TECHNICAL REPORT 3/04

CASE STUDY OF BRIDGES CONSTRUCTED IN HIGHLY MOBILE ESTUARIES OR RIVER BEDS

Report No. B4027/TR03/04
October 2004

Halton Borough Council
Rutland House
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NEW MERSEY CROSSING

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CONTROLLED DOCUMENT

Gifford and Partners Document No:	**B4027/TR03/04**		
Status:	Working Document	*Copy No:*	

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Revision Record						
Rev.	*Date*	*By*	*Summary of Changes*	*Chkd*	*Aprvd*	*Issue Aprvd*

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C O N T E N T S

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FOREWORD

Halton Borough Council, on behalf of the Mersey Crossing Group, is currently promoting a second integrated crossing of the Mersey within the Borough, between Runcorn and Widnes. Gifford and Partners were appointed as Project Manager and Lead Consultant in July 2001 to undertake the further studies necessary to take the project forward.

A substantial body of work has been undertaken to date on the project, including design, investigation of funding options and environmental studies. The work has culminated in the production of a series of reports, which are summarised in the following table:

Report Number & Status	Report Title	Principal Author	Purpose of Report
General Reports			
B4027/01 Issued November 2001	Report of Works 1 – Preliminary Sources Survey	Gifford and Partners	Report to the client on the desk study
B4027/01 Addendum No 1 Issued November 2001	Report of Works 1 – Preliminary Sources Survey – Addendum No 1 – Fiddler's Ferry Route	Gifford and Partners	Report to the client on the desk study for Route 4
B4027/02 Issued March 2003	Report of Works 2 – Volume 1	Gifford and Partners	Report to the client on the studies carried out on alternative route options
	Report of Works 2 – Volume 2	Gifford and Partners	Structure and Highways Drawings for ROW2
B4027/03 Issued March 2004	Route Selection	Gifford and Partners	Report to DfT to clarify Route selection
Environmental Impact Assessment for Options Appraisal & MSA			
B4027/EIA/01 Issued March 2002	Environmental Impact Assessment Scoping Report	Gifford and Partners	Scoping of impacts for EIA for consultation
B4027/EIA/02 Issued August 2002	Environmental Impact Assessment Scoping Report Addendum	Gifford and Partners	Addendum to scoping report taking into account comments received from consultees
B4027/EIA/03 Issued July 2003	Environmental Impact Assessment Progress Report	Gifford and Partners	Report on EIA progress to inform the ROW2 and for consultees
B4027/EIA/04 Issued March 2003	Environmental Impact Assessment Synthesis – Multi-Criteria Analysis	Gifford and Partners	Statistical analysis of impacts to assist in decision making process
B4027/EIA/05 In preparation – due to be issued November 2004	Environmental Impact Assessment Supplementary Report for the Major Scheme Appraisal	Gifford and Partners	Report on changes to EIA as a result of changes to the scheme since the submission of the MSA in July 2003
Environmental Impact Assessment for Orders and Applications			
B4027/EIA/05 In preparation – due to be issued November 2004	Environmental Impact Assessment Orders and Applications Scoping Report	Gifford and Partners	EIA Scoping Report for "The Scheme" detailing EIA to be carried out for the Environmental Statement
Major Scheme Appraisal			
B4027/MSA/01 Issued July 2003 (Will be superseded by B4027/MSA/02)	Appendix 1 Major Scheme Appraisal for New Mersey Crossing – Volume 1	Gifford and Partners	Report submitted to DfT with application for funding
	Appendix 1 Major Scheme Appraisal for New Mersey Crossing – Volume 2	Gifford and Partners	Worksheets in support of above
B4027/MSA/02 In preparation – due to be issued November 2004	Major Scheme Appraisal for New Mersey Crossing – Volume 1	Gifford and Partners	Report submitted to DfT with application for funding
	Major Scheme Appraisal for New Mersey Crossing – Volume 2	Gifford and Partners	Worksheets in support of above

In addition to these main reports, the detailed technical studies have been reported in a series of Technical Reports which provide supporting details for the Report of Works, Environmental Impact Assessment and Major Scheme Appraisal. These reports are listed in Appendix B.

The work undertaken to March 2003 focused on comparing potential options for a new crossing. In March 2003, Halton Borough Council and the Mersey Crossing Group voted unanimously for a preferred route upstream of the existing Silver Jubilee Bridge.

A Major Scheme Appraisal (MSA) for the preferred scheme was submitted to the Department for Transport (DfT) in July 2003 with Halton Borough Council's Local Transport Plan APR to apply for Central Government funding. In December 2003, the DfT responded by awarding the scheme "Super Work in Progress" status and requesting further information on the following issues:

- Traffic impact over the wider road network
- Hydrodynamic modelling
- Economic Impacts
- Statutory Procedures and Procurement
- Funding Options – consideration of tolling as a means to fund the new crossing

A second MSA submission will be made to the DfT in November 2004, after which it is hoped that funding issues will be resolved. Following this, it is intended that work on the Environmental Statement will commence, with the appropriate Applications and Orders being submitted in the autumn of 2005.

The reports being produced for the MSA submission in November 2004 are also listed in Appendix B.

Queries regarding any of the reports should be addressed to either of the contacts below:

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NON-TECHNICAL SUMMARY

In an attempt to determine the likelihood of mobile thalweg (line of the deepest point of a channel) in the upper estuary of the Mersey, attaching to the bridge piers of the proposed New Mersey Crossing, research has been carried out to determine whether there is conclusive evidence to indicate whether this phenomenon occurs in the natural world.

Research has been aimed at identifying any processes through which a mobile thalweg within an estuary or wide fluvial system could attach to a structure and case studies where attachment of a thalweg to a structure has been observed. This has been considered together with modelling used to investigate the effect or any remedial action taken. The research carried out has included a thorough literature review using library sources and the internet. In addition a range of experts in hydrological and marine engineering disciplines have been approached with reference to the problem.

A comprehensive review of the scour process which occurs at bridge piers has been carried out however no evidence has been revealed to identify how local scour can interact with a thalweg. Attempts to identify direct case studies were unsuccessful due to a lack of literature in the public domain that refers to the interaction of a thalweg with local scour regions. Furthermore the flows patterns in the Mersey estuary and the factors which affect them are very site specific and as such case studies of other estuaries are not easily comparable. However it has been possible to consider the attachment process which has been observed at training walls in some estuaries of Northwest coast of the UK although this may not be indicative of the process that could occur at bridge piers.

A number of conjectures have been made based upon the research carried out in an attempt to identify processes that could result in thalweg attachment. It has been recommended that modelling could be carried out to determine whether any of these conjectures could be proved. Furthermore where it is anticipated that the presence of a local scour hole could encourage a thalweg attachment, it is suggested that scour mitigation and protection measures be carried out. However modelling should be employed to more accurately determine the likely effects of any measures on the processes occurring within the estuary.

The findings of this report are that no significant evidence has been identified that could reliably prove or disprove whether a thalweg in the Mersey estuary will become attached to the piers of the New Mersey Crossing. However it is recommended that computer or physical modelling should be carried out to determine the effect of the proposed piers on the morphology of the estuary.

1 INTRODUCTION

The purpose of this report is to consider what evidence may exist, from other estuaries or wide rivers, regarding the impact structures have had on forcing channels to permanently change location or become ‘fixed’ to the structure itself. In addition the development and extent of scour and its possible role in this process will be considered.

1.1 Approach

The approach has been to :

- Conduct a literature search
- Contact relevant researchers in the UK and overseas
- Contact those with responsibility for the management of rivers or estuaries
- Maintain these contacts and apply regular update searches of the literature

It is proposed that this report remains a working document that will be revised and updated periodically through the feasibility and conceptual design phase of the project. It will be a source document for the design process.

2 THE CHANNELS IN THE UPPER MERSEY ESTUARY

The Mersey Estuary is sited on the north west coast of England between the Dee and Ribble estuaries (Figure 2.1). The estuary extends from Liverpool at the mouth, to the tidal limit at Howley Weir (Warrington), some 46 km upstream.

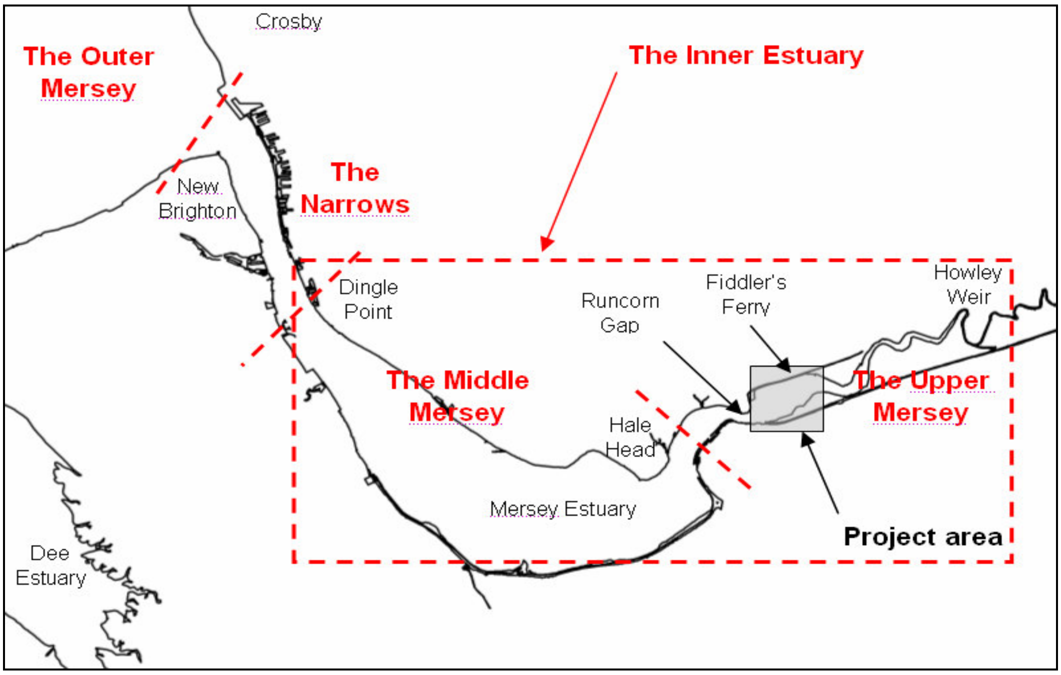

Figure 2.1.The Mersey Estuary

The Upper Estuary of the Mersey typically exhibits two distinct but mobile channels. These channels are clearly visible at low water and are the main carriage system for water until approximately 1 hour before mean high water springs when the remainder of the breadth of the estuary comes into play. The development and range of movement of these channels has been discussed within the Morphology report (B4027/TR03/03). Figure 2.2 is an extract from this report showing the historic changes in the location of the low water channels.

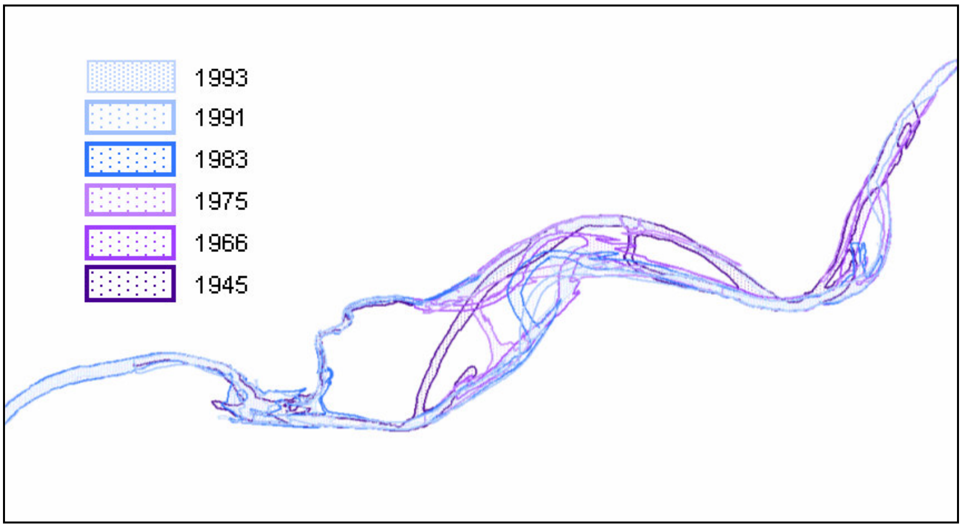

Figure 2.2. Locations of past channels derived from aerial photographs

The proposed New Mersey Crossing will consist of a major bridge with long approach viaducts. The chosen route is shown on Figure 2.3. This alignment will include a number of bridge piers and major bridge towers within the breadth of the estuary, several of which will need to be constructed in the highly mobile area within the estuary.

The mobile characteristic of the Upper Estuary is a major feature and concern has been raised that the proposed bridge crossing may permanently change this. In particular, loss of the mobility of the two channels or the permanent attachment of either to the bridge piers would be a significant detrimental impact. Further, if the structure diverted either channel to cause it to 'fix' to the edge of the saltmarsh thus increasing the rate of erosion of the saltmarsh, this would also be unacceptable.

In order to determine the impacts of the proposed structure on the Upper Estuary, a computer modelling study has been commissioned, the results of which are discussed in reports B4027/TR03/01 Rev A and 02 Rev A. However, it is not possible to use these models to predict the likelihood of a channel attaching to the bridge piers. It was therefore decided to conduct this research study, including case studies of those estuaries or wide rivers of sufficient similarity to the New Mersey, to determine whether the concerns outlined above are well founded, and if they are, to inform the design of suitable mitigation measures.

The aim of the research is to determine theoretical processes through which a thalweg[1] and thus channel could become attached to the bridge piers and to identify case studies of bridges built in similar situations where thalweg attachment has been observed. This will be carried out utilising a thorough review of literature and by approaching experts in hydraulic and river engineering with reference to the problem.

In addition, there is significant evidence that scour occurs around structures built within environments subject to tidal and fluvial flows. Scour can have a significant impact on bed morphology and will therefore be investigated further, considering factors relating to its cause and its effect on a nearby mobile channel within a wide fluvial bed or tidal estuary.

1 The thalweg is the line of the deepest point of a channel.

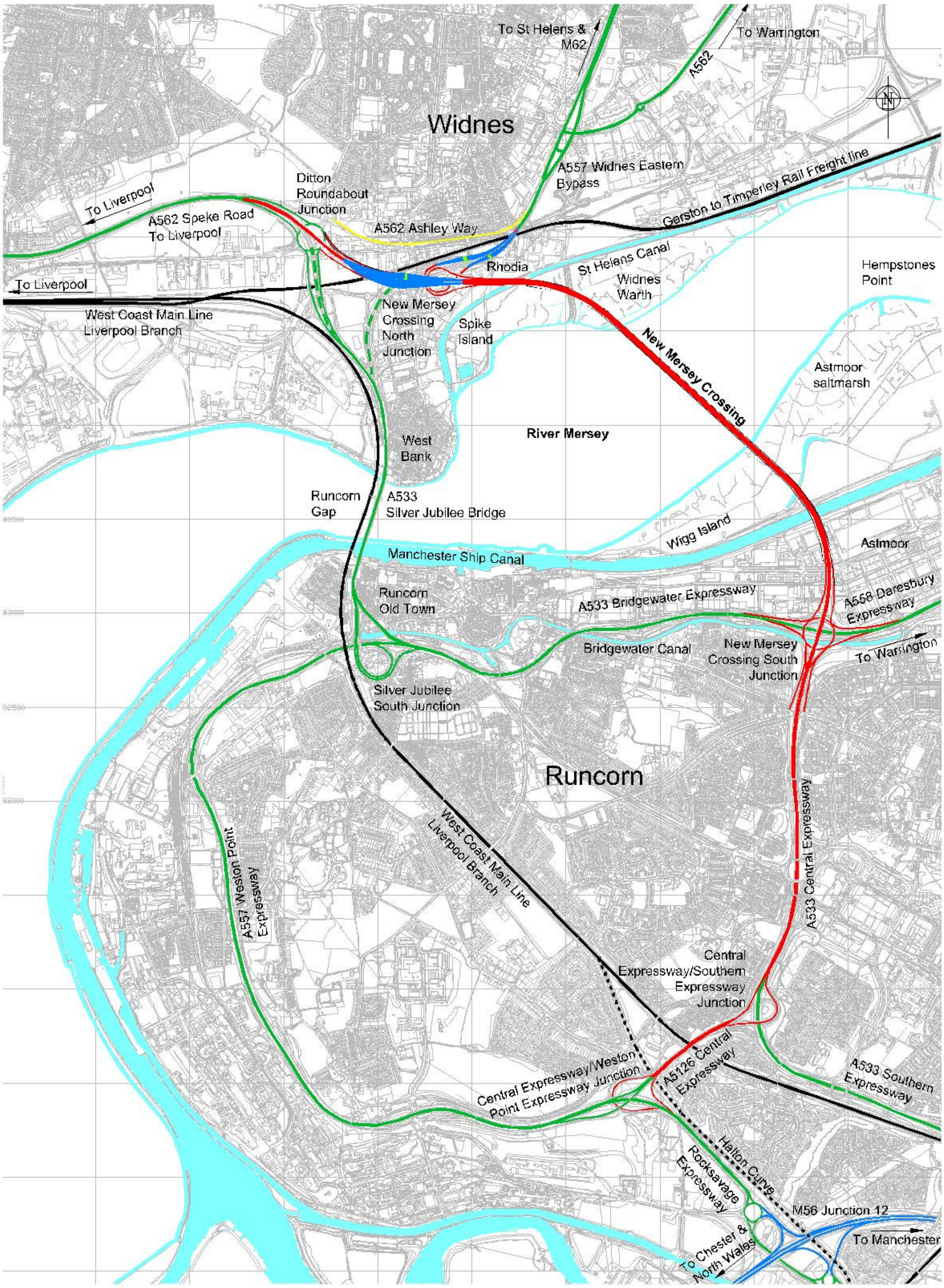

Figure 2.3. Route of New Mersey Crossing

3 EVIDENCE OF FLOWS ATTACHING TO STRUCTURES

In order to determine the likelihood of a flow attaching to a structure, an extensive review of possible mechanisms for this occurrence has been carried out. The research carried out has led to a consideration of direct case studies, the evidence of channel alignment to training structures, the mechanism of jets impinging on surfaces and the use of modelling.

3.1 Case Studies of the Impact of Bridges Built in Estuarine or Wide Fluvial Environments upon the Bed Morphology

A comprehensive literature review has been carried out and specialists have been contacted to help suggest any suitable case studies. Initially a study was undertaken to identify bridges that cross estuaries on the British coastline that could be used to draw comparison with the proposed New Mersey Crossing.

Through discussions with the contacts listed in Table 3.1 and use of maps and internet searches, three bridges which cross estuaries along the British coast have been identified. These are the Second Severn Bridge (crossing the Severn estuary), the Humber Bridge (crossing the Humber estuary), and the two bridges crossing the Runcorn gap over the Mersey Estuary.

Name	Organisation
Prof David Prandle	Proudman Oceanographic Laboratory)
Prof Robert Nicholls	University of Southampton - Head of Hydraulics Coastal and Offshore Group
Prof John Chaplain	University of Southampton - Hydraulics Coastal and Offshore Group
Dr Paul Tosswell	University of Southampton - Department of Civil and Environmental Engineering
Prof Brian O' Connor	Liverpool University - Retired, Department of Civil and Environmental Engineering
Dr Steve Millard	Liverpool University - Department of Civil and Environmental Engineering
Dr John H Loveless	University of Bristol - Senior Lecturer, Hydraulics and Coastal Engineering
Prof Alan J. Elliott,	University of Bangor - Director, Centre for Applied Oceanography
Prof Roger Falconer	Cardiff University - Civil Engineering
Prof Don Mcdowell	University of Liverpool – Ex Manchester research laboratories

Table 3.1.Contacts who have Commented on Case Studies and Probability of Low Water Channel Attachment to Piers

Each of these bridges has been considered with relation to its suitability for comparison with the situation of the proposed New Mersey Crossing and the availability of information related to low water channel attachment to piers.

The Second Severn Crossing is constructed from two viaducts on the approach to the main single channel of the estuary over which a cable stayed section is used. The viaduct approaches span a bed material which is mainly rock and the main channel is not very mobile. The Humber Bridge on the other hand is constructed on a bed material which consists mainly of cohesive sands and exhibits mobile low water channels. However the study has not yielded any research, modelling or observations since the construction of the bridges that would attribute the affect of the piers in the estuary to the “capture” or “attachment” of mobile low water channels.

The two bridges crossing the Mersey estuary at Runcorn are the closest comparable bridges to the proposed site of the New Mersey Crossing. Although they are located at a narrow neck of the river (the Runcorn Gap) in comparison to the proposed crossing which is at the widest point of the upper estuary, they do exist in the same estuary and therefore the effects they have had to date on the Mersey estuary should be carefully considered. The first major bridge built at the Runcorn gap was the Runcorn Railway Bridge which was opened in 1868 and is still open to this day. In 1905 a second bridge, the Transporter Bridge was built at the Runcorn gap and remained operational until 1961 when it was closed and replaced by the Silver Jubilee Bridge which is operational to this day.

A number of papers have been identified that discuss the dynamic morphology of the estuary from the 1800’s onwards and draw inferences as to the reasons for observed changes from environmental occurrences and man made influences that have been charted over the same period. Price and Kendrick (1963) relate that the channels in the upper2 estuary remain mobile until 1891 when “ the picture changed completely… The position since then has been relatively stable, the main low-water channel never having returned to the Cheshire side during the past 70 years”. They state that the reasons for this stabilisation of the low water channel could have been caused by a number of the following engineering works:

- The River Weaver diversion scheme, completed in 1896
- The bridge piers for the Runcorn railway bridge, completed in 1865
- The construction of the piers of the Runcorn transporter bridge, completed in about 1902
- The tipping of slag to form an embankment on the east side of the estuary (1891-1896)

Of the four possibilities covered they attribute the greatest likelihood for the stabilisation of the channels to the tipping of slag to form an embankment on the east side of the estuary and the River Weaver diversion scheme.

Cashin (1949) describes that the low water channels in the Upper estuary were observed to remain mobile between 1825 and 1880 after which the channel was confined to the Lancashire side of the estuary. However Cashin does not draw any comparisons between the changes in the bathymetry of the estuary and any factors that may have caused them. Thomas (1999) refers to the suppression of the low water channel migration and attributes this to the tipping of slag to form an embankment on the Lancashire bank of the estuary and the River Weaver diversion scheme both occurring in 1896. Van der Wal and Pye (2000) describe the reason for the “inhibited further major changes in the Upper Mersey” is the construction of a revetment between Hale Head and Widnes in 1896 (the tipping of slag mentioned in other papers).

Although Price and Kendrick (1963) comment that the stabilisation of the channel could have been caused by the bridge piers of the Railway bridge and the Transporter bridge at Runcorn they suggest that it is more likely that the cessation of mobility was caused by the

2 The papers referred to use the term “upper estuary” to describe different areas to that used in this report. Figure 2.1 is a plan of the estuary defining the region that constitutes the “upper estuary” in this study.

diversion of the River Weaver and the training of the estuary by dumping of slag on the Lancashire side in 1896. The theory of the stabilisation of the low water channels by the bridges at Runcorn is not supported by any other literature that has been reviewed however it is commonly suggested that the diversion of the River Weaver and the training of the estuary by dumping of slag on the Lancashire side in 1896 is most likely cause of the stabilisation. From this it can be inferred that the bridges at Runcorn have not been solely responsible for the loss of lateral migration of the mobile low water channels in the upper estuary and that the larger, more extensive training works have had a more profound influence.

In an attempt to identify further bridges that could be used as case studies, the search was extended to structures overseas. This has included extensive literature reviews and has drawn on the ASCE Journal of Hydraulic Engineering and the IAHR Journal of Hydraulic Research databases which extensively review scour at bridge piers across America. In addition many bridges that cross estuaries or wide fluvial systems have been considered in France, Canada and America. However there has been a great deal of difficulty identifying any information regarding changes to channels or even the thalweg as a consequence of bridge installation. Furthermore it has not been possible to identify any modelling or installation of measures that have been carried out at bridge sites to discourage the thalweg from attaching to piers.

In contrast to the lack of suitable case studies available there is a wealth of literature that identifies bed protection measures that have been used for new structures and as remedial measures at existing structures when excessive scour has occurred. However, there is no indication of how any of the possible protection measures could effect the attachment of a thalweg to them.

Further to the difficulties presented by the lack of information available for case studies from which to draw conclusions, there are additional problems that have been considered. These are mainly attributed to identifying a bridge and a location with features that are similar to those exhibited by the proposed New Mersey Crossing so that any observations made are reliably comparable. Table 3.2 below shows a list of features (which is in no way exhaustive) for the bridge and location that would need to be considered when identifying an appropriate case study.

Bridge Features	Features of the Location
Pier shape Pier size Pier alignment Pier spacing Pier location within the bed Extent of scour protection measures	General estuary shape Magnitude of fluvial channel Flood or ebb dominance of estuary Tidal Range Ratio of fluvial flow to tidal flow. Flow velocities Flow depths Presence of any other structures affecting flow patterns Mobility of thalweg Bed shear stress Cohesiveness of bed materials Local atmospheric pressure

Table 3.2.Features to be considered in the identification of an appropriate case study

An attempt to identify locations with similar features to the Mersey other than the existing crossings at Runcorn has proved difficult, let alone realising a location with a comparable structure to that of the New Mersey Crossing. A directly comparable case study has not been found. For this reason many of the contacts listed in Table 3.1 have suggested that the merits of using case studies to determine the likelihood of channel or thalweg attachment occurring are small compared to that of using a model based on the characteristics of the Mersey and the proposed bridge. This is discussed further in Section 3.4

3.2 The Effect of Training Structures on Flows

Although there has been some difficulty identifying literature for case studies of bridges built in estuaries, the research carried out has revealed literature describing morphological change in many estuaries as a result of training works. There is evidence from research carried out by Inglis, C.C and Kestner, F.J.T (1958) and Van der Wal, D. Pye, K. and Neal, A (2002) that training works constructed in the estuaries of the rivers Wyre, Lune and Ribble have led to the attachment of channels to training walls built within the bed. The Wyre, Lune and Ribble are all estuaries on the Northwest coat of England in close proximity to the Mersey estuary and have at stages in their history exhibited a highly mobile channel. Consequently they lend themselves as case study locations for comparison with the Mersey. Table 3.3 is a comparison of values for some common features of the Mersey, Wyre, Lune and Ribble.

Feature	Mersey (Upper Estuary)	Wyre	Lune	Ribble
General estuary shape	Irregular with convoluted features at the extremities	Series of five unstable reaches	Large convoluted inner estuary.	Navigation channel opening into estuary
Magnitude of channel widths	Low water channel 75m	50m at Cartford Bridge to a maximum of 700m at Skipool	-	Main channel approx 400m
Flood or ebb dominance of estuary	Ebb	Ebb	Ebb	Ebb
Mobility of thalweg	Highly Mobile at Proposed Crossing	Mobile in middle reach and stable in upper reach	Mobile in middle reach and stable in upper reach	Mobile until 1850. Since 1850 has been trained
Bed materials	Sand / Silt, Intertidal muds	Sand / Silt	Sand / Silt	Sand / Intertidal Muds
Local atmospheric pressure	Similar atmospheric pressure anticipated between each location due to close proximity to each other			

Table 3.3.Comparison of features of the Mersey, Wyre, Lune and Ribble.

Inglis, C.C and Kestner, F.J.T (1958) remark how the effect of training walls can vary widely in different estuaries with different characteristics, which supports that fact that it has been difficult to identify a case study directly comparable to the proposals for the New Mersey Crossing. From the literature studied it is evident that mobile channel attachment can occur as a result of training walls being built in the path of a meandering channel. Where a channel flow is exerted on a training wall, local scour mechanisms are likely to prevail at the toe of the wall. Furthermore, when a channel is restrained from meandering in a lateral direction by the presence of a wall, the energy which would have contributed to the development of the meander is not attenuated by the wall. As a result, the energy contributes to further erosion of the channel bed and thus the channel deepens and stabilises at the wall.

The effect of the training walls in the Wyre, Lune and Ribble estuaries has been to concentrate the ebb flow in the trained channel such that the bed outside the trained banks has been subjected to a reduced ebb flow and consequently a strengthened flood tide. This tends to promote inshore sediment movement and subsequently accretion on the bed outside the trained channel. Although immediately after construction of the training works, the channel is observed to deepen by erosion of the bed, the consequential inshore sediment movement leads to long term accretion within the trained channel. As a result, the channel in the Ribble is maintained by dredging. Van der Wal, D. Pye, K. and Neal, A (2002) relate that "recent accretion in the Navigation Channel can be explained by the cessation of dredging activities in 1980". This suggests that where a channel has been promoted by attachment to a training wall, it may consequently accrete through changes in the sediment budget (as a result of increased flood tide over the untrained bed), and finally this may lead to the thalweg detaching from the training wall especially in a region where the training works only occur on one side of the channel.

It may be that a similar process of attachment that is observed at training walls could occur at bridge piers under the correct conditions; for instance where a thalweg becomes incident to a pier due to a lateral meander and the channel is restrained by the presence of the pier. However, it is likely that for the process of attachment to occur in this way, the magnitude of the channel would itself have to be small in comparison to the pier and aligned in such a way that the thalweg could not easily divert either side of the pier. If this were not the case, the channel may be able to meander past the pier as it provides no significant restraint to the flow. It is possible therefore that the piers of a bridge could exhibit the same scour and attachment characteristics as a training wall where the size of the approaching channel is small in comparison to the length of the pier parallel to the flow.

A general arrangement of the piers in the estuary (Gifford Drg No B4027/3/B/300) shows an octagonal section with a 10m width/length that would support the cable-stayed spans of a medium span crossing. In comparison, the bathymetric profile created from a Lidar survey of the upper estuary shows that in the proposed location of the bridge, the North channel has a width of 75m at mean low water neaps and 190m at mean high water neaps and the South channel has a width of 65m at mean low water neaps, at mean high water neaps the water level floods between the north and south channels. However, the resolution of the data is quite low and the channels are constantly re-shaping, and therefore the bed profile is not particularly accurate. Nevertheless the greatest effect of the channel scour at the piers is likely to occur during the peak velocity of flood or ebb flow and this will be at the mid flood or ebb cycle when it is anticipated the channel width will be approximately 100m. This channel width is an order of 10 larger than the pier and therefore, following the conjecture above, it is more likely that the channel will meander past the pier as it provides no significant restraint to the flow.

Inglis, C.C and Kestner, F.J.T (1958) describe how a physical model of Morecambe Bay up to the tidal limit of the river Wyre was created to determine what the effect of certain stabilising structures upon the mobile channels would be. It may therefore be valuable to carry out physical or computer aided modelling to determine if a similar attachment process to that observed at training walls can be promoted at pier structures. It would also be possible to vary the size of channel and angle of incidence to the pier to promote the best conditions for attachment. However it should be considered that even though a short-term attachment of channels to training walls has been observed, this has only been maintained through regular dredging. Consequently it may be that even if a channel were initially to attach to a pier, in the longer term, the channel may accrete and thus move away from the pier. again

3.3 Research of Impinging Jets and Development of Wall Jets

Some of the academics that have been consulted have drawn comparisons of the problem of thalweg attachment to bridge piers to research where submerged flows have been observed to attach to surfaces. The observations are well researched and modelled and involve the characteristics of a submerged jet of water impinging on a plane surface. Generally the research that has been reviewed describes a submerged jet of water impinging on a surface normal to it. The result is that a wall flow, parallel to the surface propagates from the point of interaction between the jet and surface. This evidence reveals that flows impinging on a boundary surface can be observed to align with the surface, suggesting that the flow attaches to it. The flow forms wake vortices as it traverses along the surface and as the flow moves away from the point of interaction between the jet and the surface, the flow energy dissipates so that the lateral propagation of the flow diminishes. Figure 3.1 is a diagram showing the formation of a wall flow from an impinging jet and figure 3.2 is a Flow Visualisation Photograph of Jet impinging on a curved (convex) surface.

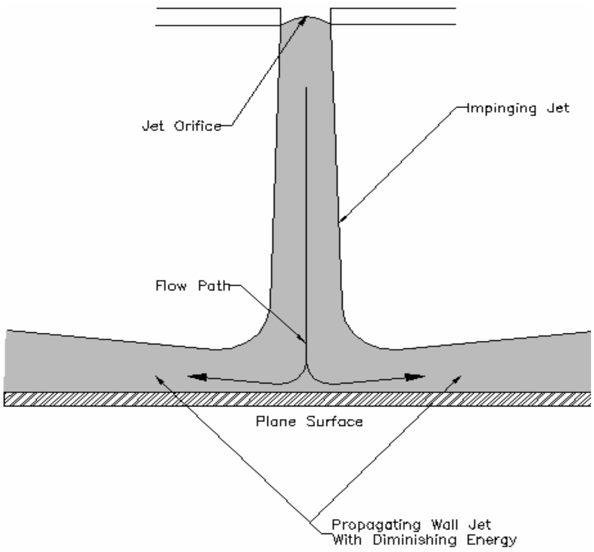

Figure 3.1. Diagram of Jet Flow Impinging on a Plane Surface

Figure 3.2. Flow Visualisation Photograph of Jet impinging on a curved surface. Adapted from Guellouz (2003)

A broad analogy could be made between the formation of a wall jet as a result of a jet impinging on a surface and a mobile channel becoming attached to a structure that it meanders towards. However, there are many factors that could affect an attachment occurring in this way. These are likely to include the relative size of the channel in comparison to the surface presented by the structure, the surface profile of the structure and the angle of incidence of the flow to the structure. The mechanism of flow/structure interaction is also likely to be affected by a range of environmental factors as described in section 3.4. The analogy could be effectively supported or disproved by simple modelling of various sizes of structures, the magnitude of flow channels and the angle of incidence of the flow similar to that described in Section 3.2, to determine whether wall flows can be achieved.

3.4 Use of Modelling

Certain specialists that have been approached regarding the possibility of mobile channel attachment to structures have suggested that modelling of a specific situation is likely to yield more conclusive results than attempting to identify case studies for comparison. This is due to both the lack of robust information identified for case studies and the particular characteristics of the Mersey estuary (discussed in section 3.1). This means that processes observed at case study locations are unlikely to be comparable to those occurring in the Mersey.

Whilst there are obvious merits of a model specific to the Mersey that could prove or disprove whether a channel flow could attach to a bridge pier, there are practical limitations to how effective a model may be. In the first instance it is difficult to determine the exact bathymetry of the estuary at any specific time taken because the bed profile is constantly changing. Furthermore it is difficult to determine how the bathymetry will change in the future which may affect the process of attachment. There are a host of environmental factors that can affect flows in both fluvial and estuarine systems such as fluvial flooding, storm surges, extreme tidal events, droughts or climate change, all of which could affect the likelihood of a mobile channel attaching to a pier. It is unlikely that a model could be comprehensive enough to account for the combined effect of alterations to each of these factors and as such the accuracy of a full model and its predictions are limited.

In light of the constraints of a full model that have been identified, it may be more effective to attempt to model the most accommodating conditions for attachment of a channel to a pier, using those constants in the model that can be reliably measured for the location of the New Mersey Crossing. This is similar to the modelling suggested in section 3.3 for determining if a wall flow can be achieved. Using this method it may be possible to determine whether the conditions required for attachment of a mobile channel to a pier structure of the form proposed by the New Mersey Crossing can be simulated. The results of this modelling would then be indicative of the likelihood of any attachment mechanism occurring. However, this modelling could not prove or disprove whether the magnitude of forces required to form the attachment or wall flow could overcome those forces causing the channel to meander, and as such the conditions required to achieve a permanent attachment of a channel in an estuary to a structure. In addition it may not be clear from the model whether a channel that forms in the vicinity of piers would eventually be silted up as has been observed for training walls described in section 3.2

4 THE CONTRIBUTION OF SCOUR TO BED MORPHOLOGY

Scour is a process whereby erodible boundary material is transported from a tidal or fluvial bed/bank via the dynamic forces of errant water currents. There are three common types of scour; “general”, “constriction” and “local”; the first of which is commonly a natural process relating to bed form and water flow characteristics while the latter two relate to the impact of imposing a structural element causing alteration to local flow patterns. When considered collectively these different modes of scour are termed “total scour”. Morphological changes that may occur in the Mersey estuary as a result of the presence of bridge piers in the bed could in part be attributed to this mechanism of total scour.

4.1 General Scour

General scour is attributed to natural processes distinct from the interaction of any structure existing on a bed, and can be effective both in the short and long terms. Short-term scour tends to be initiated by distinct events such as floods with an immediate effect on erodible boundary materials. In contrast, long-term scour can be attributed to gradual changes such as degradation and aggregation of boundary materials associated with the morphological characteristics of the channel or estuary and its boundary materials.

The process of general scour, although often unpredictable due to difficulty in forecasting discrete events that lead to short term changes, is a continually occurring process. It is therefore a baseline process distinct from the effect of a structure that may be placed in a fluvial or estuarine bed.

4.2 Constriction Scour

Constriction scour is generally caused by a local narrowing often created by the presence of one or more structures such as bridge piers or training works placed in a fluvial or marine bed. The narrowing causes an increase in flow velocity over its length and a corresponding increase in bed shear stress. The effect of the contraction on the stability of the bed can therefore be determined from the estimated flow and the nature of the bed material (its ability to resist the bed shear stress).

4.3 Local Scour

Local scour occurs at objects placed in a fluvial or marine bed where the presence of the object diverts flows incident to it. Examples of local scour are evident at structures such as piers, abutments, training works, groynes and closures or diversions. The presence of an object in a flow causes a three dimensional effect on the flow characteristics as described below:-

1. Local horizontal flow velocity is increased as the flow accelerates around the object.
2. Vertical flows develop at the upstream interface of the object: The object diverts horizontal flows at its upstream interface translating them vertically, some of which will be towards the bed (Down flow). Vertical flows towards the bed give rise to a horseshoe vortex at bed level that cause a local increase in velocity and lead to erosion of the boundary material. The horseshoe vortex creates a suction effect propagated by the low-pressure centre of the vortex that effectively draws disturbed boundary material into suspension.

3. Wake vortices form downstream of the object as a result of flow separating from the surface of the object and being carried downstream of it by the horizontal flow. The wake vortices create suction on the bed in the lee of the object and the turbulence moves mobile bed material downstream of the object.

The combined effect of these mechanisms causes erosion of boundary materials upstream of and surrounding an object. Eroded bed material is forced into suspension by the turbulent flow created by the object. Suspended sediments are transported via the general flow direction, downstream past the object until turbulence diminishes to a state where the bed material can no longer be suspended and material is deposited in the lee of the structure. Figure 4.1 is an illustration showing how a flow can contribute to local scour at a circular pier.

In the case of the New Mersey Crossing, it is likely that any scour effects observed as a result of piers being located in the estuary will be most significantly influenced by local scour. Therefore a more thorough analysis of the factors affecting local scour in these areas has been carried out (see Appendix A).

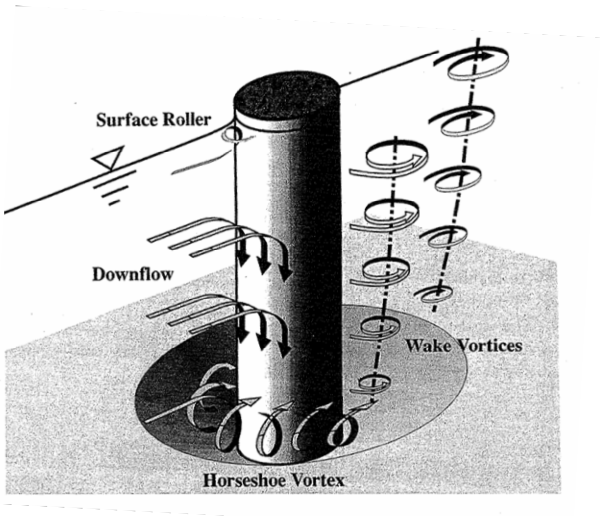

Figure 4.1. An illustration of the flow contributing to local scour at a circular pier, adapted from Melville and Coleman (2000)

4.3.1 Clear Water and Live Bed Conditions

The process of local scour can develop in both clear water and live bed conditions each of which promote an alternative development of the scour hole. In clear water conditions, general bed materials are undisturbed where the flow velocity upstream of the object does not rise above the level needed to cause bed movement. In this condition scour develops around the object where the local flows are high enough to promote bed movement. The scour hole continues to increase in size at a reducing rate until equilibrium is reached. Equilibrium occurs when the local flows at the object no longer exceed the required flow for the movement of bed materials.

In live bed conditions, flow velocities upstream of the object are great enough to lead to continual bed movement upstream of the object and a constant transport of suspended sediment in the direction of flow. Local scour prevails at the object through a similar mechanism to that of clear water scour. However there is a constant influx of suspended sediment to the scour hole from upstream of the object. The extent of local scour will continue developing around the object until an equilibrium state exists. This occurs where the quantity of sediment removed by local scour is equivalent to the quantity of suspended sediment supplied to the hole from the live bed upstream of the object.

4.3.2 Effects of Tidal Scour

The process of scour described above, in both clear water and live bed conditions requires a significant length of time for an equilibrium state to develop in the scour hole. This relies on a continuous flow being maintained for the equilibrium conditions to exist. An object in a tidal flow regime such as the proposed bridge piers of the New Mersey Crossing are not subject to a steady flow but a constantly changing flow, which reverses in direction approximately twice daily. Tidal flow magnitudes also vary between spring and neap cycles and extreme tidal events.

The effect of flows alternating in direction at approximately six-hour intervals is that it is unlikely that enough time will pass for equilibrium state local scour to develop before the tide begins to turn, especially in cohesive sediments. When the tide turns and the flow direction changes, the scour effect around the object is effectively reversed. Under the new flow direction a scour hole begins to develop on the opposite side of the object. Suspended sediment that is mobilised from the bed of the new scour hole then moves in the direction of flow and a proportion of it is deposited in the original scour hole. This process continues over the tidal cycle with alternate parts of the bed material being eroded such that the scour holes never reach an equilibrium state. Figure 4.2 shows an indicative plan of the extent of scour that is possible as a result of the dynamic tidal flows which could vary in direction.

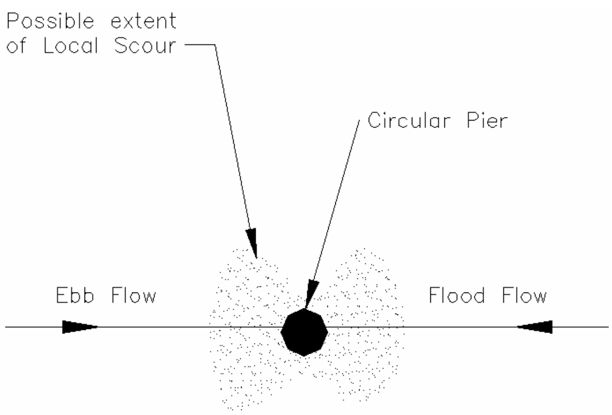

Figure 4.2. Plan showing the extent of scour that is possible as a result of the dynamic tidal flows which could vary in direction

The Morphology Report No B4027/TR03/03 describes that in the “Narrows”, which is further towards the mouth of the Mersey estuary, there tends to be a greater flood velocity than ebb velocity. It is likely that this will be reciprocated in the upper estuary (refer to Figure 2.1.) where the New Mersey Crossing will be situated; in which case higher velocities will prevail on the flood tide which will be more likely to exceed the bed shear stress at the pier structure than on the ebb tide. This could therefore lead to a deeper scour hole created by the flood than the ebb flow. In the upper estuary the ebb lasts for far longer than the flood and therefore, in contrast to the theory above, if the bed shear stress is breached at a relatively low velocity, it may be that the longer ebb flow could result in a deeper scour hole than the flood flow as it has more time to develop. It is therefore likely that depending on which flow is dominant in the development of scour, the shape of the scour hole while be asymmetric as shown in figure 4.3.

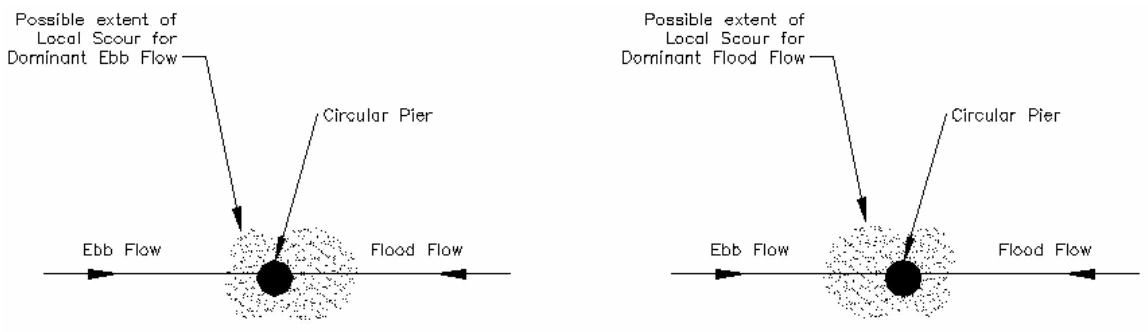

Figure 4.3. Plan of Anticipated Scour Hole for both Flood and Ebb dominant Scour

The dynamic nature of the magnitude and direction of flows in a tidal regime leads to a fluctuation of both clear water and live bed conditions throughout the flood/ebb process as flows reach the threshold required for bed movement. Subsequently, local scour in a tidal regime is likely to occur under both clear water and live bed conditions. Live bed scour will proliferate when tidal flows are at the peak of their cycle. The corresponding transport of suspended sediment to the scour hole from the live bed upstream of the object will effectively reduce the extent of local scour at the object. May, Ackers and Kirby (2002) state that “no reliably verified methods of predicting local scour in tidal conditions have yet been developed” which infers a general lack of research, analysis and understanding of this subject. This lack of well-defined understanding leads to a difficulty in accurately quantifying the effects of scour at structures in tidal conditions.

4.4 Evidence of Local Scour Interaction with Mobile Channel

In an attempt to identify any research, modelling or evidence of existing structures where it has been observed that local scour interacts with a thalweg, a thorough literature review (see list of references) and correspondence with experts in the field has been carried out. This research has not yielded any evidence to indicate how, if at all, the thalweg in estuaries can interact with local scour.

A purely conjectural analysis of a how a mobile thalweg could interact with local scour is that where a local scour hole exists from a tidal regime at a structure, a thalweg that meanders towards it would be more likely to maintain its flow within the position of the scour hole as it exhibits an easier flow path. It has been suggested that where a flow around a structure exists, there is a net increase in velocity as the flow moves past the structure. This would lead to a local low pressure environment which could attract a nearby meandering thalweg, figure 4.4 shows the stages by which this process could occur. However, in the case of a unidirectional fluvial flow channel within a bidirectional tidal waterway, this effect would only occur during the ebb tide where the fluvial flow is in the same direction as the tidal flow. Therefore the likelihood of this process leading to any permanent channel attachment is low in a tidal system.

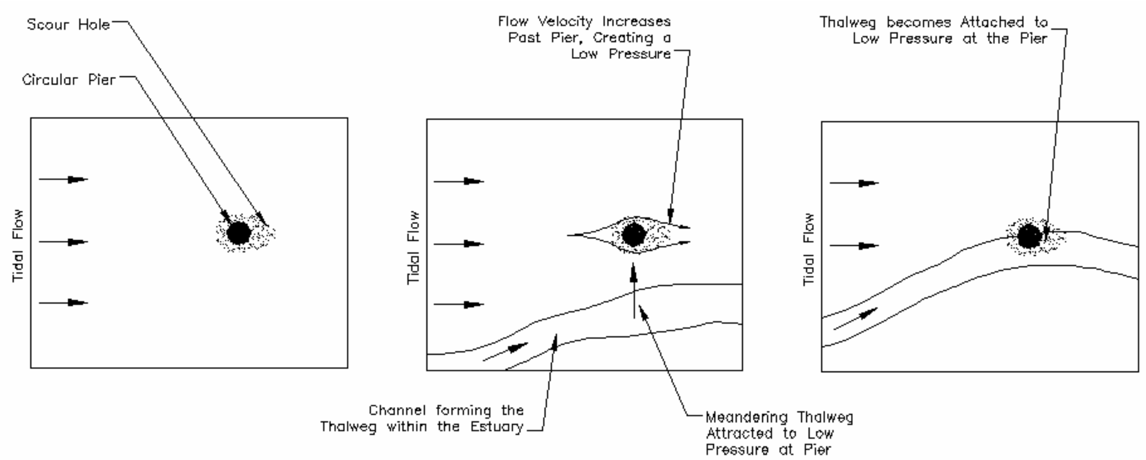

Figure 4.4. Process through which a thalweg could Attach to a Circular Pier

Indeed, many of the experts contacted have suggested that there is a possibility that a mobile thalweg could attach to a local scour hole, however the specific conditions under which this attachment would occur cannot be stated, as no evidence (that the author or those experts contacted are aware of) is available to determine this. It is likely that the major factors that could affect the attachment of a thalweg to a scour hole are those summarised in Section 4.6. Lagasse, Schall, Johnson, Richardson and Chang (1995) and May, Acker and Kirby (2002) describe the issue of a meandering thalweg as an important consideration when determining the effect of local scour. However the effect is only considered as far as making assessments of the historic bathymetry and the natural and manmade influences that have affected it, so that estimates can be made of an envelope for future thalweg migration based upon historic events. This process has been carried out within the morphology desk study report No B4027/TR03/03.

The analysis of an historical thalweg envelope would allow the structure to be placed outside the envelope of channel migration so that the thalweg is unlikely to reach the structure. Where this is not possible the structure could be designed to account for the anticipated scour that would occur if the thalweg were to migrate towards it. At no point in the literature is there any indication that if a migrating thalweg becomes incident to a structure it will attach to it or stop migrating, which suggests that there has been no significant evidence of this occurring.

4.5 Estimation of Scour Depths

Appendix 2 of the hydrodynamics report B4027/TR03/01 predicts scour depths using a range of empirical formulas and typical depths and flow velocities for a number of the proposed bridge alignments. Equation 1 defined in appendix 1 of this report is a modification of the Breusers formula used in Appendix 2 of the hydrodynamics report B4027/TR03/01. It is modified using the results of research and development carried out by a number of leading researchers on the original formula and it is anticipated that it will provide a reasonable estimate of the flow depths that can be expected at the piers of the proposed New Mersey Crossing. Therefore using equation 1, an estimate of the scour depth for both the piers of 5m width and the towers of 10m width (see Gifford Drg No. B4027/3/B/300) proposed for the medium span route 3A option will be carried out.

The measured constants required for the equation are detailed below. Values of flow velocity and depth are taken as maximum values from Figure 2 of Appendix 2 of the Hydrodynamics report B4027/TR03/01. The bed shear stress is a common value for the middle of the upper estuary taken from table C1 of appendix 2 of the hydrodynamics report B4027/TR03/01 (station R17). It is assumed that the flow is aligned with the piers and that they are octagonal in shape.

- H and G = 5 or 10m,
- y_0 = 5m,
- U =2 m/s,
- $U_{TC} = \sqrt{\dfrac{0.27}{1000}}$ = 0.0164 m/s
- S_F =1.6 (suggested value),
- ϕ_{shape} = 1.5 (Hoffmans and Verheij, 1997)
- α = 0

Therefore for 5m piers the estimated scour depth is Y_s =6.6m

and for 10m piers the estimated scour depth is Y_s =8.71m

The magnitude of the local scour depth that has been estimated for the 5m piers is supported by the fact that it is within the range of depths estimated by the various equations used in appendix 2 of the hydrodynamics report B4027/TR03/01. However, the values of scour depth are a conservative estimate indicative of a worst case scenario. In reality it is unlikely that the scour holes will ever reach the depths estimated as there will not be enough time for them to develop to its full depth before the tide turns.

Within the Mersey estuary at the proposed location of the bridge the tidal regime is ebb dominant with an approximate ebb period of 10hours and 10minutes and a flood period of 2hrs and 20minutes (taken from the Lidar survey). Threshold velocity for bed material movement is 0.0164 m/s which is very low and consequently it is anticipated that scour will occur over the majority of the tidal cycle. However it is not clear whether the period over which the scour occurs or the peak velocity will be dominant in the formation of a scour at the piers of the Mersey crossing. This effect could be determined from computer or physical modelling as discussed in Section 3.4

Figures 4.5 and 4.6 show the extent of total scour that would be anticipated at each instantaneous state of the tide for both the North and South channel. Figure 4.7 shows the Near-surface speed at the proposed location of the Route 3A Medium Span Original Alignment for baseline, extreme fluvial and extreme surge and fluvial events. The figures show how the high velocities occurring on the short flood period would cause the greatest equilibrium scour and the low velocities occurring on the long ebb tide would cause less great equilibrium scour (if enough time elapsed at a certain state of the tide for the scour hole to reach an equilibrium state).

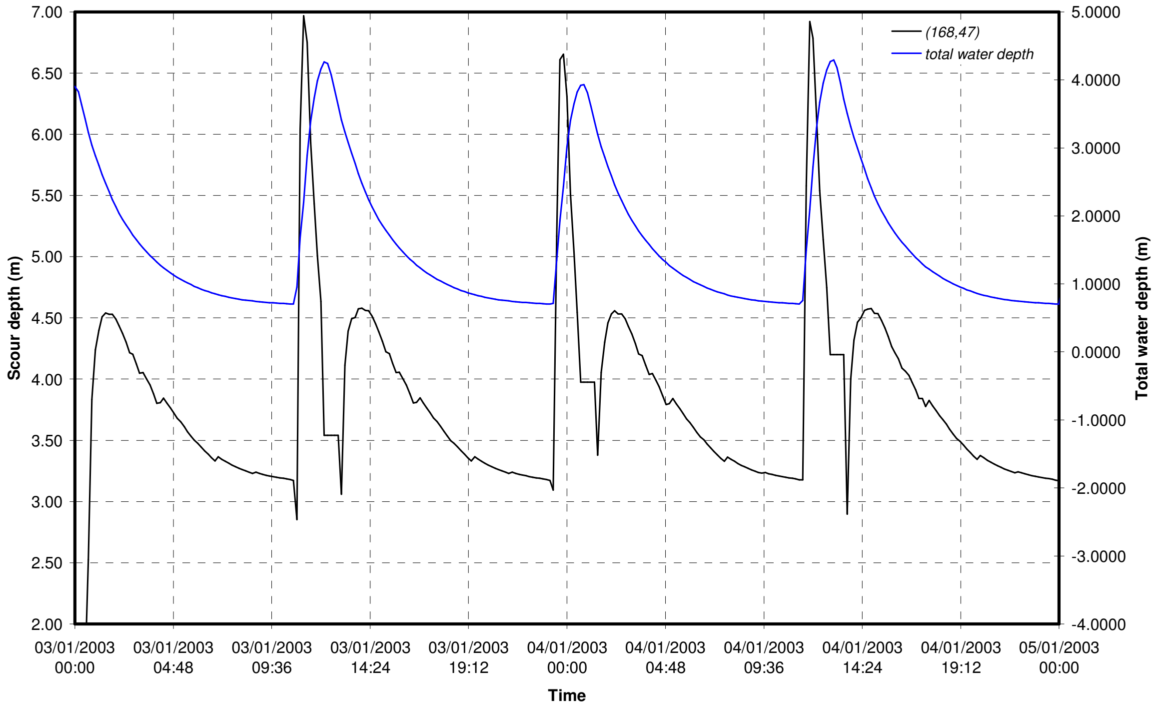

Figure 4.5. Predicted scour depth through time for piers within the South channel for Route 3A Medium Span Original Alignment. ABPmer (2004). New Mersey Crossing - Phase II Modelling Study, Oct., Report No. R.1151

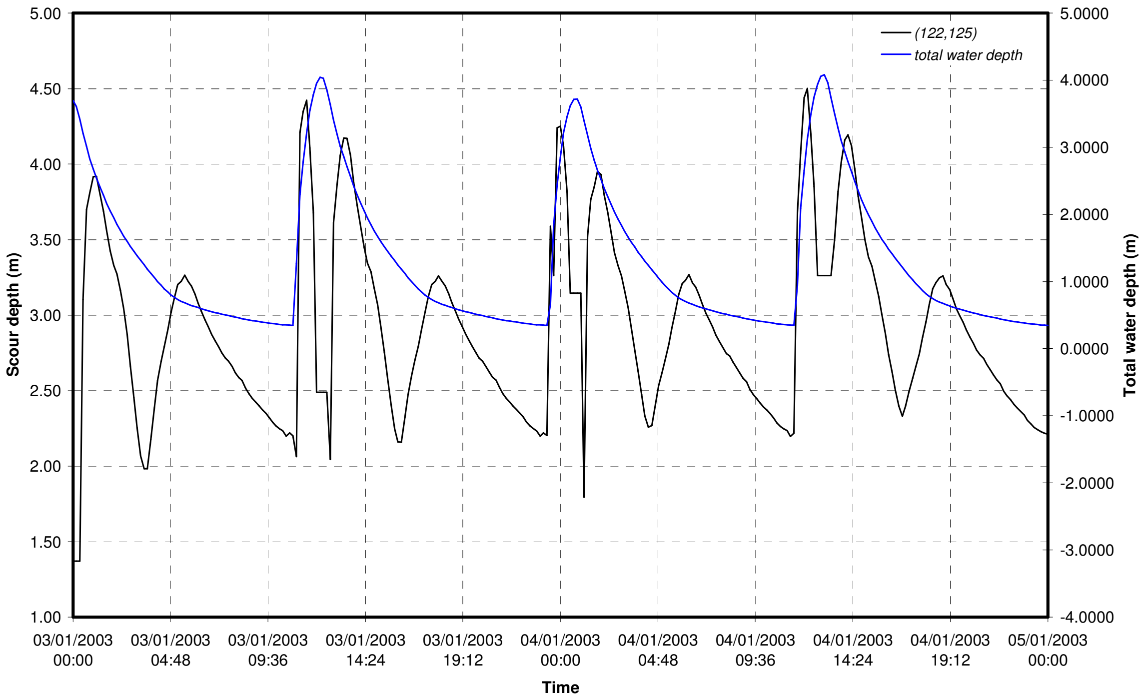

Figure 4.6. Predicted scour depth through time for piers within the North channel for Route 3A Medium Span Original Alignment. ABPmer (2004). New Mersey Crossing - Phase II Modelling Study, Oct., Report No. R.1151

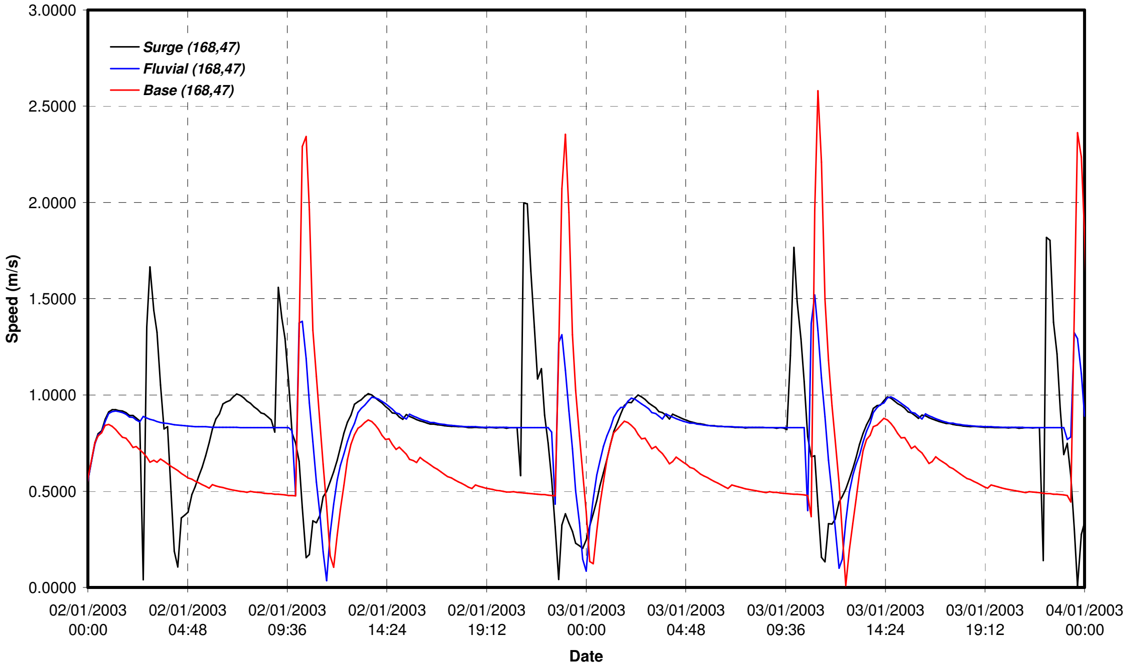

Figure 4.7. Near-surface speed at the proposed location of the Route 3A Medium Span Original Alignment for baseline, extreme fluvial and extreme surge and fluvial events. ABPmer (2004). New Mersey Crossing - Phase II Modelling Study, Oct., Report No. R.1151

May, Ackers and Kirby (2002) suggest that the key factor in predicting local scour in tidal conditions is the ratio between the tidal cycle and the time taken for the scour hole to reach half the equilibrium depth (half life) for a unidirectional flow. As the ratio increases the depth of scour occurring under tidal conditions approaches the maximum equilibrium scour value.

One of the contacts related his work on scour at a number of railway bridge piers within rivers where deep scour holes were observed at the piers under flooding conditions which, after the flood had passed, filled with loosely compacted silt under low flow conditions. This phenomenon is similar to that of the recharging of scour holes that occurs under bidirectional tidal regimes. One of the major concerns with this mode of scour is that monitoring has led engineers to believe that the extent of scour at some bridge piers is minimal due to infilling with silt whereas in fact the depth of scour has been far greater than that measured. This can result in unanticipated failure of piers where the full extent of scour has been underestimated.

The estimated local scour depths seem very excessive but it should be remembered that it is not anticipated that the depth of scour will ever reach this magnitude. However it is indicative of the fact that, in the absence of scour mitigation or protection measures, there will be a significant reduction in bed level in the vicinity of the piers where an interaction with a thalweg could occur.

4.6 Summary of Factors Pertaining to Local Scour

It is clear that there are many factors that can affect the propagation of local scour and can be attributed to the development of a scour hole. In the case of the piers of the New Mersey

Crossing, these factors, summarised below, are likely to affect the possible interaction of a mobile thalweg with the scour holes that they may become errant to:

- Tidal effects on scour – Development of the scour hole, variation between clear water and live bed conditions
- Nature of bed sediment - Cohesive or non-cohesive, particle size distribution, value of threshold velocity for bed sediment transport
- Structure shape – Effect on the extent of scour for an incident flow direction
- Depth upstream of the structure – Affecting the depth of scour
- Flow velocities around the structure - In relation to the threshold velocity for bed movement
- Angle of incidence of structure to the flow direction – considering both the tidal flow direction and direction of any fluvial channel incident the structure.

In light of the lack of evidence to describe the interaction of local scour with a meandering thalweg, it would be prudent to design piers of the New Mersey Crossing to reduce local scour. It is inevitable that the tidal flows around the piers of the New Mersey Crossing will give rise to a local scour effect that will need to be quantified so that the piers can be designed to mitigate the effect of undermining. This mitigation may be reached by creating piers that remain stable when the scour depth reaches its peak or by protection or armouring of the bed so that the structure cannot be undermined; this is described further in Section 4.7.

It is significant that the effect of tidal scour is likely to redistribute mobile bed material from a scour hole back to the scour hole during the flood and ebb cycle. Hypothetically, the effect of constant re-profiling of the bed around the scour hole via the tidal regime could make it difficult for a thalweg to become established close to the scour hole, such that it could be difficult for a channel to attach to a structure. The extent to which this effect may occur is likely to be related to the ratio of fluvial to tidal flow magnitudes, and which is most dominant in the development of scour at a structure.

4.7 Possible Measures for Mitigation and Protection from Local Scour

There are a range of methods described in the literature that has been reviewed which can be used to mitigate the effect of scour at bridge piers. In the case of the New Mersey Crossing, provision of these measures may ensure that a thalweg will not attach itself to the bridge piers. One of the common systems used is to train the flow of the thalweg using longitudinal, transverse and bed level training structures or guide banks such that the channels are restrained from meandering towards the piers and causing severe scour. Although this method is likely to reduce the severity of scour at bridge piers, it is unlikely that it would be provided for the New Mersey Crossing as it is will reduce the mobility of the thalweg, which is the characteristic that is trying to be maintained within the upper estuary.

Another common system for scour mitigation is to create deflectors upstream of bridge piers (this would be on both sides of the piers of the New Mersey Crossing due to the bi-directional tidal flow) such that the major forces of the flow which would contribute to scour at the piers would be dissipated. This is generally carried out by providing sacrificial piles or vanes (vertical angled plates) in advance of the pier. Provision of these types of mitigation measures should be carefully considered with reference to any hazards presented to local shipping movements.

Many of the factors which can affect the development of scour are natural coefficients that cannot be adjusted for a specific location, such as tidal effects, nature of bed sediment, flow depth, flow velocity and angle of incidence of flows to the structure. However, the extent of scour caused by local flow characteristics could be partly mitigated by carefully placing and designing a structure so that the contribution of each of these factors to scour is minimal.

The shape of the structure and its alignment with the flow direction significantly affects the extent of scour. In the case of a tide dominant estuary like the Mersey, the significant flow direction will be caused by bi-directional tidal flows. However, it is likely that the direction of these flows could alter according to changing bed morphology within the estuary. This would lead to a less well defined scour hole that would proliferate over a greater area as the structure is affected by flows from various directions as described in Section 4.3. It is also difficult to predict the exact flow angle of a mobile fluvial channel or thalweg that could become incident to the piers and consequently design the pier to account for this. Therefore in the case of the New Mersey Crossing, it may be most effective to provide a pier that is relatively uniform in shape (for instance a cylinder) that would lead to a uniform depth of scour if subjected to a range of flow directions.

There are a vast range of scour protection measures available which generally act to protect the vulnerable bed in the vicinity of a bridge pier by locally improving the critical shear stress of the bed. These include providing concrete aprons around the pier, flexible or rigid mattresses (constructed from concrete blocks, gabions or grout filled bags) laid on a geo-textile, or Rip Rap (loose quarry stone) laid around the base of the pier. Another method of protection is to stabilise the bed using biotechnical solutions such as promoting vegetation growth around the pier, laying mattresses of woven vegetation or reinforcing the bed using geo-textiles. It is suggested that during the design of the piers, the anticipated scour depths should be considered along with the maximum flow rates and bed properties so possible scour mitigation or protection measures can be sought. During the design, the options considered should be carefully selected as it is conceivable that measures intended to reduce scour could lead to a greater possibility of thalweg attachment. Therefore it is proposed that any scour protection measures considered during the design are either modelled physically or by computer so that this potential problem can be resolved.

5 CONCLUSIONS AND RECOMMENDATIONS

The research that has been carried out has identified a range of evidence relevant to the theory of thalweg attachment to bridge piers. A great deal of literature has been reviewed that describes the scour effect occurring at bridge piers when they are subject to a flow. However, none of this research has revealed how the inevitable scour caused by a diurnal tidal flow may interact with a mobile thalweg that could meander towards it.

The research carried out has not identified any case studies other than that of the Runcorn Bridges of the Mersey estuary that are directly comparable to the situation proposed by the New Mersey Crossing. This is mainly due to:

- A distinct lack of information available that describes changing bathymetry as a result of bridges being constructed in estuaries.
- The processes occurring in the Mersey being very site specific and as a result comparable case studies are extremely hard to identify.

This fact is supported by many of the specialists that have been contacted such that they have suggested modelling the situation is likely to give more conclusive and reliable results than case studies.

There is significant evidence that experiments involving submerged jets in an artificial environment, impinging upon a surface can result in the propagation of a jet along the interface with the wall, emerging from the point of interaction. It has been suggested that this process could be comparable to the interaction of a thalweg with a bridge pier however it would be necessary to carry out modelling to determine whether this conjecture holds true.

The process of thalweg attachment to training structures in estuaries on the Northwest coast has been identified. Research has revealed that :

- Although attachment to training structures can be observed shortly after the training works are constructed, a well defined attached channel is often only maintained in the long term by regular dredging.
- This suggests that under natural conditions the channel may not remain attached.
- It is not clear whether the process of attachment observed at training walls is likely to occur at bridge pier structures, although it has been conjectured that this may be unlikely because, for the majority of the tidal cycle, the channels are far wider than the bridge piers.

It has been suggested that modelling could be carried out to clarify this, taking into account alternative ratios of the size of channel to the size of pier and the angle of incidence of the pier to the flow.

Based upon the study carried out, a conjecture has been formed to suggest processes by which “attachment” could occur as follows:

- The thalweg could be attracted to the low pressure created at the piers when water flows past them.

However there are a number of reasons why this theory may not hold true because:

- This process could only occur during the ebb flow and therefore it is unlikely to contribute significantly to any attachment mechanism.
- In a tidal situation such as the Mersey, the extent of local scour created by tidal flow is unlikely to maintain its depth and may dissociate a thalweg.
- The scour hole created by an ebb flow could be effectively re-nourished by the sediment carried in the flooding flow and vice versa.

In light of the lack of evidence to determine whether local scour can contribute to channel attachment, it is suggested that:

- The piers be designed with careful consideration of the pier shape and alignment, and also possible scour mitigation or protection measures.
- The design should ensure that the extent of local scour will be minimal for a range of incident flow directions possible if a thalweg meanders close to the pier.
- Any scour mitigation or protection measures be modelled prior to construction to ensure they could not unduly promote thalweg attachment.
- It is prudent to determine the historic path that a meandering thalweg has followed and may follow in the future, so that bridge piers can be positioned outside their anticipated path or designed to account for them. This has been covered in the Morphology Desk Study Report no B4027/TR03/03

The use of modelling has been suggested to convincingly support or disprove many of the conjectures that have been made and so that it would be possible to determine the probability of the conditions required for attachment, occurring within the design life of the bridge.

In conclusion, no significant evidence has been identified that could reliably prove or disprove whether the thalweg of the Mersey estuary will become attached to the piers of the New Mersey Crossing. A number of conjectures have been made to define a process under which attachment could occur and it is recommended that modelling should be carried out to determine whether these conjectures can be proved.

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APPENDIX A

SCOUR ANALYSIS

APPENDIX A - SCOUR ANALYSIS

A1 - Sediment Characteristics

Disregarding the size and shape of an object placed in a fluvial or marine bed, the key factor determining the local scour depth is the flow velocity at which bed movement occurs (the Threshold Velocity - U_{TC} (m/s)). For non cohesive sediments with uniform particle size, the equilibrium local scour depth is at a maximum when the ratio $U/U_{TC} = 1$(where U (m/s) is the depth averaged velocity upstream of the structure), this is the limit of clear water scour. Where $U/U_{TC} > 1$, live bed conditions exist and the scour hole is re-nourished by suspended sediments from upstream of the object. For non uniform, non-cohesive sediments the value of U_{TC} is taken for the mean particle size d_{50} because the various particle sizes will have a different threshold velocity. In this case the peak equilibrium local scour depth is not reached at $U/U_{TC} = 1$ and local scour depth tends to increase generally with increase in flow velocity.

In contrast to the theory above, estuarine sediments that consist of a range of silts, sands and mud's, tend to be cohesive where electrochemical forces and biological slimes attract particles to each other. In this case it is the critical shear stress of the bed τ_C (N/m^2), which must be reached before the bed becomes mobile. The attractive forces present in cohesive sediments mean that a greater flow velocity than non-cohesive sediments of similar particle size are required to initiate bed movement.

Although cohesive sediments reach their threshold for bed movement through a different process than that of non-cohesive sediment, once the threshold is reached, local scour proceeds in a similar fashion for both cohesive and non-cohesive sediments. May, Ackers and Kirby (2002), conclude that "the main difference between cohesive and an equivalent non-cohesive material is that the time needed for the cohesive material to reach its equilibrium scour depth is likely to be longer".

A2 - Factors Effecting Local Scour and Estimation of Scour Depths

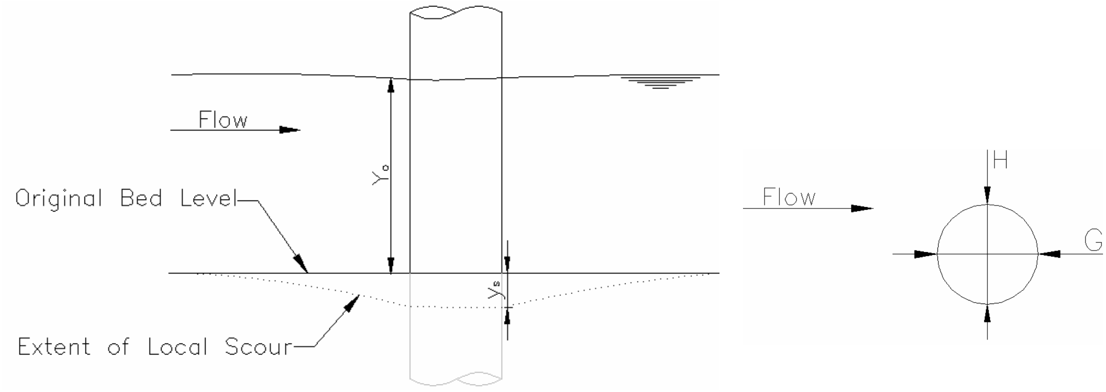
There are a host of factors that can affect the development of local scour at objects or structures subjected to a flow. May, Ackers and Kirby (2002) provide a local scour equation for bridge piers in a uni-directional (non tidal) flow based on a combination of results from leading researchers. The dimensionless ratio, equation 1 gives a conservative estimate of scour depths for prototype structures which although is not directly applicable to the development of scour in a tidal regime, exhibit the majority of factors that will contribute towards scour.

$$\frac{Y_s}{H} = S_F \cdot \phi_{shape} \cdot \phi_{depth} \cdot \phi_{velocity} \cdot \phi_{angle}$$

Equation 1 (May, Ackers and Kirby 2002)

Y_s (m) represents the equilibrium depth of scour measured below the bed level upstream of a structure and is primarily effected by H (m), the horizontal width of the structure -

measured normal to its longitudinal axis. The scour depth ratio $\frac{Y_s}{H}$ is related to the other factors in the equation as described below and shown in figure A.1.



Elevation Plan

Figure A.1 Plan and Profile of Circular Pier Showing Factors Required for Equation 1

- S_F is a factor of safety which can be applied to take into account unforeseen modes of scour development or flow characteristics. These values can be selected from those recommended, based on research by Johnson (1992). However a value of 1.6 corresponds to the maximum depths observed in laboratory studies.

- ϕ_{shape} is a value based on the effect of the shape of the structure on the extent of local scour. Values for ϕ_{shape} can be taken from research by Hoffmans and Verheij (1997) of the scour depth achieved in deep water when $U/U_{TC} > 1$ and the longitudinal axis of structure is in line with the flow. Effectively structures with better flow dynamics result in less scour propagation than those with poor flow dynamics.

Note: $U_{TC} = \sqrt{\frac{\tau c}{\rho}}$ where τc is the bed shear stress (Nm^{-2}) and ρ is the density of water Kg/m^3

- ϕ_{depth} is a value based on the effect of the relative water depth on the depth of local scour, which can be calculated from equations 2 a and 2 b by May and Willoughby (1990)

$\phi_{depth} = 0.55\left(\frac{y_0}{H}\right)^{0.60}$, for $y_0/H \le 2.7$ **Equation 2 a (May and Willoughby (1990)**

$\phi_{depth} = 1.0$, for $y_0/H > 2.7$ **Equation 2 b (May and Willoughby (1990)**

y_0 (m), defines the local water depth upstream of the structure, accounting for natural and local scour.
Effectively the scour depth around large structures is significantly reduced where the ratio y_0/H is small, i.e. where a large structure is placed in a shallow bed.

- $\phi_{velocity}$ is a factor quantifying the effect of the flow velocity on the scour depth which can be determined from the equations 3 a, b and c given in May, Ackers and Kirby (2002). The equations effectively show that the extent of scour increases with increasing velocity, up to the threshold $U/U_{TC} = 1$.

$\phi_{velocity} = 0$, for $U/U_{TC} \leq 0.375$ **Equation 3a**

$\phi_{velocity} = 1.6\left(\frac{U}{U_{TC}}\right) - 0.6$, for $0.375 \leq U/U_{TC} \leq 1.0$ **Equation 3b**

$\phi_{velocity} = 1.0$, for $U/U_{TC} > 1.0$ **Equation 3c**

(May, Ackers and Kirby 2002)

- ϕ_{angle} Is a factor which quantifies the effect of the alignment of the structure on the extent of scour which can be calculated from equation 4:-

$$\phi_{angle} = \left[\cos\alpha + \left(\frac{G}{H}\right)\sin\alpha\right]^{0.62}$$

Equation 4 (Frohelich 1988)

Where G(m) is the longitudinal length of the structure, H(m) is the horizontal width of the structure (perpendicular to G) and α is the angle of incidence between the flow direction and the longitudinal axis. In essence the equation represents an increased contribution to local scour for greater angles of incidence.

APPENDIX B

LIST OF TECHNICAL REPORTS

Appendix B
List of Technical Reports

Technical Report Number	Revision	Report Title	Principal Author	Current Status
B4027/TR01/01		The Aquatic Ecology of Intertidal and Subtidal Habitats	APEM	Issued July 2003
B4027/TR02/01	A	Terrestrial Ecology + Birds	ERAP	Issued August 2003
B4027/TR03/01	A	Hydrodynamics	Gifford	Issued October 2004
B4027/TR03/02	A	Addendum to Hydrodynamics	Gifford	Issued October 2004
B4027/TR03/03		Hydrodynamics Morphology Report	Gifford	Issued October 2004
B4027/TR03/04		Hydrodynamics Case Study Report	Gifford	To be issued October 2004
B4027/TR03/05		Hydrodynamics – Fine Model	Gifford	To be issued October 2004
B4027/TR04/01		Contamination of Soil, Sediments and Groundwater	Gifford	Issued July 2003
B4027/TR05/01		Surface Water Quality	Gifford	Issued July 2003
B4027/TR06/01		Air Quality + Climate	Gifford	Issued July 2003
B4027/TR06/02		Air Quality + Climate	Casella	To be issued November 2004
B4027/TR07/01		Landscape + Visual Amenity	Bertram Hyde	Issued July 2003
B4027/TR08/01		Cultural Heritage	Gifford	Issued July 2003
B4027/TR09/01		Transport Impact Assessment	Gifford	Issued July 2003
B4027/TR09/02		Transport Impact Assessment	Gifford	To be issued November 2004
B4027/TR10/01		Navigation Impacts	Gifford	Issued July 2003
B4027/TR11/01		Noise Impacts	Casella	Issued July 2003
B4027/TR11/02		Noise Impacts	Casella	Issued July 2003
B4027/TR12/01		Social Impacts	Gifford	Issued July 2003
B4027/TR12/02		Social Assessment of Tolling	Gifford	To be issued November 2004
B4027/TR13/01		Economic Impacts	Amion	Issued July 2003
B4027/TR13/02		Economic Impacts of Preferred Route	Amion	To be issued November 2004
B4027/TR14		*Health Impact Assessment*	-	*Health Impact Assessment will be incorporated in Social Impact Report in 2005*
B4027/TR15/01		Geotechnical Interpretative Report	Gifford	Final Draft issued in July 2003 – Final to be issued November 2004
B4027/TR16/01		Consultations	Gifford	Issued July 2003
B4027/TR16/02		Consultations	Gifford	To be issued November 2004
B4027/TR17/01		Cost Report	Gifford	Issued July 2003
B4027/TR17/02		Cost + Risk Assessment Report – Preferred Route	Gifford	To be issued November 2004
B4027/TR18/01		Construction Methods	Gifford	Issued July 2003
B4027/TR18/02		Construction Methods – Preferred Route	Gifford	To be issued December 2004

Technical Report Number	Revision	Report Title	Principal Author	Current Status
B4027/TR19/01		Design Standards	Gifford	Issued July 2003
B4027/TR19/01		Design Standards – Preferred Route	Gifford	To be issued November 2004
B4027/TR20/01		Funding Options	Gifford	Issued July 2003
B4027/TR21/01		Traffic Survey	Gifford	Issued July 2003
B4027/TR21/02		Traffic Survey	Gifford	To be issued November 2004
B4027/TR22/01		Model Validation	Gifford	Issued July 2003
B4027/TR22/02		Model Validation	Gifford	To be issued November 2004
B4027/TR23/01		Traffic Forecasting	Gifford	Issued July 2003
B4027/TR23/02		Traffic Forecasting	Gifford	To be issued November 2004
B4027/TR24/01		Induced Traffic	Gifford	Issued July 2003
B4027/TR24/02		Induced Traffic	Gifford	To be issued November 2004
B4027/TR25/01		Transport Economic Efficiency	Gifford	Issued July 2003
B4027/TR25/02		Transport Economic Efficiency	Gifford	To be issued November 2004
B4027/TR26/01		Accidents	Gifford	Issued July 2003
B4027/TR26/02		Accidents	Gifford	To be issued November 2004
B4027/TR27/01		Description of Alternatives	Gifford	To be issued November 2004