges, trees, dense vegetation etc
- b) Flood plain offers moderate resistance to flow with some obstruction due to hedges, trees, etc.
- c) Flood plain offers low resistance to flow, little or no obstruction from vegetation, fences etc.

A large depth of flow over the flood plain during floods will result in worse hydraulic conditions than a shallow depth:

River (3):
- a) Very shallow or shallow flow depths of flow over the flood plain at the location of the bridge element
- b) Medium flow depths over the flood plain at the location of the bridge element
- c) Deep flood plain flows over the flood plain at the location of the bridge element

If the element has been subjected to scour during a previous flood, there may be a visible scour hole or signs of erosion:

Bridge (1):
- a) No signs of scour or erosion visible at bridge element
- b) Signs of minor or localised scour

or erosion visible at bridge element

c) Widespread or severe scour or erosion visible at bridge element

The degree of natural or artificial scour protection around the bridge element should be assessed. A lack of scour protection indicates greater susceptibility to scour:

Bridge (2): a) Ground adjacent to bridge element well protected by plentiful permanent vegetation or artificial measures - no soil exposed

b) Ground adjacent to bridge element protected by some vegetation

c) Ground adjacent to bridge element unprotected - soil exposed and prone to scour

The soil type may influence the degree of scouring which takes place:

Bridge (3): a) Bridge element founded on rock, or material with high resistance to scour

b) Bridge element founded in cohesive soil with moderate resistance to scour

c) Bridge element founded in non-cohesive soil eg sand and gravel, which is readily scoured

Shallow foundations result in higher vulnerability to scour:

Bridge (4): a) Bridge element founded on deep foundations eg piled foundations

b) Bridge element founded on shallow foundations eg spread footings

8.4 Flood relief arch through approach embankment (eg Fig 7)

The main risk of scour at a flood relief arch is general scour caused by flood waters flowing through the constriction of the relief arch at high velocity. The risk will be increased if water levels reach to above the springing of the arch, or to above the soffit level. A further feature which can increase scour is partial blockage of the opening by debris.

River (1):
River (2): These are the same as in Section 8.3 above
River (3):

Debris which becomes trapped within the arch can increase scour at relief arches:

River (4):
a) Little chance of relief arch trapping debris which could increased scour (eg open arch, little catchment vegetation carried with floods)
b) Moderate chance of relief arch trapping debris which could increased scour
c) High chance of relief arch trapping debris which could increased scour (eg some existing blockage due to debris, fence, hedge etc, catchment vegetation such as trees and other debris carried down by flood)

A large constriction of main channel and flood plain flows will tend to increase flows through the relief arch, resulting in tendency for greater *scour: The degeree of constriction may be judged by calculating the ratio d_{gl}/Y_u, see Section 7.3.1:*

Bridge (1) a) Very little or little constriction of the channel and flood plain flows (d_{gl}/Y_u less than 0.3)

b) Moderate constriction of the channel and flood plain flows (d_{gl}/Y_u between 0.3 and 1.5)

c) Severe constriction of channel and flood plain flows (d_{gl}/Y_u greater than 1.5)

If the relief arch has been subjected to scour during a previous flood, there may be a visible scour hole or signs of erosion:

Bridge (2): a) No signs of scour or erosion visible at bridge element

b) Signs of minor or localised scour or erosion visible at bridge element

c) Widespread or severe scour or erosion visible at bridge element

The degree of natural or artificial scour protection within the relief arch should be assessed. A lack of scour protection indicates greater susceptibility to scour:

Bridge (3): a) Ground adjacent to relief arch well protected by plentiful permanent vegetation or artificial measures - no soil exposed

b) Ground adjacent to relief arch protected by some vegetation

c) Ground adjacent to relief arch unprotected - soil exposed and prone to scour

The soil type may influence the degree of scouring which takes place:

Bridge (4) a) Relief arch foundations founded on rock, or material with high resistance to scour

b) Relief arch foundations founded in cohesive soil with moderate resistance to scour

c) Relief arch foundations founded in non-cohesive soil eg sand and gravel, which is readily scoured

Shallow foundations result in higher vulnerability to scour:

Bridge (5) a) Relief arch founded on deep foundations eg piled foundations

b) Relief arch founded on shallow foundations eg spread footings

8.5 Earth embankment
eg approach embankment
(eg Fig 8)

An earth approach embankment which crosses a flood plain may be subject to erosive action during flood. Particular risks include erosion behind abutments, and erosion to the toe of the embankment. An embankment may be at particular risk if the line of the embankment is near to the main river channel: in this case, erosion of the river bank may lead to collapse or partial collapse of the embankment.

9 FURTHER ACTION

The procedures in the Sections 7.1 - 7.7 and Sections 8 enable the risk of failure of a bridge due to scour to be assessed. This section outlines the further action which should be taken. This depends on the priority category of each part of the bridge. It is recommended that, initially, the priority for action on all parts of the bridge should be based on the highest priority rating obtained for the individual elements. Three levels of investigation are identified and discussed. NOTE: The categorisation is preliminary at this stage, awaiting calibration of the method against a number of test cases. The divisions between the six categories are provisional. Note also that a bridge placed in the high priority category indicates that further study of the bridge is required to assess the hydraulics and risk of scour. In some cases it may be found that scour protection measures are not required.

9.1 High priority bridge

This section applies to bridges with a high priority rating. Bridges in this category are expected to be at greatest risk of failure from scour, and should be placed under special observation to ensure the safety of rail traffic.

The following action is recommended:

- Arrangements should be made to receive flood warnings and to act accordingly. Specialist advice should be sought where necessary to advise on the likely risk to the bridge from floods of different severities.

- Consideration should be given to monitoring of scour at the bridge. This can detect scour which is not visible during a flood, and can be used to assess whether scour is threatening the foundations. Scour monitoring also provides a direct measurement of scour, and can be used to improve estimates of scour depth.

- Specialists should be consulted to carry out more detailed and refined hydraulic studies of bridges in this category.

- Scour protection works may be appropriate, although implementation of scour protection works is not recommended on the basis of this procedure alone.

9.2 Medium priority bridge

This section applies to bridges with a medium priority rating. A bridge in this category is not in immediate risk, but should be monitored regularly to ensure that it remains safe. The following studies may be appropriate for bridges with marginal risk.

- Occasional measurement of bed level during or immediately following a large flood.

- Regular inspection using this procedure to monitor changes which may be taking place to the bridge or river.

9.3 Low priority bridge

This section applies to bridges with a low priority rating. A bridge in this category is at low risk, but the following studies are recommended.

- Infrequent inspection using this procedure to monitor changes which may be taking place to the bridge or river

- Infrequent measurement of bed levels, during or immediately following a large flood.

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

1. This report describes possible types of failure due to hydraulic causes, but deals mainly with the problems of scour. Features of the bridge, river or catchment which may affect the risk of hydraulic failure are discussed. Guidelines are included for assessing the risk of failure due to scour. Modifications to the bridge, river or catchment which can affect the safety of a bridge are discussed.

2. The guidelines are designed to enable a wide variety of bridges to be assessed rapidly and with minimal data requirements and without specialist equipment or expertise. There are limits to the accuracy and reliability of this type of assessment.

3. Many factors combine to make reliable prediction of hydraulic risk to a bridge very difficult. Some of these are listed below.

- There is a lack of basic knowledge about the scour phenomenon particularly in field conditions.

- Some features of the river or bridge cannot easily be quantified.

- Bridges and rivers may have complex geometries which are not covered by existing prediction techniques.

- Reliable estimates of peak flood flows and depths cannot be made without a long period of field monitoring.

- The underlying geology of the site may be important, but may not be known unless a detailed site investigation has been carried out.

- The depth and condition of the bridge's foundations may be important, but may not be accurately known.

10.2 Recommendations

1. A number of bridges should be assessed in a number of regions, in collaboration with HR, using the guidelines contained in this report. This will enable calibration of the method.

2. Once the guidelines are judged to be satisfactory, bridges should be examined with the aid of the guidelines to estimate degrees of risk and to assess levels and frequencies of future inspections.

3. A database should be set up containing all available information relevant to hydraulic conditions at each bridge site.

4. Details of any existing or planned modifications to the bridge, river or catchment which are relevant to the hydraulic safety of the bridge should be obtained. The effect of modifications on the safety of the bridge should be assessed. Specialist advice should be sought when necessary.

5. Further research is needed into scour at bridges over British rivers. A programme of research which includes field measurements of scour at a number of bridge sites during floods would enable improved methods of scour prediction to be developed.

LIST OF SYMBOLS

		Section
A	Cross sectional area of tidal waterway	6.3.2
AF	Adjustment factor to account for 'residual' scour	7.5.3
B	Factor to account for bends	7.5.1
BMG	Factor to account for bed material grading	7.5.1
d_f	Depth of foundations	7.4.2
d_g	Depth of general scour	7.5.1
d_{g1}	Intermediate value of depth of general scour	7.3.1
d_l	Depth of local scour	7.5.2
d_t	Depth of total scour	7.5.3
FL	Factor for local scour	7.5.2
L_p	Length of pier	7.2.4
T years	Return period of flood	7.1
T	Tidal period	6.3.2
TR	Type of river score	6.4
v	Flow velocity	6.3.2
V	Tidal volume	6.3.2
W_a	Width of abutment	7.2.4
W_B	Net width of main channel under bridge	7.2.2
W_o	Flood plain width	7.2.3
W_p	Pier width	7.2.4
W_u	Channel width upstream of the bridge	7.2.1
Y_B	Channel depth (to bank top level or flood level) under bridge	7.2.2
Y_o	Flood plain flow depth	7.2.3
Y_u	Channel depth (to bank top level or flood level) upstream of bridge	7.2.1
α	Angle of attack	7.3.5

Table

Table 1

Bridge element	Primary risks	Main worstening features	Secondary risks	Fig No
Bridge pier in main river channel	• Local scour • General scour	• Angle of attack on enlongated pier • Channel constriction • River bend at bridge or immediately upstream • Shallow foundations	• Channel stability • Dredging • Changes to river or catchment • Flood plain constriction	(1)
Abutment projecting into main river channel	• Local scour • General scour	• Angle of attack • Channel constriction • Flood plain constriction • Abutment on outside of bend • Shallow foundations	• Channel shifting • Dredging • Changes to river or catchment	(2)
Bridge pier on flood plain near to main river channel	• Channel shifting/ bank instability • Local scour	• River unstable • Banks unstable/ unprotected • Outside of bend • Shallow foundations	• General scour	(3)
Abutment on flood plain near to main river channel	• Channel shifting/ bank instability	• River unstable • Banks unstable/ unprotected • Shallow foundations • Outside of bend	• Local scour • Erosion behind abutment	(4)
Bridge pier on flood plain set well back from main river channel	-	-	• Local scour	(5)
Abutment on flood plain set well back from main river channel	-	-	• Local scour • Erosion behind abutment	(6)
Flood relief arch	• General scour and 'culvert' flow	• Large constriction of flood plain • Deep flood plain flows	-	(7)
Earth embankment eg approach embankment	• Erosion • Slope failure exacerbated by high pore-water pressure	• High velocity flood plain flows • Large constriction of flood plain. Wave attack • Erodible embankment soil	-	(8)

Figures

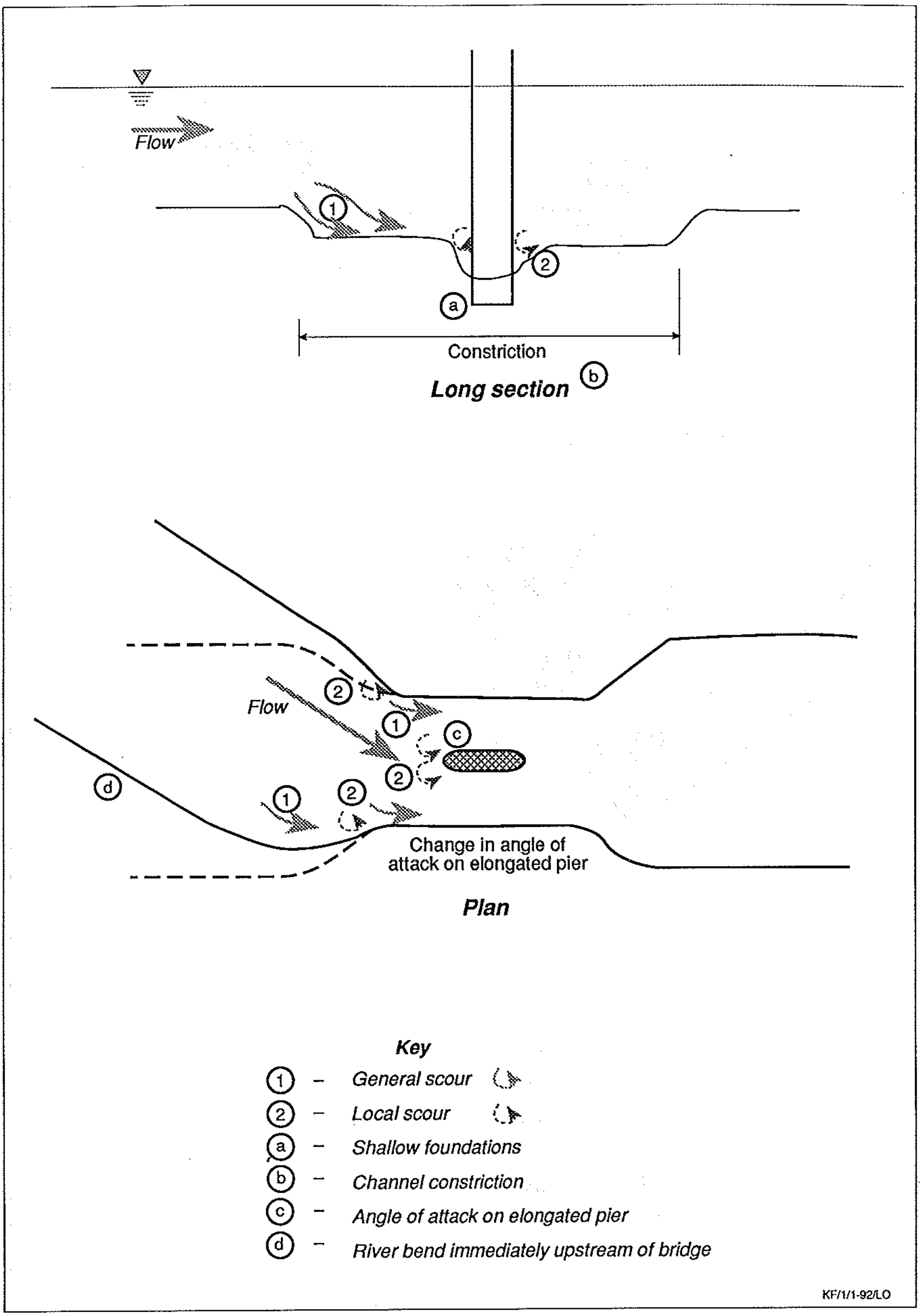


Figure 1 Illustration of scour at a pier in the main river channel

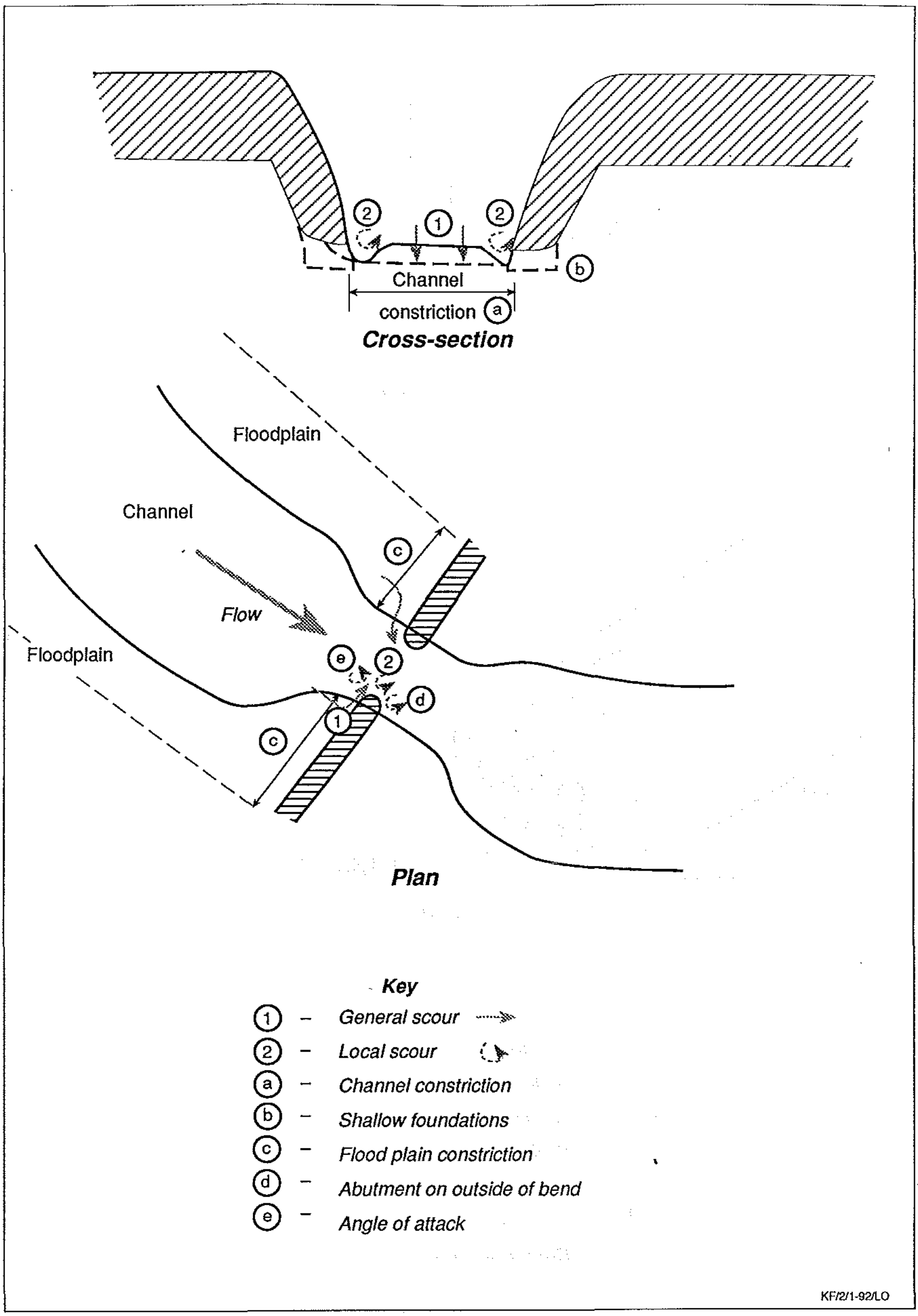


Figure 2 Illustration of scour at abutments in the main river channel

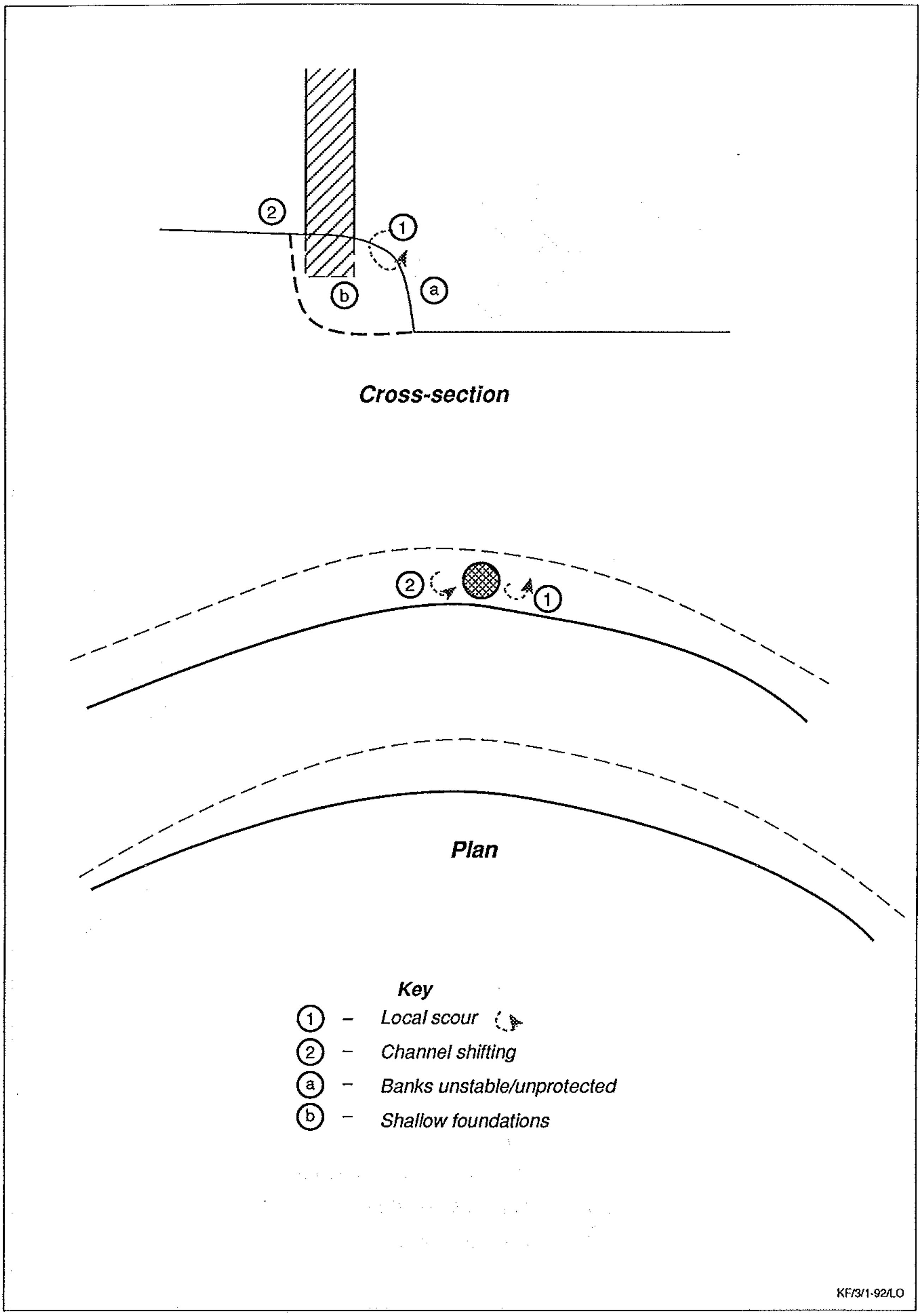


Figure 3 Illustration of main risks to pier on the flood plain near to the main channel

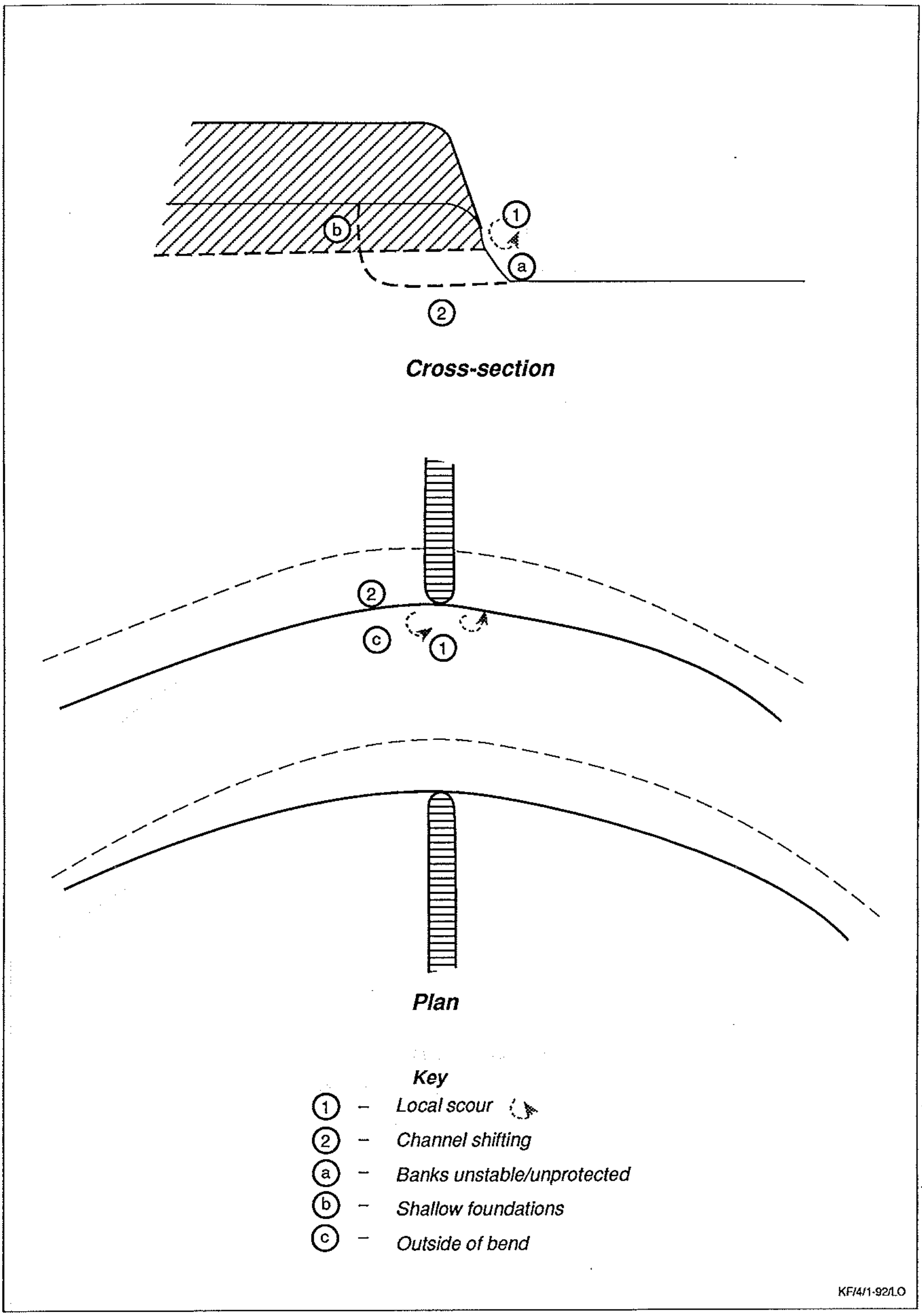


Figure 4 Illustration of main risks to abutments on flood plain near to main river channel

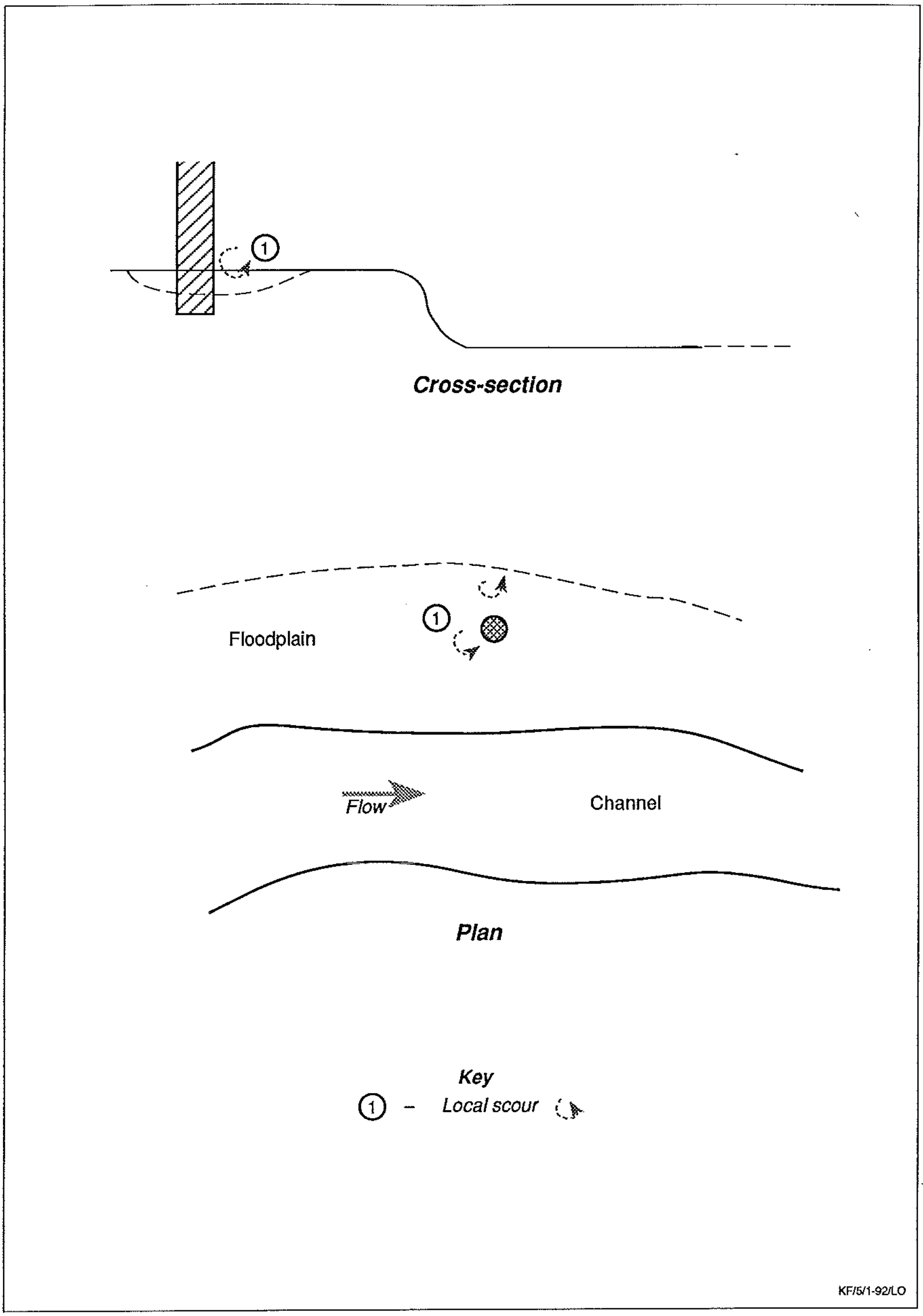


Figure 5 Illustration of risk to pier on the flood plain well away from the main river channel

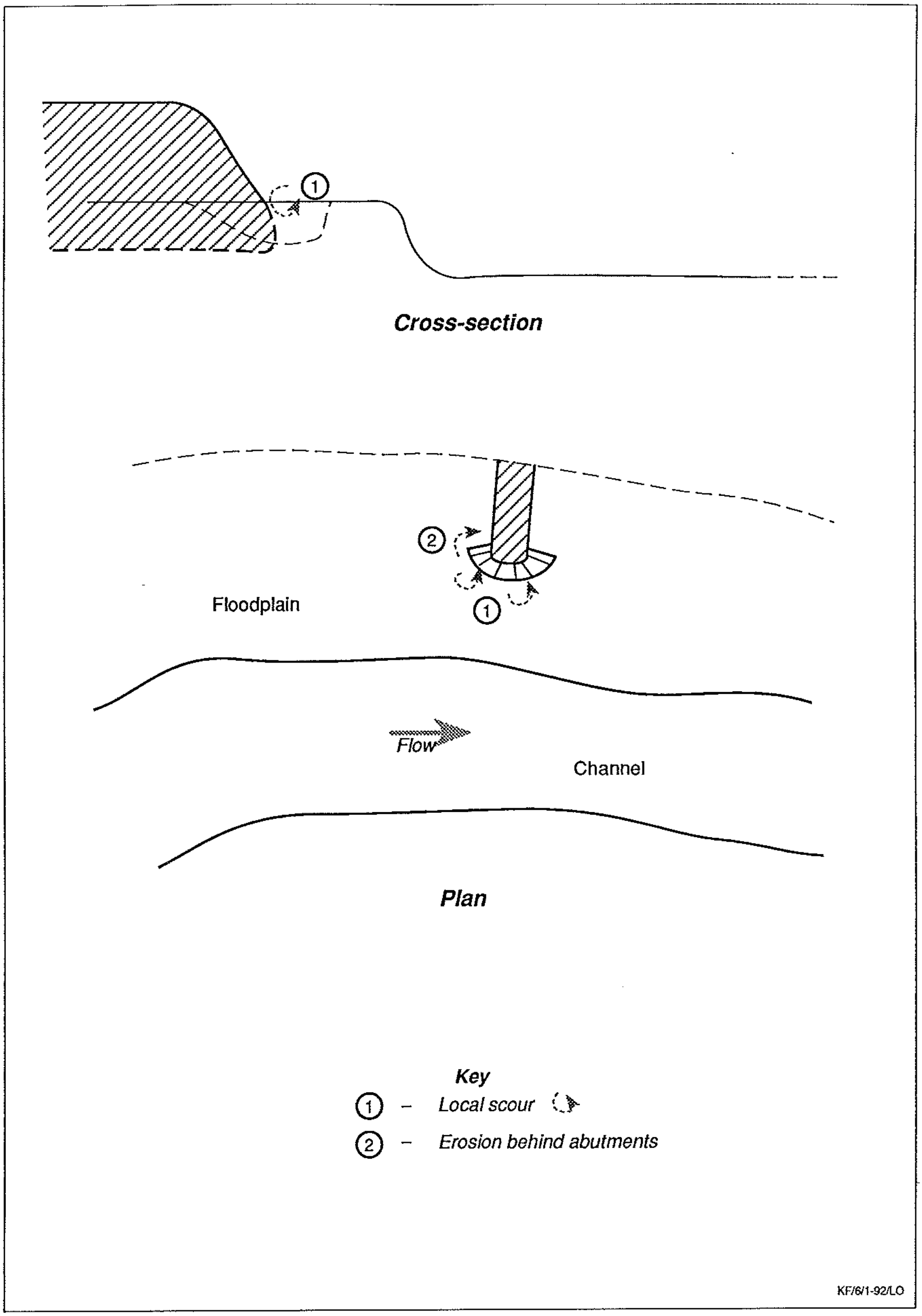


Figure 6 Illustration of risk to abutment on the flood plain well back from the main river channel

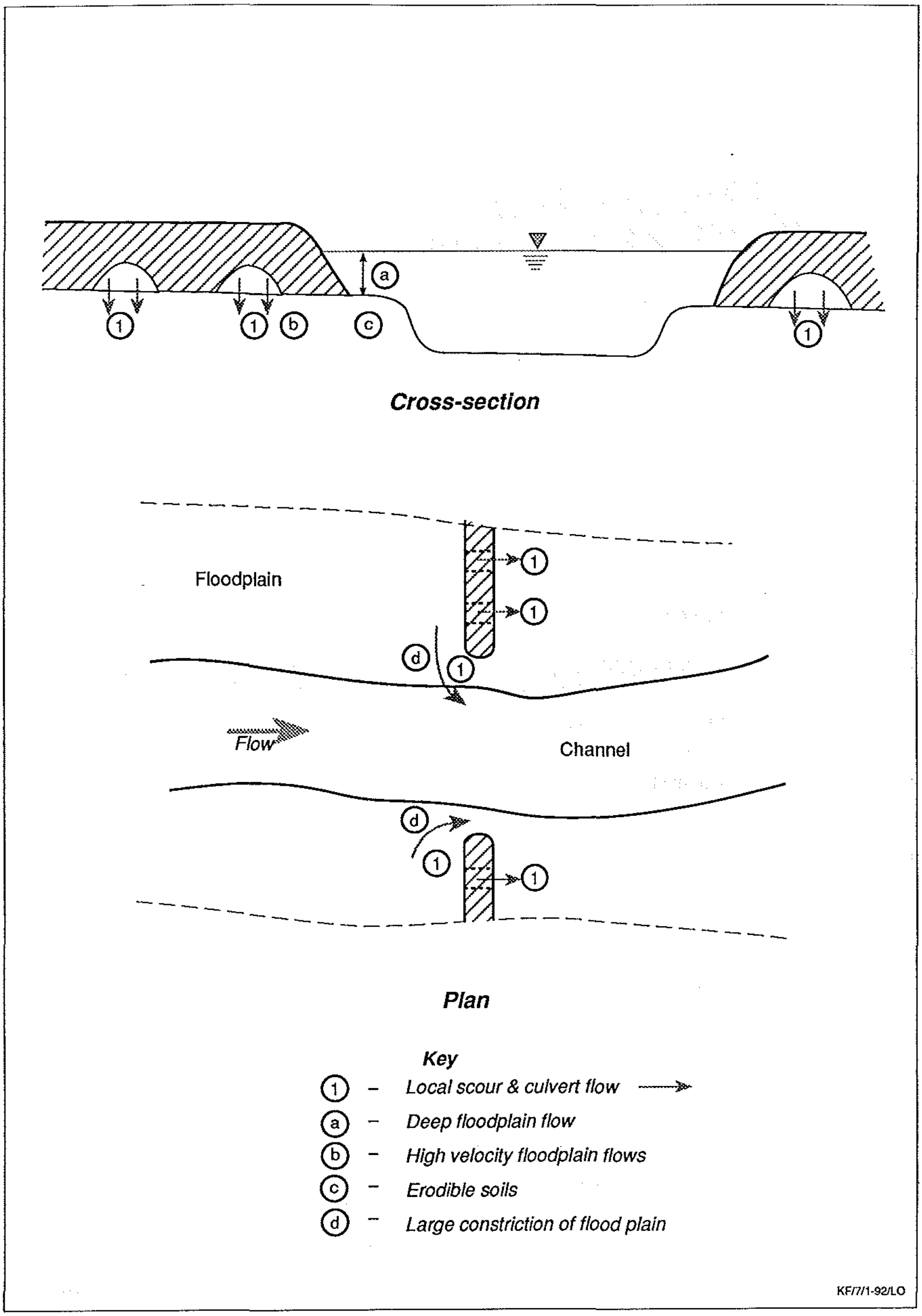


Figure 7 Illustration of risk to flood relief arches

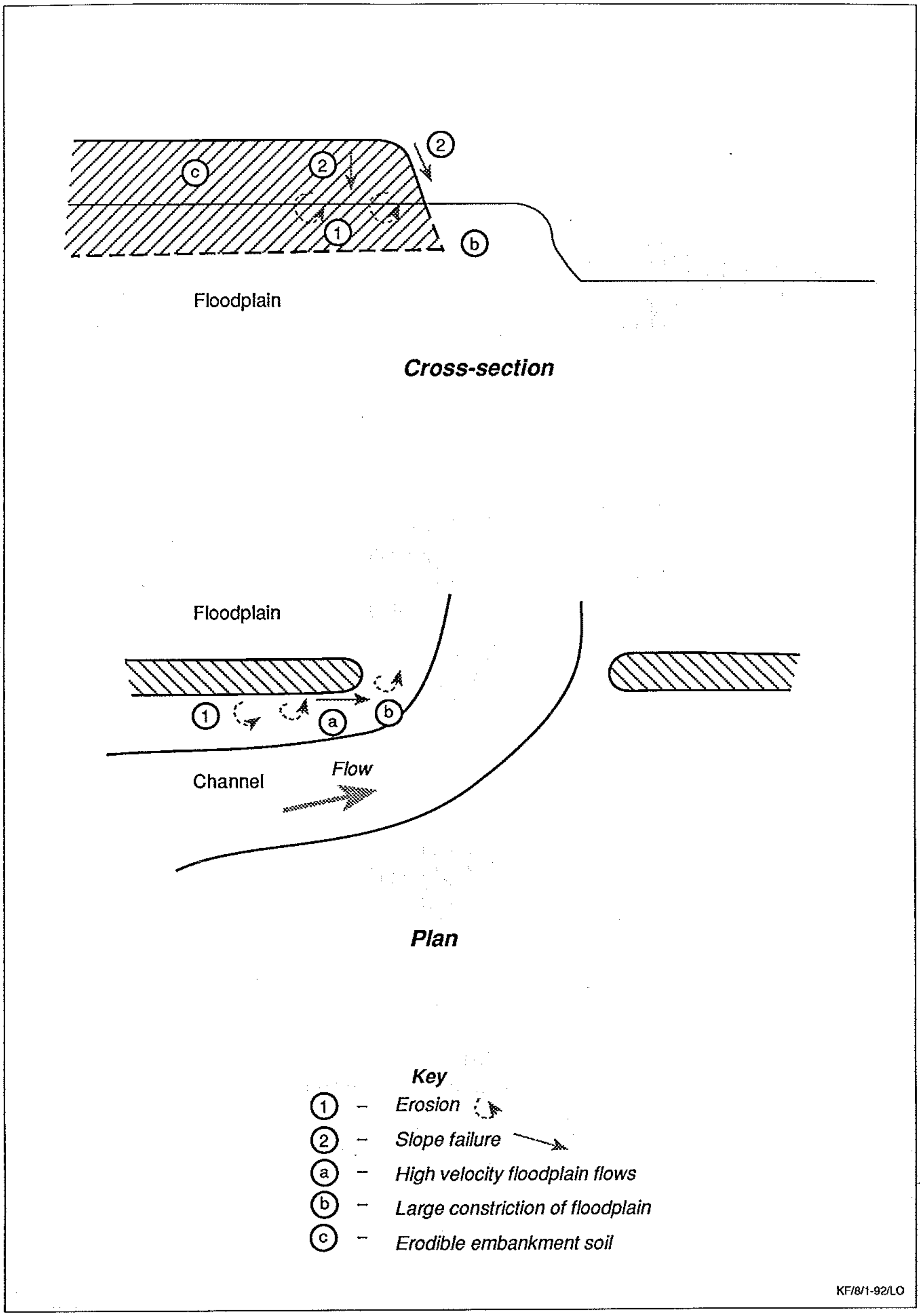


Figure 8 Illustration of risks to approach embankments

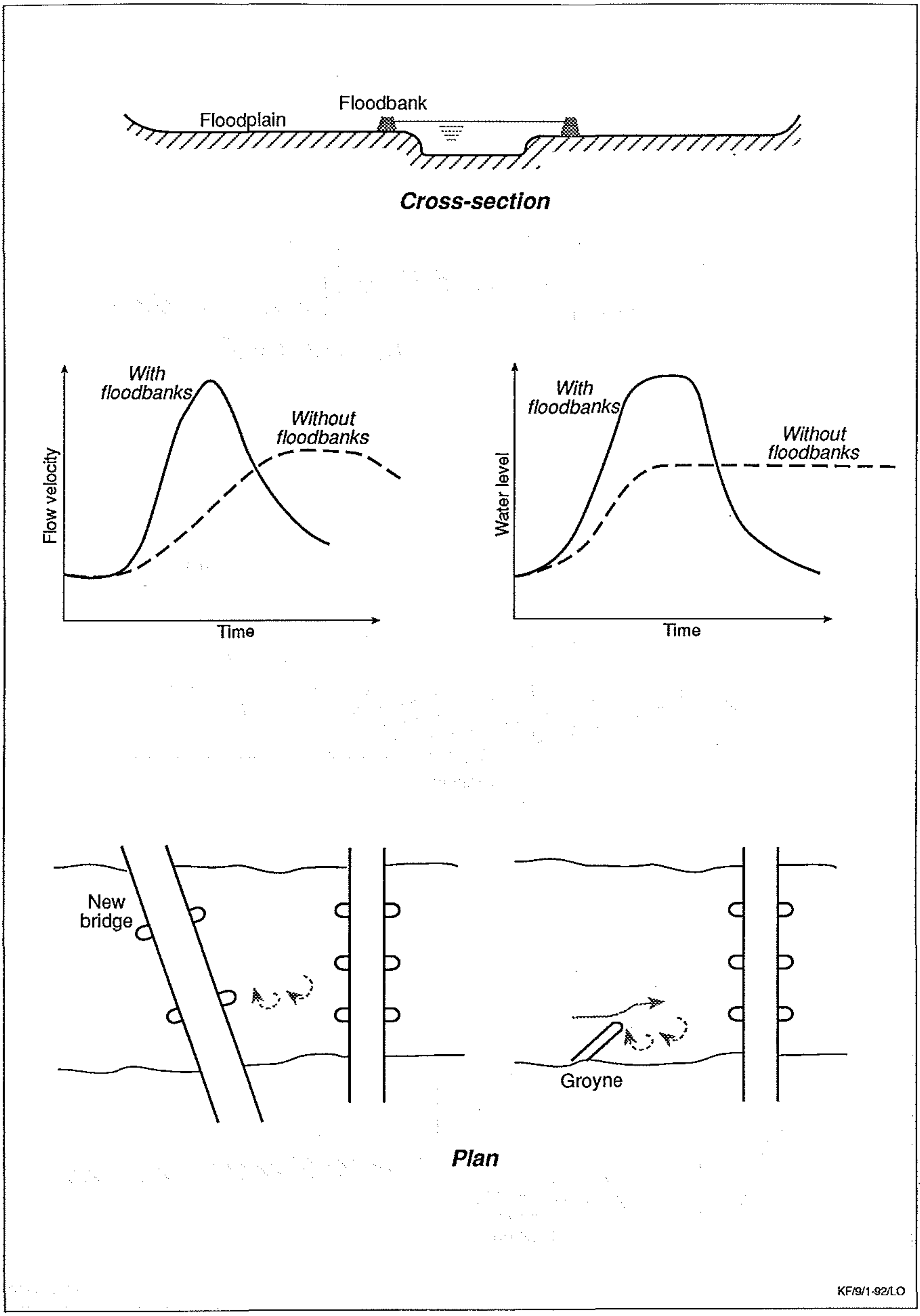


Figure 9 Examples of changes in flow conditions

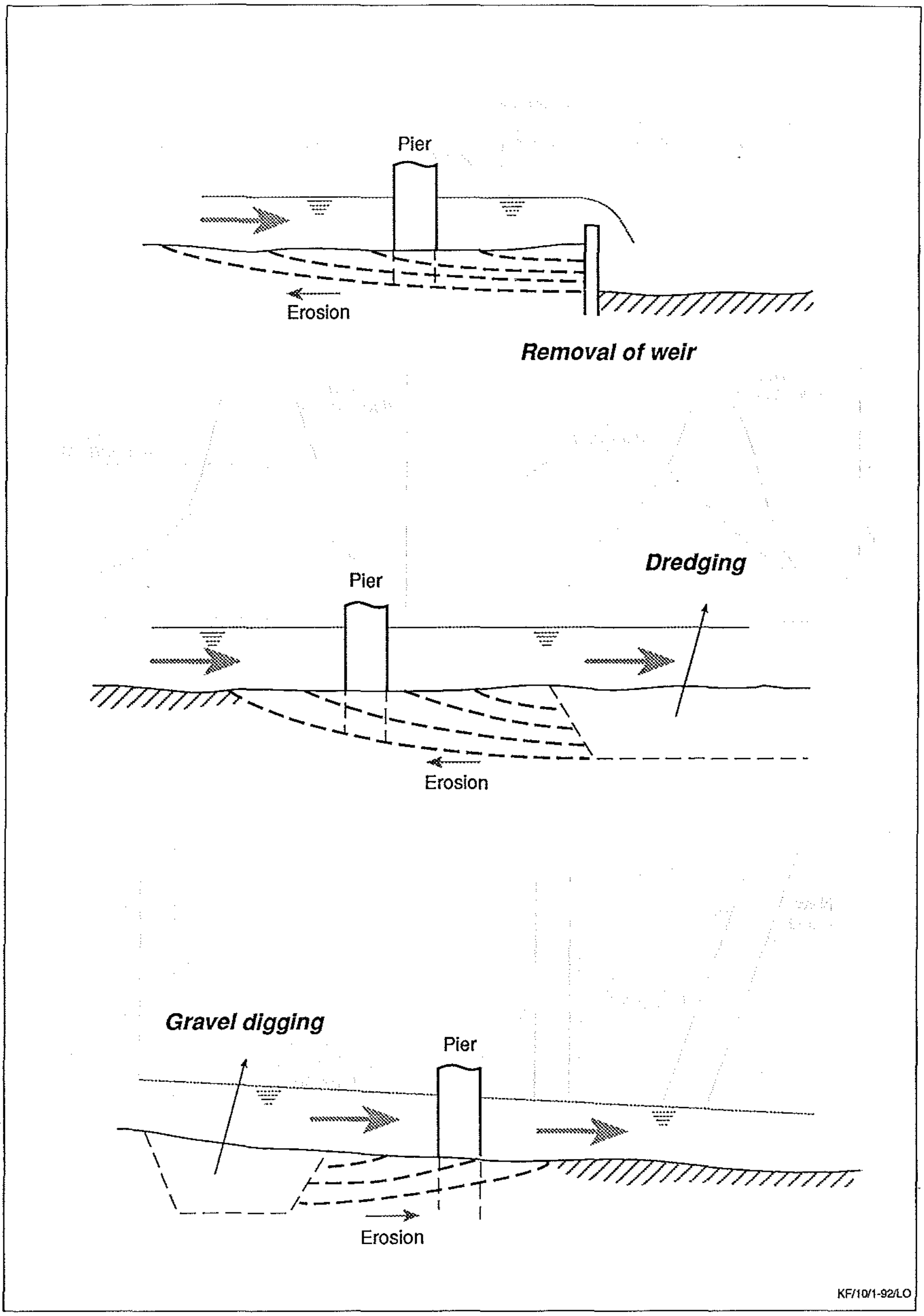
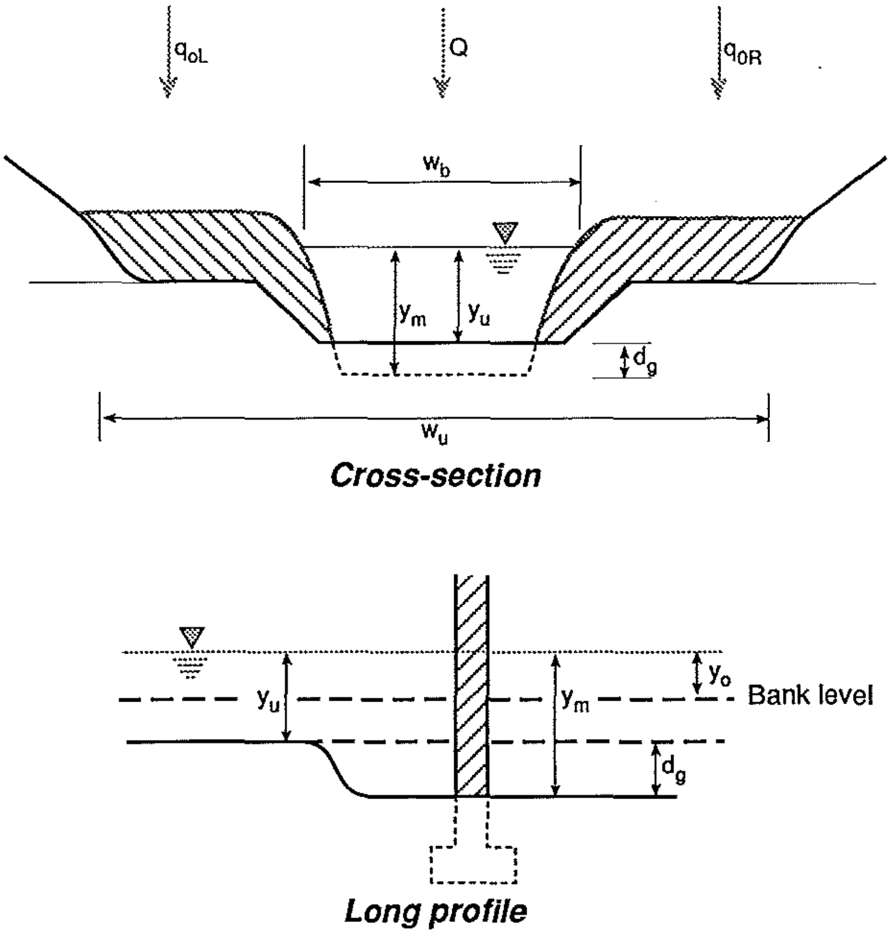


Figure 10 Examples of modifications which cause changes in bed level



d_g = *depth of general scour*

y_u = *depth of water in upstream channel*

y_m = *depth of water under bridge after general scour*

$q_o = q_{oR} + q_{oL}$ = *overbank flow*

Q = *flow in upstream channel*

w_u = *width of channel at expected high water level*

w_b = *width of bridge opening at expected high water level*

y_o = *depth of water on floodplain*

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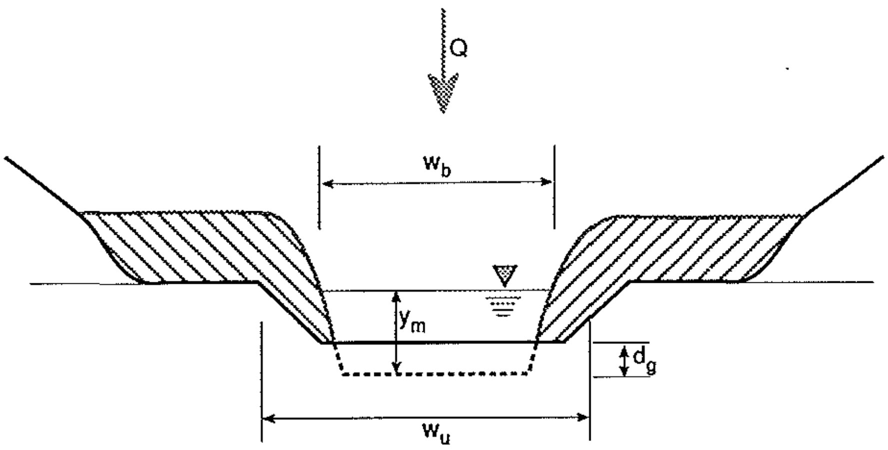
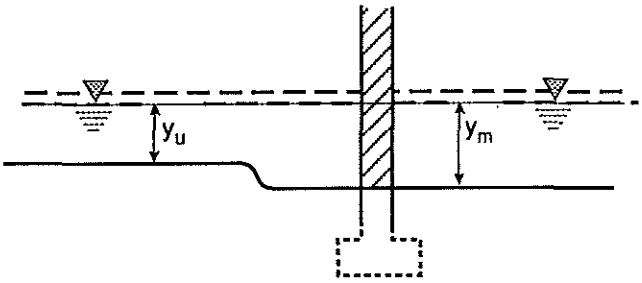
Figure 11 Channel constriction: abutments encroach into main channel, overbank flow



Cross-section



Long profile

d_g = *depth of general scour*

y_u = *depth of water in upstream channel*

y_m = *depth of water under bridge after general scour*

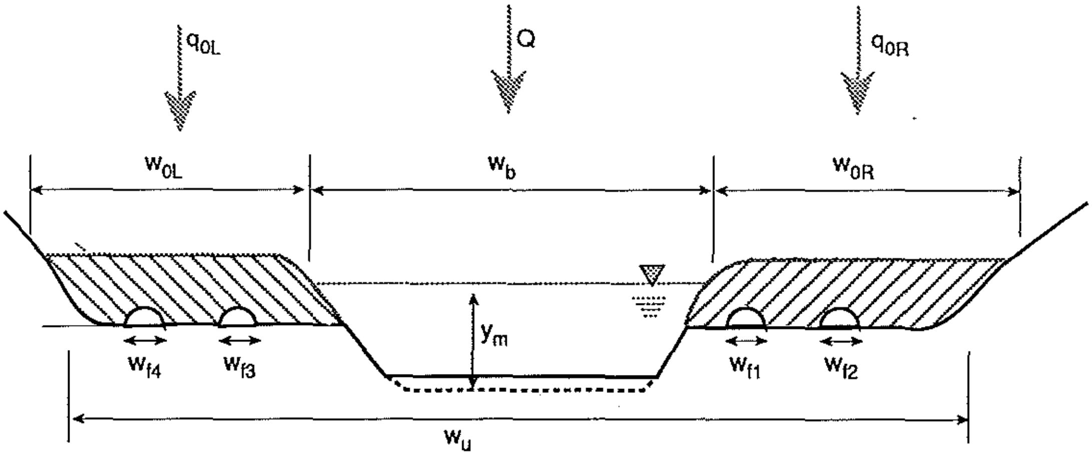
Q = *flow in upstream channel*

w_u = *width of channel at expected high water level*

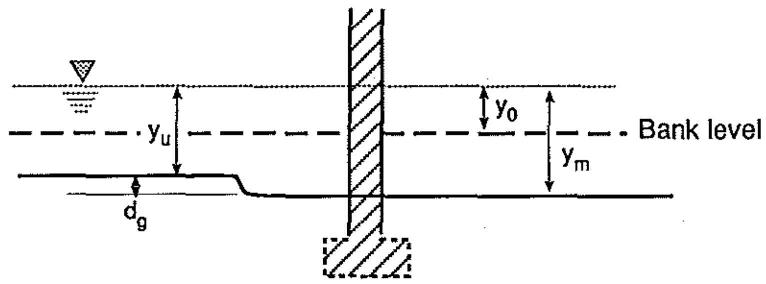
w_b = *width of bridge opening at expected high water level*

KF/12/1-92/LO

Figure 12 Channel constriction: abutments encroach into main channel, no overbank flow



Cross-section



Long profile

d_g = *depth of general scour*

y_u = *depth of water in upstream channel*

y_m = *depth of water under bridge after general scour*

Q = *flow in upstream channel*

$q_o = q_{oR} + q_{oL}$ = *overbank flow*

w_u = *width of channel at expected high water level*

w_b = *width of bridge opening at expected high water level*

y_o = *depth of water on floodplain*

$w_f = \sum_{i=1}^{n} w_{fi}$ = *width of 'n' flood relief arches*

$w_o = w_{oL} + w_{oR}$ = *width of flow on floodplain*

KF/13/1-92/LO

Figure 13 Channel constriction: abutments on floodplain close to channel, overbank flow

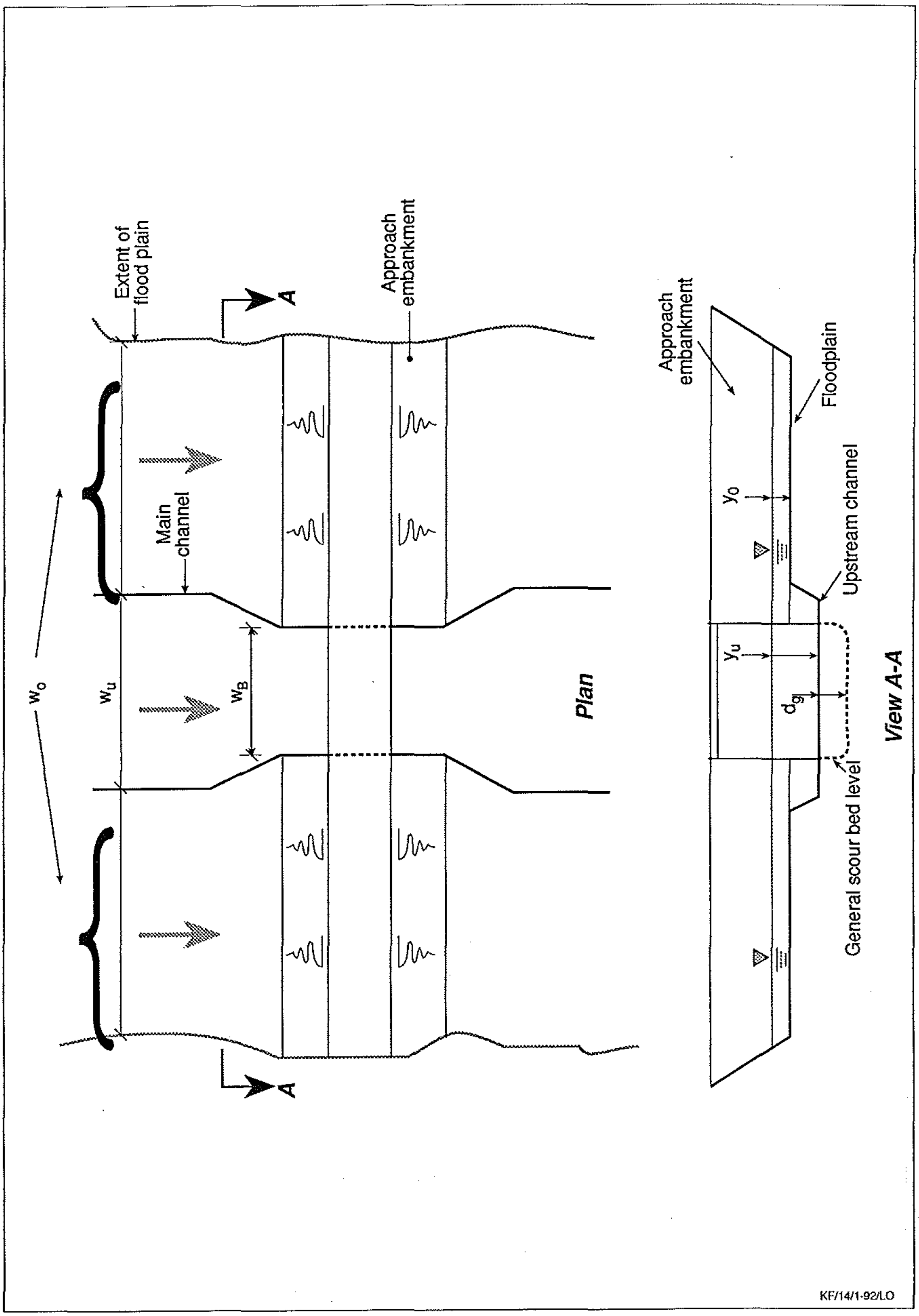


Figure 14 General scour

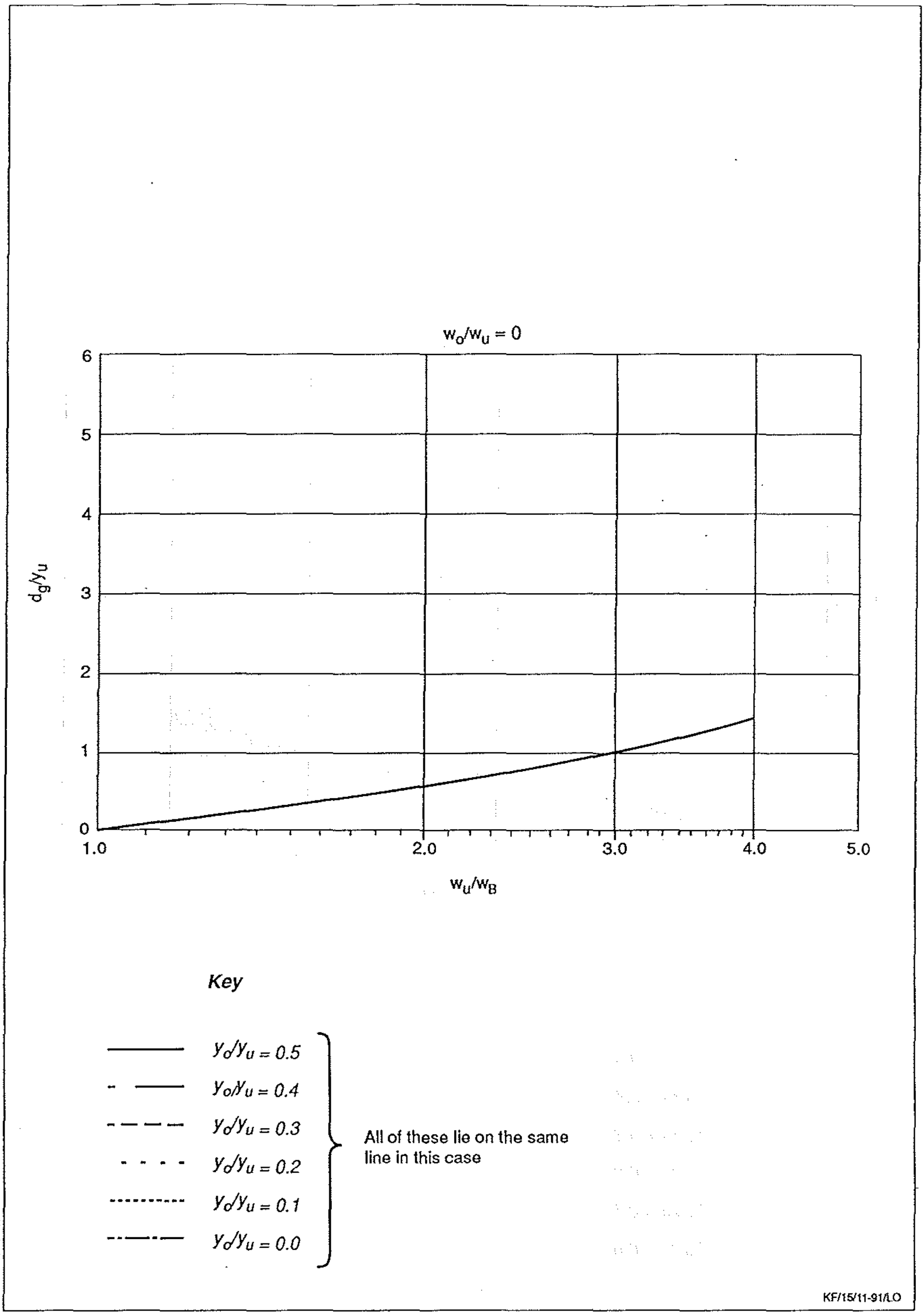


Figure 15 General scour function, $w_o/w_u = 0$

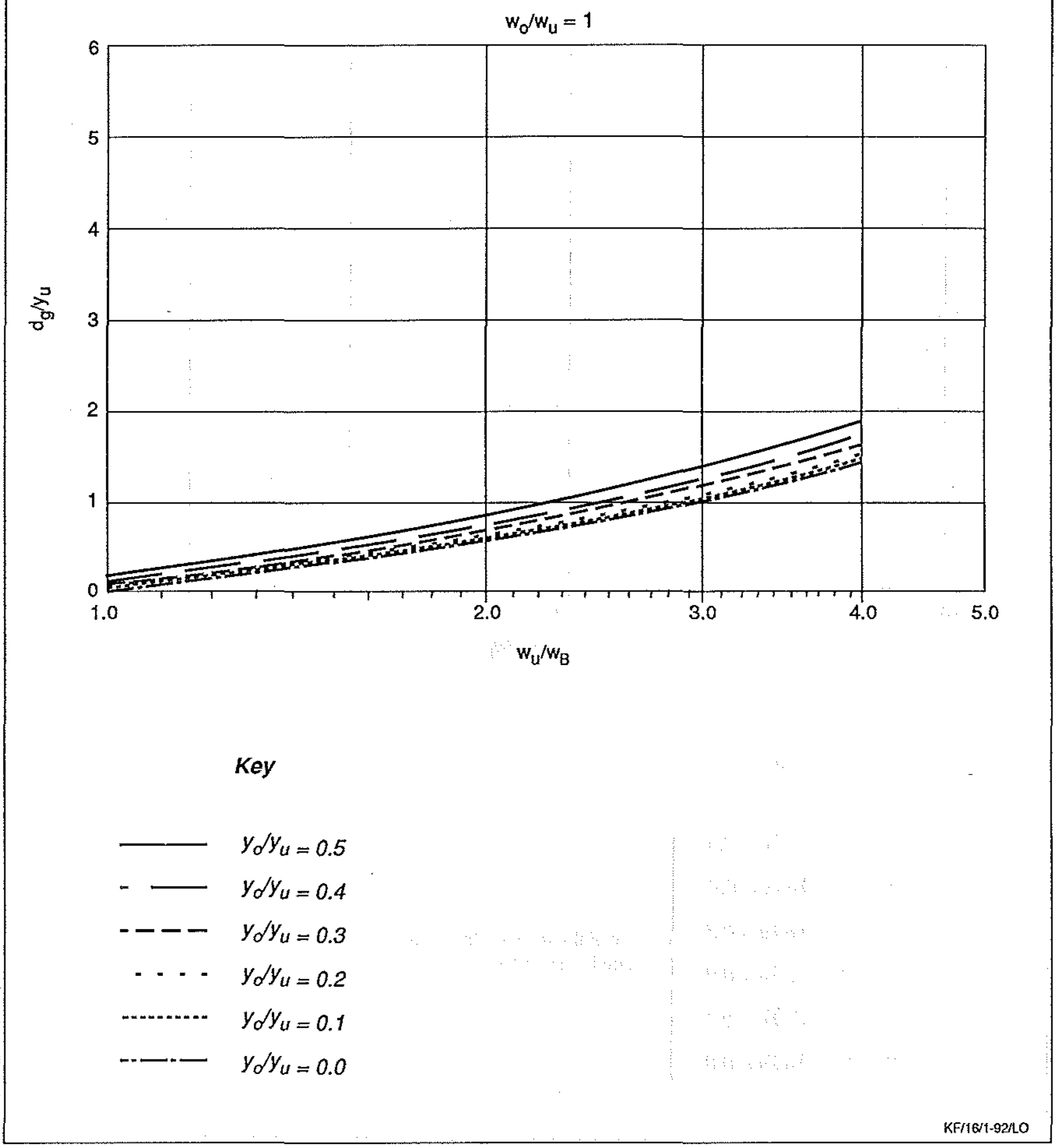


Figure 16 General scour function, $w_o/w_u = 1$

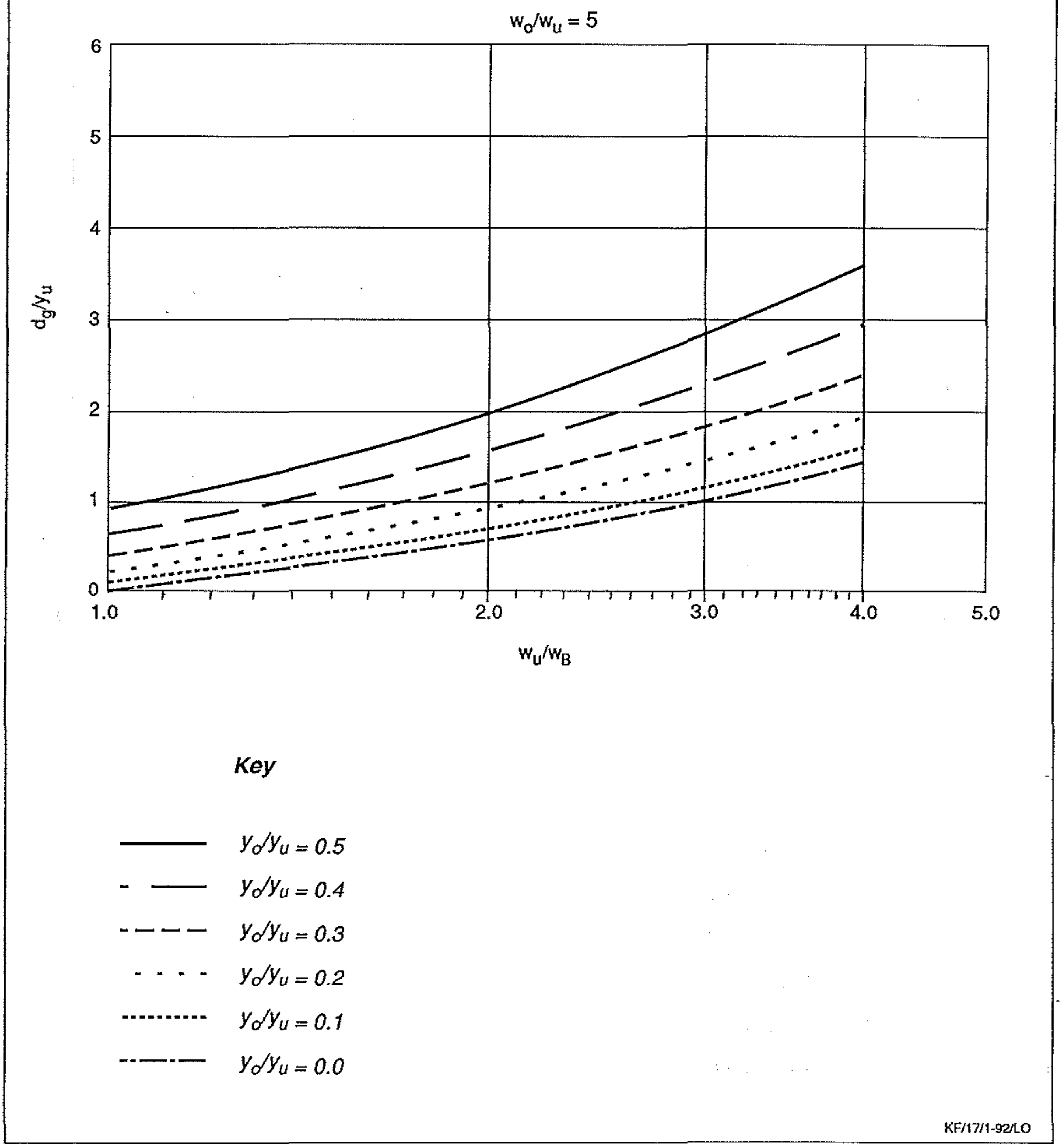


Figure 17 General scour function, $w_o/w_u = 5$

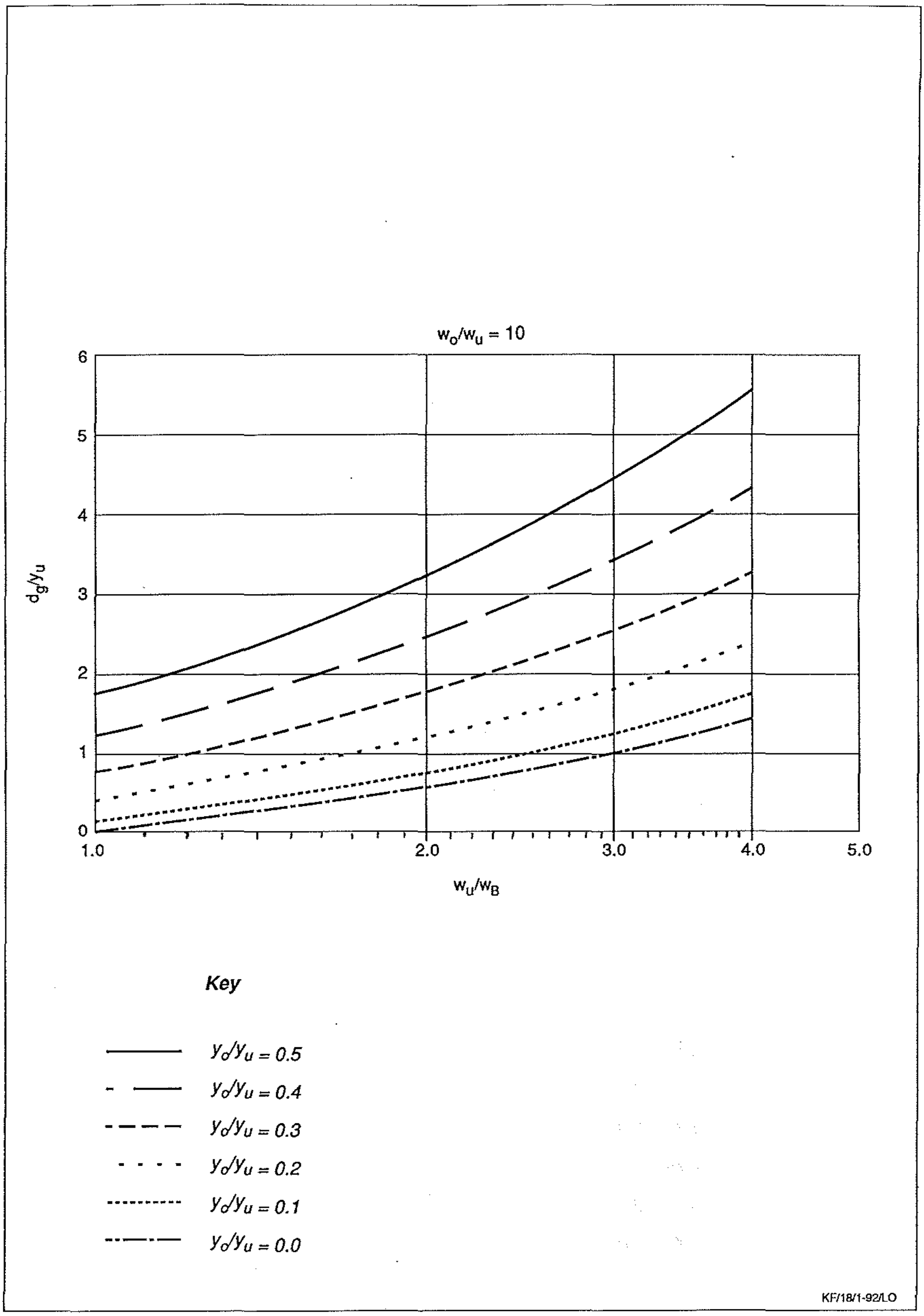


Figure 18 General scour function, $w_o/w_u = 10$

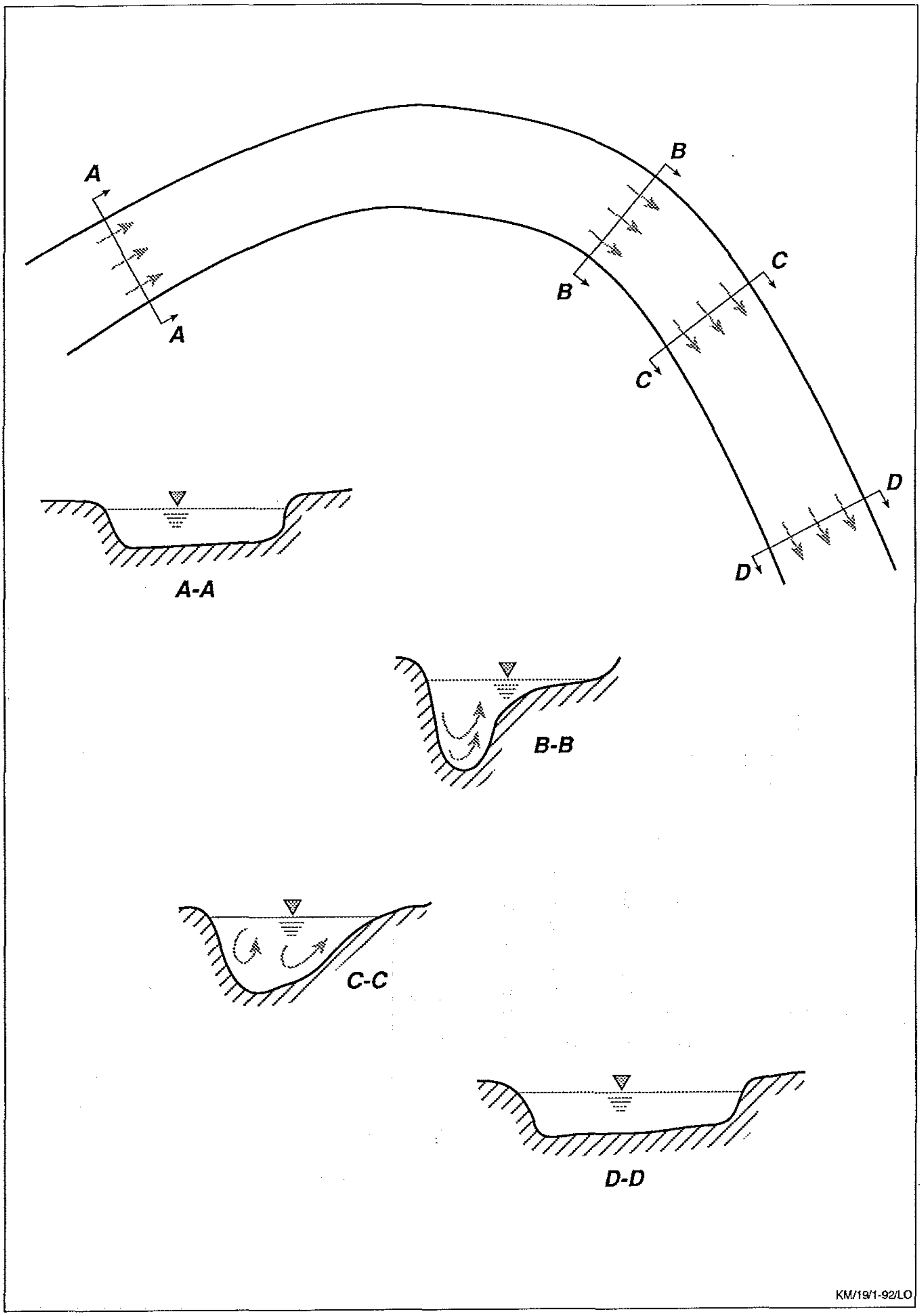
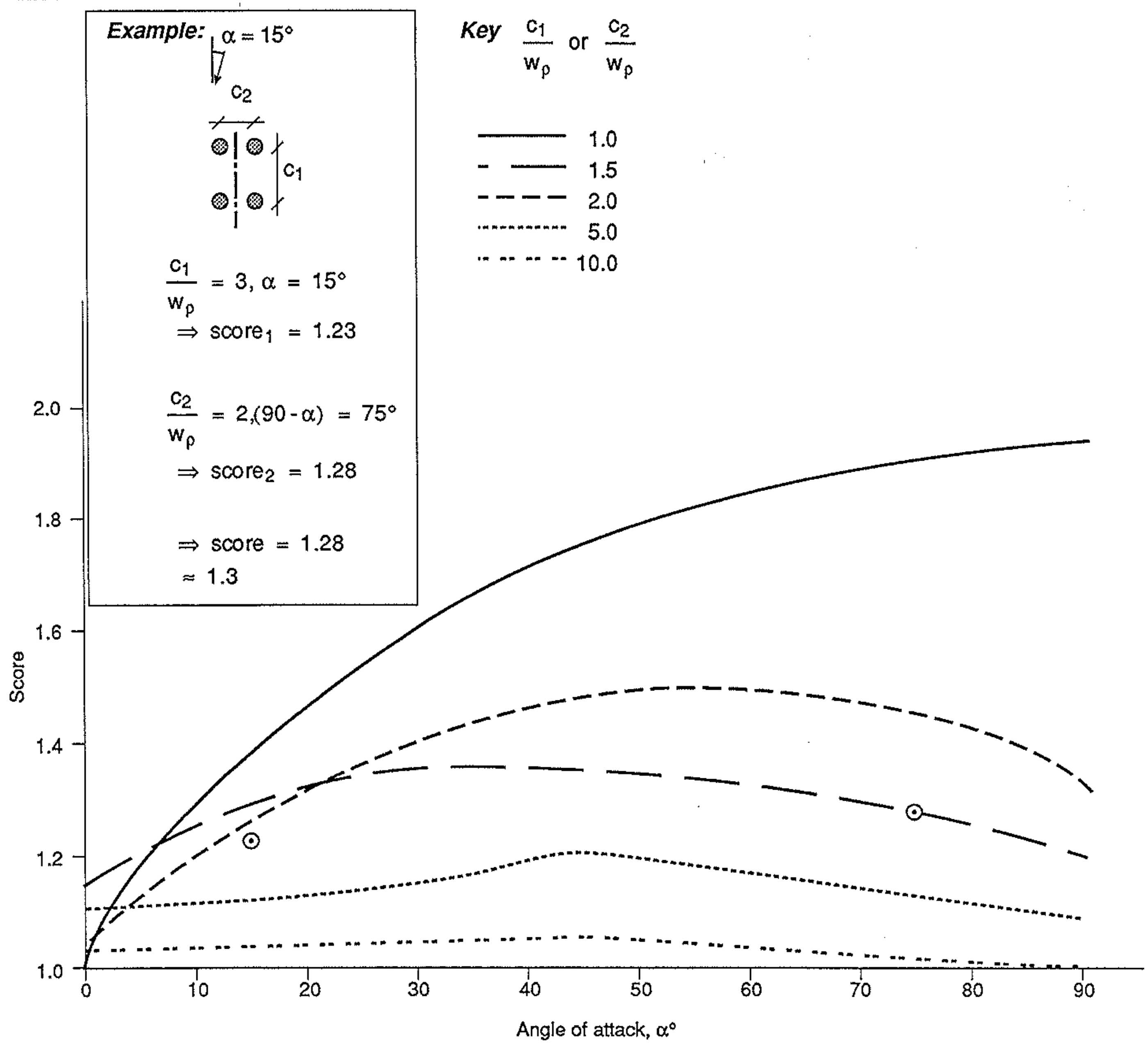
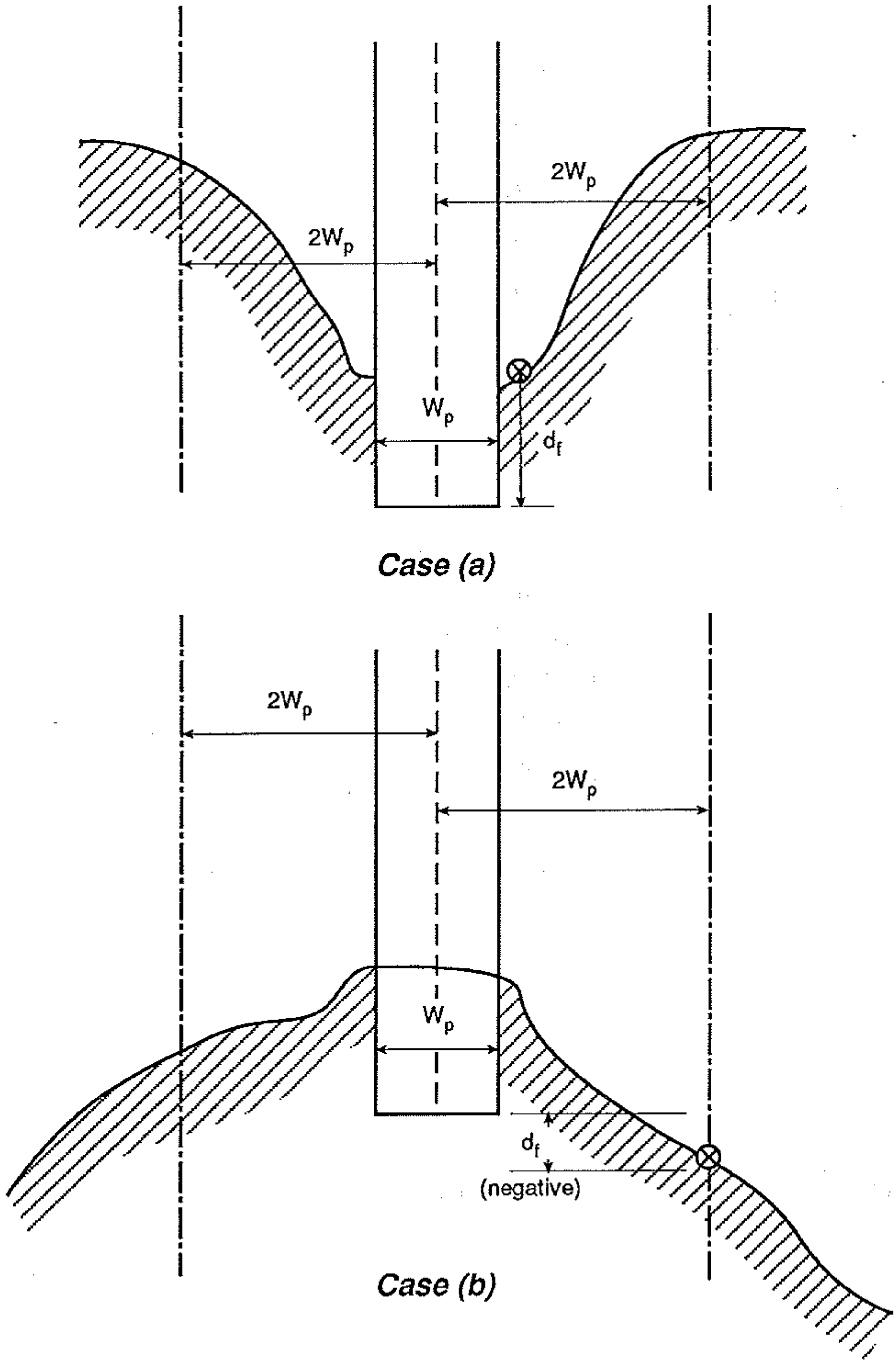


Figure 19 Flow around a bend

Figure 20 Scour at piers consisting of a group of columns



KF/20/1-92/LO



Key

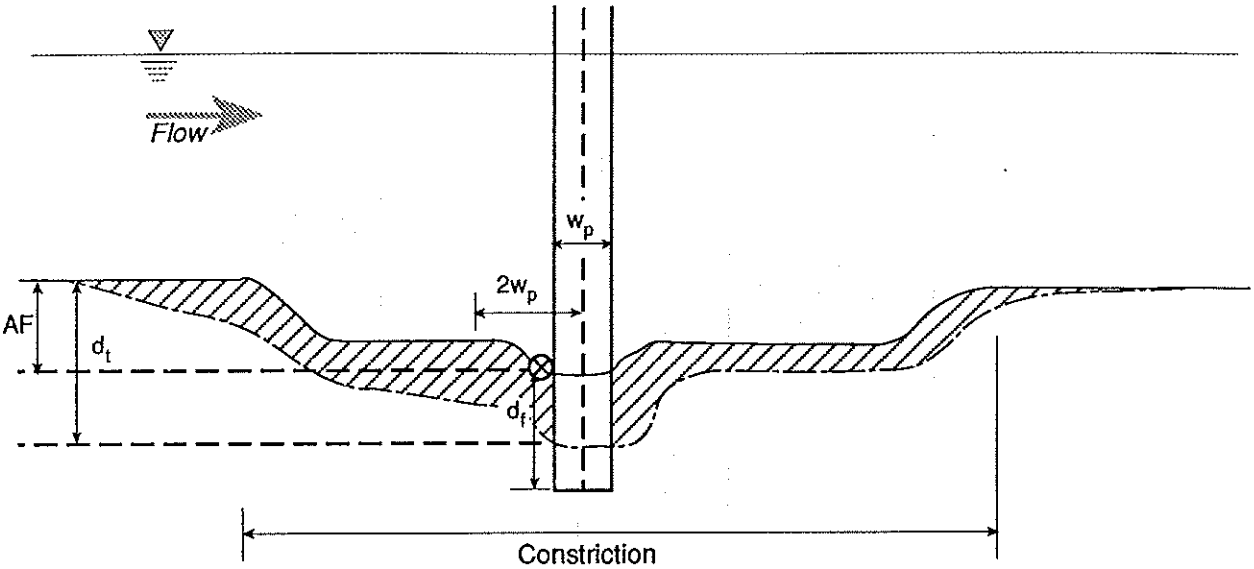
W_p – *Pier width*

d_f – *Depth of foundation*

⊗ – *Position of minimum bed level within an area of the pier with radius $2W_p$*

KF/21/1-92/LO

Fig 21 Measurement of foundation depth



Long section

Key

AF – *Adjustment factor*

d_f – *Depth of foundation*

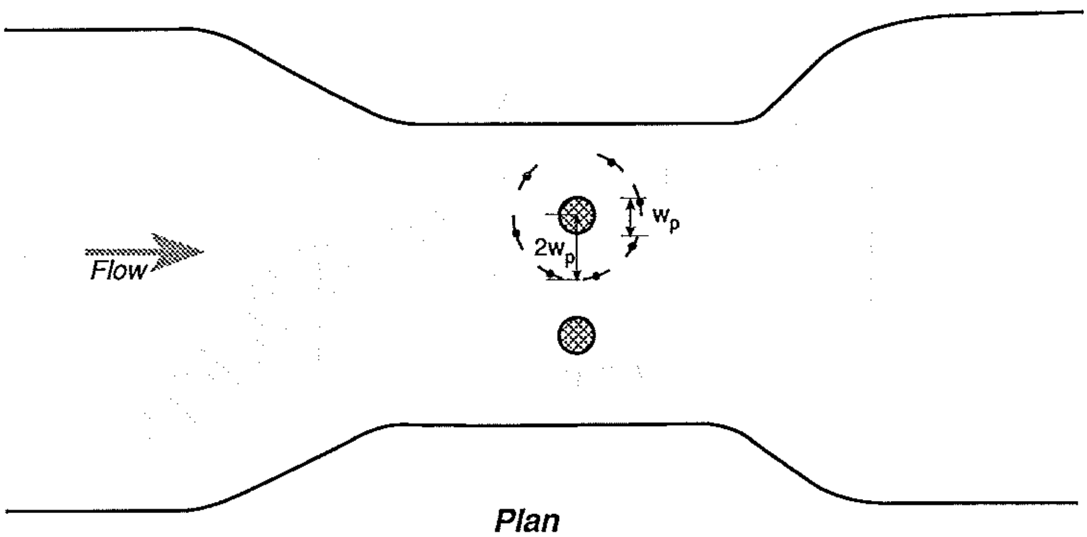
d_t – *Total depth of scour (local scour + constriction scour)*

w_p – *Pier width*

–·–·– – *Scour level after large flood*

////// – *Infill material between flood and normal flow condition*

⊗ – *Measurement position for d_f*



Plan

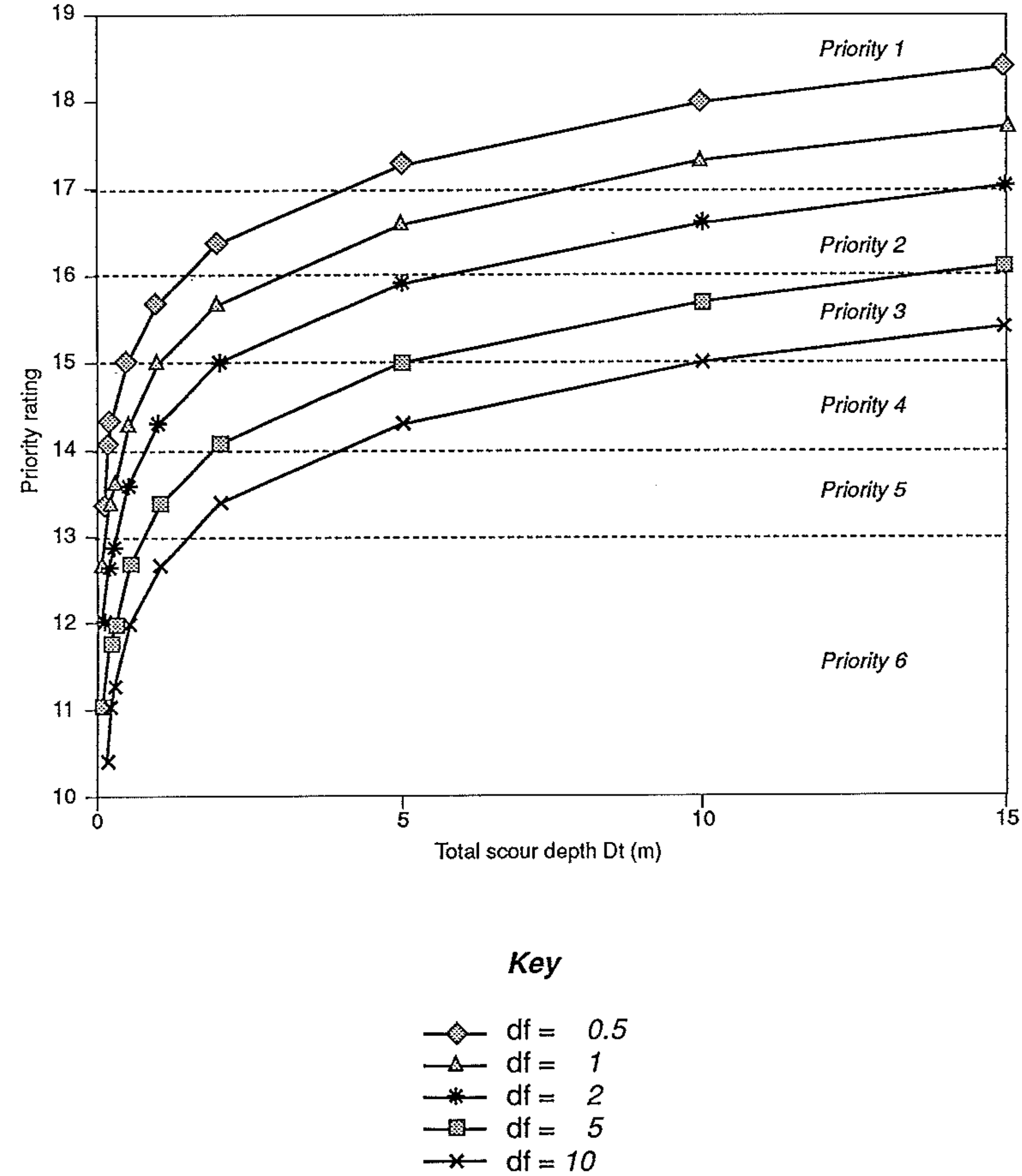
Key

w_p – *Pier width*

–•– – *Pier foundation depth to be measured from inside this area*

KF/22/1-92/LO

Figure 22 Foundation depth and adjustment factor AF



KF/23/1-92/LO

Figure 23 Priority rating graph

APPENDICES

APPENDIX A

Explanation of the method for finding the scour priority rating.

Scour at a bridge is in general the sum of two types of scour - general and local. General scour is a lowering of the bed level during a flood, and is increased by any constriction in the width of the river. Local scour is the erosion of the river bed adjacent to a structure, and is caused by a complex three dimensional disturbance of the flow pattern which increases velocities and turbulence near the bed. The total scour at a bridge will typically comprise depth of general scour due to channel constriction caused by abutments and embankments, plus a depth of local scour at the base of each pier and abutment. If the total scour extends to below a certain critical foundation level, the bridge will be at risk of failure.

Theoretical basis for the scour assessment procedure

The two types of scour, local and general are the result of distinctly different hydraulic phenomena. They depend on different sets of features and are calculated separately and finally summed.

The following features could affect general or local scour:

General scour:
- Degree of channel constriction
- Degree of flood plain constriction
- Length of constriction
- Water depth upstream of bridge
- Bed material - size, grading, cohesiveness, solid rock or discrete particles.

Flow velocity upstream of bridge
Plan shape of channel in the neighbourhood of the bridge

Local scour: Pier - width, length, shape, alignment with flow, footing details, trapped debris, interaction between piers within a group

Flow -velocity, depth, flood duration

Bed material - size, grading, cohesiveness, solid rock or discrete particles.

The following sections discuss each feature, and present the theory behind the assessment procedure in section 7.

Calculation of general scour

<u>Channel constriction and floodplain constriction (Section 7.3.1)</u>

The method is based on formulae recommended by the US Federal Highways Administration (FHWA, 1991). The formulae have been simplified slightly. The method is equivalent to that given in the May 1989 edition of Handbook 47 for channel constriction, with a revised value of the exponent. In addition, flood plain constriction is now included in a quantitative sense.

<u>Length of constriction</u>

The method used for estimating the depth in a contracted section assumes that the contracted reach is long, and the flow is uniform. The flow in a short contracted section may be non-uniform and affected by turbulence produced at the contraction. The turbulence is expected to have a small influence on depth, and it is not feasible in the present report to include procedures to deal with it. It has been assumed for the purposes of the general scour calculation that any contracted section at a bridge is long, and that the flow is uniform within the contracted section.

Water depth upstream of the bridge (Section 7.3.1)

The primary equation for general scour enables the mean depth at the bridge to be calculated as a function of the degree of constriction and the upstream depth (see section on 'Degree of channel constriction'). The mean depth at the bridge Y_B varies in direct proportion with the upstream depth Y_u for a given bridge site.

It is recommended that the upstream depth is measured directly, but where this is not possible the equation given in section 7.2.1 may be used. This equation is based on a number of regime equations which have been produced for British rivers (Lewin (1981)).

Bed material size

It has been assumed that during a flood, the shear stress on the river bed upstream of the bridge will exceed the critical shear stress of the bed material, irrespective of the mean size of the bed material. This may be a conservative assumption, because if the critical shear stress is not reached, the general scour in the contracted section will be lower than predicted. Due to the difficulties of estimating velocities and critical shear stresses, it has been decided to assume that the critical shear stress is exceeded, and that general scour is independent of bed material size.

Bed material grading (Section 7.3.7)

Bed material which is widely graded will be more resistant to scour than material which is uniform, but with the same mean grain size. During a flood, the mean grain size of the graded bed material may increase and its surface may become armoured by the larger particles, which are more resistant to scour. If the bed material is uniform, then no armouring takes place and scour will be more severe.

Very little data is available to enable an estimate to be made of the reduction of scour, both general and local, due to armouring of a graded bed. Raudkivi (1986) presents results of laboratory experiments on local scour at piers under both clear water and live bed conditions. His results show that local scour of a non-uniform bed may be considerably less than scour of a uniform bed, but the reduction is not as large if the critical shear stress of the bed is exceeded. In the latter case, a scour depth approximately 70% of the scour depth in a uniform bed was recorded.

In view of the fact that armouring is a well accepted phenomenon the results of Raudkivi's study have been tentatively extended to make some allowance for a reduction in general scour. A maximum reduction of 30% has been assumed, for widely graded bed material.

Bed material cohesiveness (Section 7.7.2)

A cohesive material such as heavy clay is expected to have a higher resistance to scour than a noncohesive bed of sand or gravel. The erodibility of cohesive materials depends not only on the type of material, but also on factors such as weathering, the degree of saturation and the chemical environment. No accurate procedure can therefore be recommended to allow for cohesive bed materials, particularly in the absence of laboratory testing of the soil, but it is recommended that the score for potential scour severity, which includes both general and local scour, is reduced by one if the bed is of heavy clay.

Bed of solid rock (Section 7.7.2)

Bedrock is highly resistant to scour, and if the bridge is founded on bedrock then it assumed to be at low risk.

Flow velocity upstream of the bridge

The basic method for calculating general scour assumes that the bed shear stress upstream of the bridge is equal to the critical shear stress of the bed material. For most British rivers in flood, velocities are high enough to ensure that the critical shear stress is exceeded. According to Peterson, as the shear stress increases above the critical value, general scour in a long contracted section decreases slightly. The assumption made in this report that the approach velocity equals the critical velocity is therefore likely to lead to slight over-estimation of general scour.

Plan shape of the channel in the neighbourhood of the bridge (Section 7.3.2)

If the bridge is located on a bend, the abutments or piers towards the outside of a bend will be exposed to greater than average scour depths. This is because at a bend, secondary flows at the bed develop which carry bed material from the outside to the inside of the bend. The cross-sectional shape tends to become approximately triangular if the bend is severe. The mean depth, however, remains similar to that in a straight section of the river. Factors to account for the increase maximum in depth are given in Charlton & Farraday.

These figures have been used in the present guidelines and extended to cases of piers or abutments on the insides of bends where the depth will be less than average.

The factors include a small allowance for the fact that even in straight reaches the channel shape tends to be non-rectangular, and the maximum depth will therefore exceed the mean depth.

Calculation of local scour

Many formulae are available for predicting local scour at piers. Local scour at a cylindrical pier in a bed of uniform material can be calculated as a function of the geometry of the pier and properties of the flow, but published formulae do not in general agree on the significant variables. For example, Laursen & Toch (1956) find that, to a first approximation, local scour depends only on the geometry, whereas the equations given by Shen et al (1969) show scour to depend on the approach flow velocity and pier width. Neill recommends that the basic local scour depth is directly proportional to the pier width only, and that the factor of proportionality is increased if the depth of flow exceeds a certain value. Depth of flow appears in the basic equation for scour in several methods. It is apparent that no one equation can be completely satisfactory even for the basic case of scour of a uniform bed around a cylindrical pier.

Our approach has instead been to use published results to establish how each of the significant features affects local scour, having started from a basic scour depth which is proportional to the pier width. The following sections describe how the basic scour depth and modification factors were derived.

Pier width (Section 7.2.4)

Neill suggests that for a pier with a circular nose aligned parallel to the flow, an allowance of d_l = 1.5 w_p is made for local scour, where

d_l = depth of local scour
w_p = pier width

If the flow depth is greater then (5 w_p) than the coefficient should be increased to 2.2.

In other studies on local scour, (e.g. Chiew & Melville (1987), Raudkivi (1986)) the scour depth is non-dimensionalised with pier width, and the time averaged scour depth under live bed conditions is found to lie between 1.4 w_p and 2.3 w_p depending on the bed material and the flow velocity.

Dargahi (1982) presents five sets of flume data and one field measurement, and for all the data, $d_l \leq$ 1.8 Dargahi also compares the relationship between predicted scour depth and pier width for seven methods, and all except two predicted that $d_l \leq 2$ w_p for all flow depths.

Taking these results into account, a basic equation of

$$d_l = 1.5\ w_p$$

has been adopted for this report. It is assumed that an abutment which has a width w_a in the main channel has the same scour characteristics as a pier with effective width $w_p = 2\ w_a$. This approximation has been made by assuming the symmetrical flow about the longitudinal axis of a pier. It is expected that this procedure is conservative in that it is likely to over-predict the scour at an abutment.

The above equation gives the scour of a circular pier in deep water, in a cohesionless uniform bed, with the approach velocity equal to the critical velocity for the bed material. The effects of deviations from these conditions are discussed below.

Depth of flow (Section 7.5.2)

If the water depth (before local scour) is shallow relative to the pier width, local scour will be less than predicted by the above equation. Factors to account for this reduction in local scour are based on laboratory results given by Chiew & Melville (1987) and May and Willoughby (1990).

Pier length

The length of a pier is of secondary importance for local scour, provided that the pier is well aligned with the approach flow. (See section on Angle of attack in this appendix).

Pier shape (Section 7.3.6)

The plan shape of the upstream nose of a pier has a small effect on local scour. The basic equation for depth of scour assumes that the pier has a semi-circular nose. A square nose will result in slightly greater scour and an elongated nose will cause less scour. The factors used in this report are based on those published by Laursen & Toch (1956) and adopted by Charlton & Farraday.

If a pier is not well aligned with the approach flow, no allowance should be made for pier nose shape, as its effect is small in comparison with the effects of pier alignment.

Alignment of pier with approach flow (Section 7.3.5)

Experiments by Laursen & Toch (1956) showed that the angle between the axis of a pier and the direction of the flow approaching the pier is the most important geometric detail of an elongated (i.e. non-circular) pier and that its significance depends on the slenderness of the pier. Both Neill and Charlton & Farraday recommend the use of the factors presented by Laursen and Toch, which cover a wide range of pier slenderness and alignment angle. These factors have been used in the present report.

Foundation details

Piers may have enlarged foundations, and the enlargement may be above or below the general scoured bed level. Foundations can either increase or reduce local scour depending on their level relative to the bed, and methods are available for estimating the effects of foundations of different widths and heights, see for example Imamoto & Ohtoshi (1987). If an enlarged foundation is visible, the limiting case is to assume that the width of the pier is equal to the width of the foundation, and to calculate scour based on this width. Unless the foundation extends a large distance above the bed this will almost certainly lead to an overestimation of scour, but it is felt this is acceptable bearing in mind uncertainties concerning the geometry of the pier and foundation and the effect of foundations on scour.

Trapped debris on piers (Section 7.3.8)

Debris such as trees, branches and other vegetation often becomes trapped on the upstream nose of piers, particularly during floods. This can increase the effective pier width and therefore increase local scour at the pier. The magnitude of the increase depends on many factors which cannot be determined, such as the width of the debris, its permeability and its vertical distribution.

In the present report, an allowance has been made for the increase in local scour due to debris. It has been assumed that a bridge over a river which drains a flat catchment with few trees or bushes will be unaffected by debris, but if the catchment is steep and heavily forested, potential local scour will be increased by a factor of 1.5. This corresponds to 50% increase in pier width throughout the depth of flow.

Scour at pile groups

Flow past pile groups can be very complicated, particularly where a pile cap is exposed above the bed, and local scour cannot be predicted without scale model tests.

Charlton & Farraday recommend that local scour is calculated using the assumption that the group acts as a single pier, with dimensions of the outer piles in the group. In this report, a less conservative method has been adopted based on physical model experiments to investigate the effect of column - column interaction on scour. A magnification factor is obtained which is used to represent the increase in scour at a group of columns compared with the scour at a single isolated column (Raudkivi, 1990).

Flow velocity

Local scour depends on the approach flow velocity, but the variation is non-linear and depends on the critical velocity at which the bed material begins to be transported. Chiew & Melville (1987) and Raudkivi (1986) present graphs of local scour non dimensionalised with pier width, plotted against

mean velocity u non-dimensionalised with the critical velocity, u_c.

The curves show that scour rises to a local maximum at $u = u_c$, and then falls slightly at higher velocities.

As the velocity increases further, scour gradually increases to another local maximum. It is expected that during floods, the velocity will exceed the critical velocity, and the curves show that variation in local scour at this stage is small over a wide range of velocity, from $u = u_c$ to $u = 4u_c$ and above.

This report does not include recommendations for calculating flow velocities, and it has been assumed that local scour is independant of velocity.

Flood duration

Very little research has been carried out into rates of scour, and almost all experiments on local scour have been concerned only with the maximum equilibrium scour. This is the depth of scour which is approached if steady conditions are imposed for a long period of time.

Due to the lack of any general method for predicting rates of scour, and in order to avoid the complication of deriving design flow hydrographs for each site, the conservative approach has been adopted of assuming that a flood has a sufficient duration to cause the maximum (i.e. equilibrium) local scour.

Bed material size

If the bed material is fine enough to be transported during a flood, the size of the bed material has no significant effect on local scour, provided that the grain size is small relative to the pier width. Laursen and Toch (1956) gives a physical explanation for this, and experimental model results are presented in Chiew & Melville

(1987) which show local scour depth to be independent of grain size for if $D_{50}/w_p \leq 0.02$, where D_{50} is the mean particle size.

Bed material grading (Section 7.3.7)

Armouring of a non-uniform bed has been allowed for in the same way as described in the 'General scour' section of this Appendix. Using the results given by Raudkivi (1986) as a guide, a reduction in the depth of local scour of up to 30% is made for widely graded bed material while no reduction is made if the bed is uniform.

Bed material cohesiveness (Section 7.7.2)

As in the case of general scour, it is not possible to recommend a comprehensive method for allowing for the degree of cohesiveness. Local scour of a very cohesive bed material is expected to be less than that of non-cohesive materials which form the basis for almost all of the laboratory studies into local scour. The reduction in the overall score for scour severity is expected to take this into account.

Bed of solid rock (Section 7.7.2)

If the bridge is founded on bedrock then it is assumed to be at low risk.

References to Appendix A

1 Charlton, F G and Farraday, R V, 1983. Hydraulic factors in bridge design. Hydraulics Research Station Limited: Wallingford.

2 Chiew Y M and Metville B W, 1987. Local scour around bridge piers, Journ Hyd Res, 25, No 1, pp 15 - 26.

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-VBI-114, Royal Institute of Technology Hydraulics Laboratory, Stockholm.

4 Federal Highways Administration, 1991. Evaluating scour at bridges. HEC-18. US Department of Transportation, February , 1991.

5 Imamoto H and Ohtozhi K, 1987. Local scour around a non-uniform circular pier, Proc IAMR Congress, Lausanne.

6 Jansen P Ph, et al., 1979. Principles of river engineering. Pitman Publishing Ltd: London.

7 Laursen E M and Toch A, 1956. Scour around bridge piers and abutments, Bulletin No 4, Iowa Highway Research Board.

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9 May R W P and Willoughby I R, 1990. Local scour around large obstructions. Hydraulics Research Ltd. Report No SR 204, March 1990.

10 Neill C R, 1973. Guide to bridge hydraulics. University of Toronto Press: Toronto.

11 Peterson M S, 1986. River Engineering. Prentice Hall: New Jersey. Appendix A.

12 Raudkivi A J, 1986. Functional trends of scour at bridge piers, ASCE Journ Hyd Eng, 112, No 1, p 1. 1-13.

13 Raudkivi A J, 1990. Loose boundary hydraulics. Pergamon Press.

14 Shen H W et al., 1969. Local scour around bridge piers, Proc ASCE Journ Hyd Div, 95, No HY6.

APPENDIX B

Explanation of the scheme for combining features to assess scour

The basic method for calculating scour is to find estimates for the general scour and local scour and then add the two together. General scour is found by estimating the upstream bank full channel depth and applying factors to this depth to account for channel and flood plain constriction, the presence of bends, and bed material grading. Local scour is estimated by multiplying the pier width by factors to account for angle of attack and pier thinness, pier nose shape, column - column interaction, bed material grading and the effect of trapped debris. The bases for inclusion of these features and for selection of suitable values for the factors are discussed in Appendix A. Section 7.3 of the report provides the method for assessing each feature and for assigning a score of 1 to 7. The scores have been chosen so that factors can be calculated from scores using appropriate linear formulae. These formulae are presented in the 'calculation' columns in Tables 1 and 2 in section 7.5.1. The tables are arranged so that factors for general scour are placed in Table 1 and factors for local scour are placed in Table 2.

A relative depth of general scour resulting from channel and flood plain constriction, d_{g1}/Y_u is calculated, and adjusted to take account of bends and bed material grading. The resulting value d_g is assumed to represent general scour.

The depth of local scour below bed level is given by

$$d_l = 1.5 \text{ FL} \times w_p$$

Where w_p is the pier width and the factor of 1.5 is obtained from the basic scour equation.

The total scour depth below the upstream bed level is therefore given by

$$d_t = d_g + d_l$$

The scour depth d_t is then combined with the foundation depth d_f to obtain the preliminary priority rating (Section 7.6). The rationale for the formula

preliminary priority rating =

$$15 + \ln [(d_t - d_f)/d_f + 1]$$

is that the important aspect as far as risk is concerned is the proportion of a bridge's foundation which has been scoured. Thus two different bridges, with different foundation depths, pier widths etc, will have the same preliminary priority rating if, for example, scour in each case results in erosion down to half of the foundation depth.

A preliminary priority rating is obtained and this may be modified to take account of scour protection measures, bed material type and the nature of the river.

Foundations

In order to assess the risk that scour will pose a threat to the bridge foundations, the depth of foundation is assessed as described in section 7.4.2.

APPENDIX C

Explanation of the method for the assessment of catchment characteristics

In section 6.3, catchment characteristics are used to assess the severity of an extreme flood peak.

The Flood Studies Report (FSR) (NERC 1975) contains a detailed analysis of flood records for UK rivers. Methods are recommended for determining flow duration reduction curves and region curves for any catchment. The former are indicators of the flashiness of a catchment, while the latter relate floods with a given return period to the mean annual flood.

The statistical analysis carried out by NERC showed that the flow duration reduction curve relating floods of a given duration to the mean annual maximum calendar day flood can be defined for a catchment as a function of channel slope only. The slope of the channel is defined as the mean channel slope from 10% to 85% of the main channel length measured upstream from the site. The function of slope given in the FSR is used as the basis of the scoring system used in section 6.3.1.

Reference to Appendix C

NERC. 1975. Flood studies report, London : NERC.

APPENDIX D

HYDROGRAPHIC SURVEY Calculation Sheet (1 of 4)

BRIDGE No.
STATION : MILEAGE: ELR:

DETAILS		SCORE
Type of Stream	St =	.....
Bank Stability	Bs =	.....
Distance : River source to Bridge L = ... km 85% Distance upstream : x = 0.85 L x = ... km O.S. Contour line : a a = ... m 10% Distance upstream : y = 0.1 L y = ... km O.S. Contour line : b b = ... m $Slope\ (m/km) = \frac{(a-b)}{(x-y)} = \frac{(.....-.....)}{(.....-.....)}$ $= .....\ m/km$ **Flashiness**	Fs =	.....
River type : $Tr = \frac{(St+Bs+Fs)}{17} - 1.12$ $= \frac{(.....+.....+.....)}{17} - 1.12$ **Main dimensions** Channel width : W_u = ... m Channel depth : Y_u = ... m Channel width under bridge : W_b = ... m Channel depth under bridge : Y_b = ... m Floodplain width : W_o = ... m Flood plain flow depth : Y_o = ... m Pier width : w_p = ... m Pier length : L_p = ... m Column - Column distance, if appropriate : C_1 = ... m C_2 = ... m	Tr =	.....

HYDROGRAPHIC SURVEY Calculation Sheet (2 of 4)

BRIDGE No.
STATION : MILEAGE: ELR:

DETAILS	SCORE
Size ratios W_u/W_b = ... Y_o/Y_u = ... W_o/W_u = ... From figs 15 - 18: d_g/Y_u =	
Scour due to Bends Sb =	.....
Pier thinness = Lp/Wp = ... Angle of attack = α = ...° **Angle of Attack and Pier Thinness** Aa =	.....
Group of columns Gc =	.....
Pier / Abutment Nose Shape Ns =	.....
Bed Material Grading Bm =	.....
Blockage due to Debris Bd =	.....
Adjustment factor AF =	.....
Foundation Depth d_f =	.....

Table I

Description	Res. S	Calculation	Res.	
Scour due to Bends Sb=	.....	0.25 x S + 0.25	.....	B
Bed Material Grading Bm=	.....	0.05 x S + 0.65	.....	BMG

d_{g1} (Section7.3.1) = ...	
d_{g1} + 1.0 = ...	
(d_{g1} + 1.0) * B * BMG = ...	
[(d_{g1} + 1.0) * B * BMG] - BMG = d_g/Y_u = ...	
Multiply by Y_u to give general scour d_g = ...	

HYDROGRAPHIC SURVEY

Calculation Sheet (3 of 4)

BRIDGE No.
STATION : **MILEAGE:** **ELR:**

General scoured depth:

$Y_m = Y_u + d_g$: Y_m = ...

Relative flow depth Y_m / w_p = ...

Relative flow depth score Rf **Rf =** .....

Table II

Description	Score S	Calculation	Result
Relative Flow Depth **Rf =**	.....	0.11 x S + 0.23	.....
Ang of Attack,Pier Thckns **Aa =**	.....	1.0 x S	.....
Group of columns **Gc =**	.....	1.0 x S	.....
Pier/Abutment Nose Shape **Ns =**	.....	0.1 x S + 0.6 =	.....
Bed Material Grading **Bm =**	.....	0.05 x S + 0.65	.....
Trapped Debris **Bd =**	.....	0.08 x S + 0.92	.....
		Product FL =	.....

HYDROGRAPHIC SURVEY Calculation Sheet (4 of 4)

BRIDGE No.
STATION : MILEAGE: ELR:

Local scour d_l = 1.5 x FL x w_p : d_l = ...

Total scour $d_t = d_g + d_l$: d_t = ...

Adjusted total scour $d_t = d_t - AF$: d_t = ...

Preliminary priotity rating, function of d_t and d_f (using figure 23)
Preliminary priority rating PPR = ...

Adjust for river type:
PPR = PPR + TR : PPR = ...

Adjust for load bearing material (See section 7.7.2)
PPR adjusted for load bearing material = ...

Final priority rating = ...

This determines into which priority category the bridge element falls.

Category:
Priority 1 (Highest priority)
Priority 2
Priority 3
Priority 4
Priority 5
Priority 6 (Lowest priority)

HYDROGRAPHIC SURVEY HANDBOOK 47 (section 8)

BRIDGE No.
STATION: MILEAGE: ELR:

CATEGORY 2 ELEMENT - ABUTMENT < 20% FROM CHANNEL				
	A	B	C	D
River (1)				---
River (2)				---
River (3)				---
River (4)				---
River (5)				---
Bridge (1)			---	---
Bridge (2)				---
Bridge (3)				
Bridge (4)			---	---
Bridge (5)			---	---
Bridge (6)			---	---
Bridge (7)			---	---

HYDROGRAPHIC SURVEY HANDBOOK 47 (section 8)

BRIDGE No.
STATION: MILEAGE: ELR:

CATEGORY 2 ELEMENT - ABUTMENTS > 20% FROM CHANNEL			
	A	B	C
River (1)			
River (2)			
River (3)			
Bridge (1)			
Bridge (2)			
Bridge (3)			
Bridge (4)			---

HYDROGRAPHIC SURVEY HANDBOOK 47 (section 8)

BRIDGE No.
STATION: MILEAGE: ELR:

CATEGORY 2 ELEMENT - FLOOD RELIEF ARCH			
	A	B	C
River (1)			
River (2)			
River (3)			
River (4)			
Bridge (1)			
Bridge (2)			
Bridge (3)			
Bridge (4)			
Bridge (5)			---

APPENDIX E

HYDROGRAPHIC SURVEY Calculation Sheet (1 of 4)

BRIDGE No.
STATION : MILEAGE: ELR:

DETAILS	SCORE
Type of Stream St =	2
Bank Stability Bs =	2
Distance : River source to Bridge L = 155 km 85% Distance upstream : x = 0.85 L x = 132 km O.S. Contour line : a a = 90 m 10% Distance upstream : y = 0.1 L y = 16 km O.S. Contour line : b b = 15 m $Slope\ (m/km) = \frac{(a-b)}{(x-y)} = \frac{(90 - 15)}{(132 - 16)}$ = 0.65 m/km Fs = **Flashiness**	2
River type : $Tr = \frac{(St+Bs+Fs)}{17} - 1.12$ Tr = $= \frac{(2 + 2 + 2)}{17} - 1.12$	-0.77
Main dimensions Channel width : W_u = 20 m Channel depth : Y_u = 4.15 m Channel width under bridge : W_b = 17 m Channel depth under bridge : Y_b = 4.15 m Floodplain width : W_o = 50 m Flood plain flow depth : Y_o = 0.2 m Pier width : w_p = 1.5 m Pier length : L_p = 17.2 m Column - Column distance, if appropriate : C_1 = — m C_2 = — m	

HYDROGRAPHIC SURVEY Calculation Sheet (2 of 4)

BRIDGE No.
STATION : MILEAGE: ELR:

DETAILS	SCORE
Size ratios W_u/W_b = 1·18 Y_o/Y_u = 0·05 W_o/W_u = 2·50 From figs 15 - 18: d_g/Y_u = 0·12	
Scour due to Bends Sb =	6
Pier thinness = Lp/Wp = 11 Angle of attack = α = 10 ° Angle of Attack and Pier Thinness Aa =	2·0
Group of columns Gc =	1
Pier / Abutment Nose Shape Ns =	7
Bed Material Grading Bm =	5
Blockage due to Debris Bd =	7
Adjustment factor AF =	0
Foundation Depth d_f =	2. m

Table I

Description	Res. S	Calculation	Res.	
Scour due to Bends Sb=	4	0.25 x S + 0.25	1·25	B
Bed Material Grading Bm=	5	0.05 x S + 0.65	0·90	BMG

d_{g1} (Section7.3.1)	= 0·50	
d_{g1} + 1.0	= 1·50	
(d_{g1} + 1.0) * B * BMG	= 1·69	
[(d_{g1} + 1.0) * B * BMG] - BMG = d_g/Y_u	= 0·79	
Multiply by Y_u to give general scour d_g	= 3·26	

HYDROGRAPHIC SURVEY **Calculation Sheet (3 of 4)**

BRIDGE No.
STATION : **MILEAGE:** **ELR:**

General scoured depth:

$Y_m = Y_u + d_g$: Y_m = 7.41

Relative flow depth Y_m / w_p = 4.94

Relative flow depth score Rf **Rf** = 7

Table II

Description	Score S	Calculation	Result
Relative Flow Depth **Rf** =	7	0.11 x S + 0.23	1.0
Ang of Attack,Pier Thckns **Aa** =	2	1.0 x S	2.0
Group of columns **Gc** =	1	1.0 x S	1.0
Pier/Abutment Nose Shape **Ns** =	7	0.1 x S + 0.6 =	1.3
Bed Material Grading **Bm** =	5	0.05 x S + 0.65	0.9
Trapped Debris **Bd** =	7	0.08 x S + 0.92	1.48
		Product FL =	3.46

HYDROGRAPHIC SURVEY Calculation Sheet (4 of 4)

BRIDGE No.
STATION : MILEAGE: ELR:

Local scour d_l = 1.5 x FL x w_p : d_l = 7.79

Total scour $d_t = d_g + d_l$: d_t = 11.1

Adjusted total scour $d_t = d_t$ - AF : d_t = 11.1

Preliminary priotity rating, function of d_t and d_f (using figure 23)
Preliminary priority rating PPR = 16.7

Adjust for river type:
PPR = PPR + TR : PPR = 15.9

Adjust for load bearing material (See section 7.7.2)
PPR adjusted for load bearing material = 15.9

Final priority rating = 15.9

This determines into which priority category the bridge element falls.

Category:
- Priority 1 (Highest priority)
- Priority 2
- Priority 3 ✓
- Priority 4
- Priority 5
- Priority 6 (Lowest priority)

HYDROGRAPHIC SURVEY HANDBOOK 47 (section 8)

BRIDGE No.
STATION: MILEAGE: ELR:

CATEGORY 2 ELEMENT - ABUTMENT < 20% FROM CHANNEL				
	A	B	C	D
River (1)		✓		---
River (2)		✓		---
River (3)		✓		---
River (4)			✓	---
River (5)	✓			---
Bridge (1)	✓		---	---
Bridge (2)	✓			---
Bridge (3)	✓			
Bridge (4)		✓	---	---
Bridge (5)		✓	---	---
Bridge (6)	✓		---	---
Bridge (7)	✓		---	---

HYDROGRAPHIC SURVEY HANDBOOK 47 (section 8)

BRIDGE No.
STATION: MILEAGE: ELR:

CATEGORY 2 ELEMENT - ABUTMENTS > 20% FROM CHANNEL			
	A	B	C
River (1)		✓	
River (2)		✓	
River (3)		✓	
Bridge (1)	✓		
Bridge (2)	✓		
Bridge (3)		✓	
Bridge (4)		✓	---

HYDROGRAPHIC SURVEY HANDBOOK 47 (section 8)

BRIDGE No.
STATION: MILEAGE: ELR:

CATEGORY 2 ELEMENT - FLOOD RELIEF ARCH			
	A	B	C
River (1)		✓	
River (2)		✓	
River (3)		✓	
River (4)			✓
Bridge (1)		✓	
Bridge (2)	✓		
Bridge (3)	✓		
Bridge (4)			
Bridge (5)		✓	---