

Transport Crossings of Canals

by

J E Saunders CEng, FICE

W S Atkins, Consulting Engineers

Updated March 2017 by

Tony Ford BSc, CEng, MICE

Roy Sutton BA, MSc, CEng, MICE(Ret.)

BACKGROUND

Highway/Canal Crossings

1. Early highway crossings over canals often used the humpback bridge to a greater or lesser degree. When the "right of navigation" was removed, these bridges were often removed and the highway was "dropped" to improve vertical alignment and sight lines. If land drainage was important then a culvert or pipe beneath the road was included. Elsewhere "Moveable Bridges" have been permanently fixed in position.
2. Subsequently, in many cases two other factors have arisen:
 - The infilling of urban and/or industrial development alongside the highway which can create access problems if the highway is now raised to present day alignments to pass over the canal.
 - The use of the highway to route and carry public services, which in themselves will require diversion.

Railway/Canal Crossings

3. Railway crossings of canals were generally constructed during the railway development period of the mid 1800s whilst canals were still in use with rights of navigation. Crossings over canals were therefore engineered to give navigable clearance. When the right of navigation ceased, the structures were often removed, in part or in whole and continuous railway embankment was established with, where necessary, a through land drainage pipe.
4. Generally, the headroom for a navigable opening remained, although infilled and without the bridging structure.

All Canal Crossings

5. Where road or railway passed beneath a canal then an aqueduct to carry the canal was required. However again if the right of navigation had been cancelled then the canal could be stopped up and the aqueduct or embankment removed subject to adequate land drainage arrangements.
6. This background explains how the current day situation facing the canal restoration movement has arisen. Almost no problems are the same. Each case must be evaluated against a list of required criteria. A solution must be developed which satisfies the engineering requirements and design criteria of road, railway and canal. The environmental needs of the situation must be considered. The solution must also be cost effective. The following list and discussion of the required criteria and options give an appreciation of the possibilities.

CURRENT CRITERIA FOR RESTORATION OF CANALS

(which should be checked with the waterway owner and/or transport authority before detailed design)

Waterway Requirements at Crossings:

7. Limiting dimensions of many waterways are in the Canal and River Trust's 'Dimension Data' (<https://canalrivertrust.org.uk/notices>). These provide a template for design of similar or linked waterways under restoration.

8. Dimensions to be aspired for are given in the IWA's policy 'Standards for Construction, Restoration and Maintenance of Inland Waterways'

(https://www.waterways.org.uk/information/policy_documents/standards_for_construction) and the IWA's 'Towpaths Policy' (https://www.waterways.org.uk/information/policy_documents/towpaths_policy).

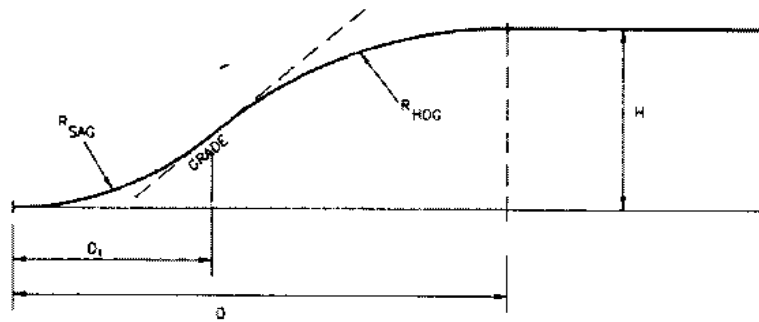
Additional, complementary, dimensions are:

- Minimum straight navigable width at bridge narrows 3m (narrow) and 5.5m (broad)
- Minimum towpath headroom 2.2m
- Minimum freeboard 0.3m

Highway Requirements at Crossings:

9. The minimum clearance for an aqueduct or bridge over a highway is defined in Highways England's 'Design Manual for Roads and Bridges' (DMRB) Vol 6, Section 1, Part 2, TD27/05, Table 6.1 as 6.45metres (for High Load Routes), 5.7 metres (standard), or 5.3 metres if the structure is designed to withstand impact loadings.

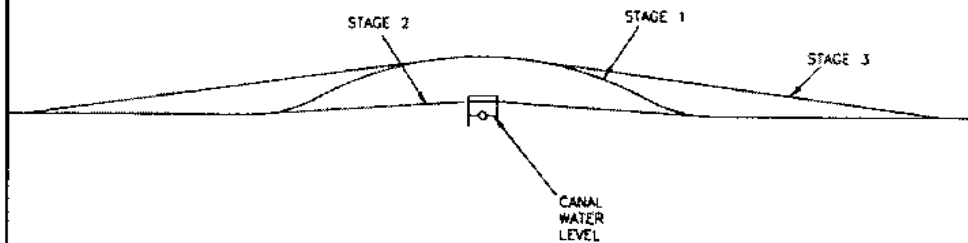
10. Highway geometry (eg to clear a canal structure) is currently calculated using DMRB Vol 6, Section 1, Part 1, TD9/93 "Highway Link Design". TD9/93 gives a complete definition of the process of calculating the road geometry, starting with the calculation of design speed, then the calculation of sight distances which are then applied to design horizontal and vertical alignments. Vertical alignments are based on design radii for vertical curves (sag and hog) that lead to a final design vertical alignment that is a combination of uniform gradients and parabolae. Horizontal alignments are based on straights, circular curves and clothoids (spirals applied at entry to curves). The calculations are complex and advice should be sought if in any doubt. Sketch No.1 (below) gives an interpretation of the requirements for highway design speeds of 30 and 60 mph. This covers restricted and derestricted roads up to and including trunk road class. Motorways are not included since the lengths and widths etc. of carriageways that would have to be raised become so great that cost together with traffic delay costs renders this method of overcoming the problem uneconomic.



DESIGN SPEED M.P.H.	H METRES	R SAG METRES	R HOG METRES	D ₁ METRES	GRADE %	D METRES
60	1	2600	10000	32.76	1.3	158.75
60	2	2600	10000	46.53	1.8	224.50
30	1	1300	1700	33.57	2.6	77.46
30	2	1300	1700	47.47	3.7	109.55

SKETCH No. 1

NOT TO SCALE



STAGE 1: ORIGINAL HUMP BACK BRIDGE ALIGNMENT

STAGE 2: CANAL BRIDGE REMOVED, HIGHWAY DROPPED,
CANAL PIPED THROUGH

STAGE 3: CANAL BRIDGE REINSTATED, HIGHWAY RE-ALIGNED
TO PRESENT DAY STANDARDS

11. Highway loadings (standard and abnormal) for non-arch bridge design used to be defined in three relatively simple and publicly accessible documents 'BD37/01', 'BD21/01' and 'BD86/01' in the 'Design Manual for Roads and Bridges'. Unfortunately, these have now been withdrawn and replaced by a series of 'EuroCodes' intended to standardise highway loadings (to provide a level playing field for bridge designers across Europe). However, since each country can impose its own 'National Annexes' this has resulted in each country's design loading differing markedly from those of others. So, the intention has not been met. The EuroCodes are available at great expense from the British Standards Institution. All the following codes (which cross-reference each other) are required to derive traffic loadings on a UK bridge...
 - EN1990
 - EN1990-1
 - UK NA to EN1990
 - EN1991-2
 - UK NA to EN1991-2

In practice the complexity of the formulae imposed by the EuroCodes requires that they be applied using a computer bridge design package that includes a 'load optimisation' module.
12. Engineers faced with a very simple design requirement could consider using the superseded DMRB documents since the UK National Annexes are derived to recreate within the EuroCode the same loadings as the documents they replaced. [See "Background to the UK National Annexes to EN1990: Basis of Structural Design - Annex A2: Application for Bridges and EN1991-2: Traffic Loads on Bridges" by WS Atkins]
13. For arch bridges the MEXE (Military Experiment Establishment) Method is still applied for assessment (though it is crude by comparison to computer programs such as 'Ring' and 'Archie'). It is described in 'BA16/97' in the 'Design Manual for Roads and Bridges'.

Railway Requirements at Crossings:

14. Railway criteria will be required for these cases. However, the development from inception of a scheme, through design to construction will normally be carried out by Network Rail. However, it is possible for a "third party" (such as a canal restoration trust) to propose the design concept and to then work with Network Rail's "Scheme Development Manager" to refine and develop the concept through to detailed design and approvals. The third party can undertake all the design, with Network Rail employing their own consultant to check and verify the design and the construction proposals.
15. Due to the different nature of rail traffic i.e. fixed track, there is less flexibility for traffic movement during construction. Possible alternative rail routes etc. are more limited and essentially greater emphasis is placed upon methods which maintain rail traffic upon the existing track during construction of the crossing.

NB Nearly all Railway Traffic Loadings are now included in the same 'EuroCodes' that are described above for Road Traffic Loadings.

PERMISSIONS AND AUTHORISATIONS

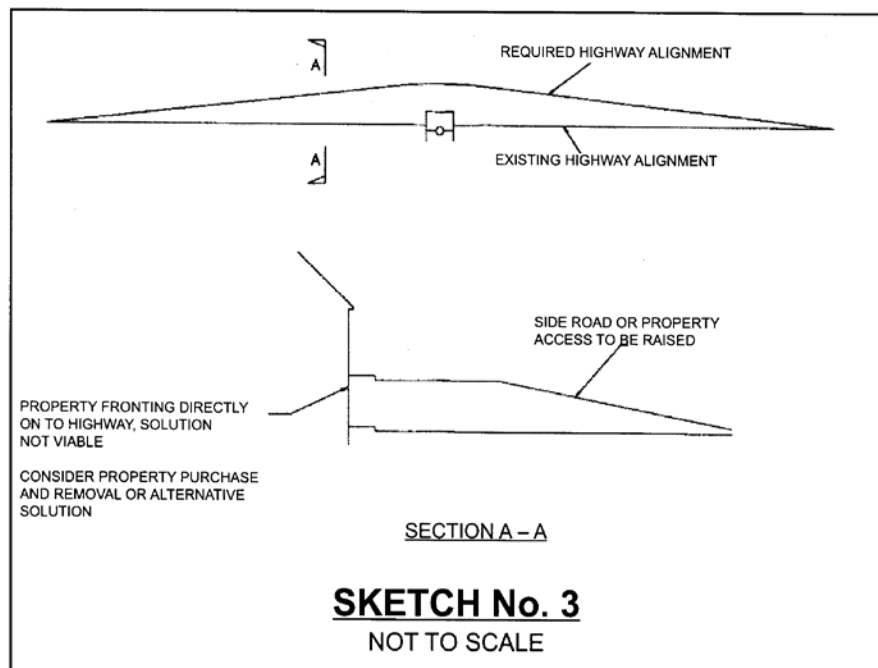
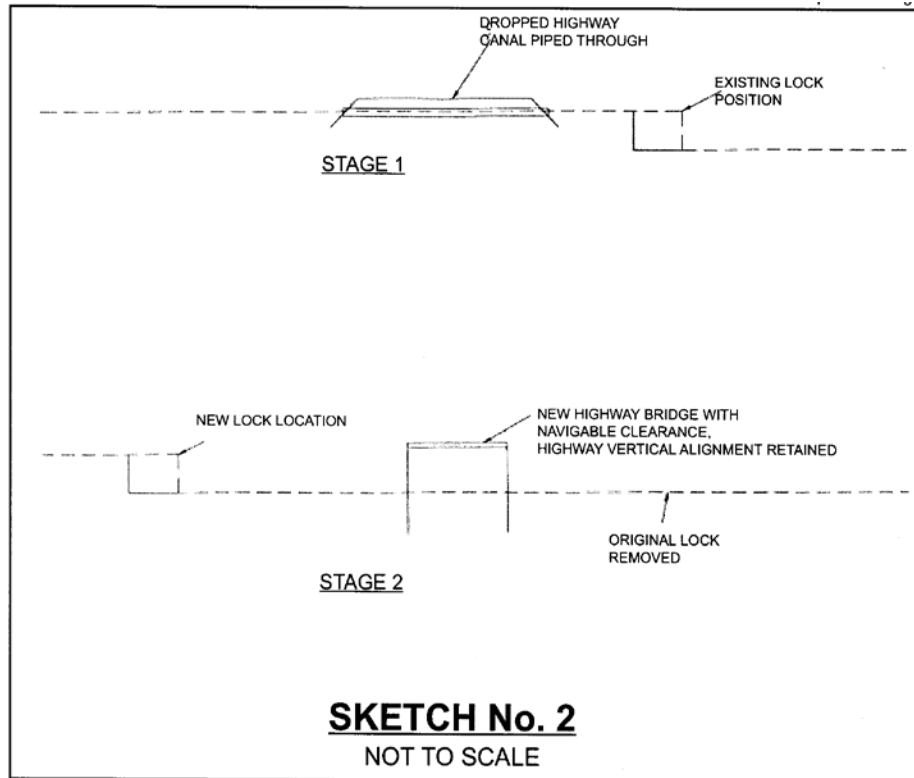
16. Several permissions and authorisations will be needed:
- Landowner permission for the proposed permanent structure (i.e. land boundaries, etc.)
 - Agreement from the Highway Authority or Network Rail on who will be responsible for ownership and maintenance of the structure
 - Technical approval from the Highway Authority or Network Rail to the design and the proposed construction method
 - Planning permission from the Local Authority
17. Note that whilst Network Rail have “permitted development rights” to undertake sometimes quite major engineering works on the railway, these works must be for “rail operational reasons”. A third-party project such as to facilitate canal restoration would not qualify for permitted development.

POSSIBLE SOLUTIONS

18. These are the main problems and the required criteria for alteration that confront those wishing to restore a canal at a highway or rail crossing. The possible options available, where the relative levels clash in terms of providing highway, rail or canal clearance for traffic or navigation are broadly:
1. Raise the road or railway.
 2. Lower the canal.
 3. A combination of 1 and 2.
 4. Create a moveable crossing (e.g. lift or swing bridge)
 5. Realign horizontally road, railway and canal.
 6. Raise the canal.
 7. Drop the pound.
19. The Restoration Engineer, defined as any person or persons concerned with the methods of restoring a canal, must consider a broader range of options when seeking a solution. For example, option 5 (a realignment in plan) might assist in conjunction with any of the options, 1 to 4.

Options 1 and 2

20. Levels normally need to be altered by 2 to 3 metres depending upon the existing relative levels.
21. Lowering the canal can be the simplest option. This is however very dependent upon the position of the locks in relation to the crossing. If a lock is present or planned on the downstream side of the crossing, this could be transferred to the upstream side and in most cases this simple operation will give the added height to achieve a navigable clearance at the road / railway, see Sketch No. 2. The average lock changes the canal water level by 2 to 3 metres to provide the headroom required. The costs involved would be those of lowering a length of canal, building a new lock and removing an existing one and providing a bridge structure.



22. Against this the cost of raising a road will still involve providing a bridge structure in addition to raising the road to give the required vertical sight lines. Distances vary with highway speed classification. Also, properties or side roads fronting on to the raised road will require to be ramped up to meet the new level often in a very short distance, see Sketch No. 3. The public services will also have to be raised to cross the new bridge structure.
23. The planned raised highway may aggravate traffic noise levels and create undesirable sight lines, difficulties with access to adjacent properties, all leading to the creation of undesirable

impact on the infrastructure and environment. This could lead to refusal of planning permission regardless of the cost relative to that of lowering the canal. Obviously the lowering of the canal is likely to be the cheapest option, if the length of canal involved can be kept to a minimum. It is also likely to be the most acceptable change to the infrastructure and environment.

24. Two other factors however will concern the canal Restoration Engineer:

- Lowering a canal for a very long length can adversely affect the benefits. Cruising without being able to see the surroundings is not popular and is regarded as a dis-benefit.
- Ground water conditions could make drained maintenance of the lowered canal difficult. A situation could be created where the upwards water pressure exceeds the weight of the liner and protection. Site investigation, piezometer readings over a long period together with knowledge of the surface deposits geology will be essential where this is suspected. These problems can arise with any form of artificial lining, i.e. high density polyethylene (HDPE) or puddle clay).

Option 3

25. Examination of the location may show that the best and most economical solution is a combination of items 1 and 2 above. No two situations giving rise to canal blockage are identical. The Restoration Engineer must be prepared to consider each as a one-off problem to be solved from the range of options available.

Option 4

26. This involves virtually accepting the vertical alignment of road and canal at their point of crossing. This will then require the provision of a moveable bridge: in place to carry the highway traffic, open to allow the passage of boats. There are many examples of these bridges in the UK. Most of them have been in position for many years. Nowadays it is increasingly difficult to obtain agreement from highway authorities for the establishment of new crossings by this means.

27. On any trafficked highway the moveable bridge carries with it delays to highway traffic and the need for a safe queuing distance for the stationary traffic. The bridge solution, if accepted would certainly be electrically operated, using the boater's key. This is a one-stage operation comprising closing of the highway barriers, warning lights and the operation of the bridge itself. Note: the boater does not get his key back until he has closed the bridge after use.

28. Boat passage will take between 5 and 10 minutes for a single boat and with ever increasing traffic densities on our highways it is not difficult to understand why the authorities shy away from this solution. It is however a viable option for little used roads and there is always the possibility of electronically preventing the opening of the bridge during morning and evening peak traffic flow times. They can also be viewed as traffic calming measures.

29. At locations of minimal highway use or farm accesses the hand operated moveable bridge is still in use but this is increasingly at a disadvantage as the size and weight of farm vehicles and machinery increases and becomes more sophisticated. It also must be acknowledged that the moveable bridge attracts a higher maintenance cost due to its moving parts and is more open to vandalism. The bridge deck pulled off its closure wedges, makes an excellent structure to bounce up and down on, to the detriment of bearings and alignments.

30. There are two basic types for these bridges:

- The lift bridge usually involves an overhead framework on to which is mounted a counter-balanced beam which allows the bridge deck to be raised and lowered either electrically or by hand through the medium of a small hydraulic pump. The hydraulic ram type, that

pushes the bridge deck up from below, involves a large structure for a major highway and is seldom seen due to cost and complexity.

- The swing bridge has the cantilevered section of bridge deck mounted on a pintle and bearing ring and this moves through 90 degrees from closed to fully open. Again, this can be operated, depending upon size, either electrically or by hand using a hydraulic pump or motor.

31. Moveable crossings require sufficient land and/or water channel to be available to mount the moveable deck and counterweight and to allow the opened bridge deck to be clear of the navigable channel. The span of these bridges can be limited to 3 metres for a narrow boat canal and 5 metres for a broad boat canal. The width of bridge deck would normally be a minimum of 6 metres; a 7.3 metre carriageway plus 2 metre footways is possible but this would need more room to swing.

Option 5

32. In addition to options 1, 2 and 3 any or all of them may be used to obtain a solution in conjunction with moving the crossing point horizontally. It is entirely dependent upon the local conditions and contours at any specified obstruction.

Option 6

33. Where the old Ashby Canal crossed beneath Measham High Street the preferred route for restoration has the canal diverted in plan along a redundant Railway embankment to cross the High Street at a different location, where the road is at a much lower level, with an aqueduct over the road.

34. The new aqueduct carrying the restored route of the Lichfield and Hatherton canal over the M6 Toll is another example of a canal being raised to provide clearance. Both examples demonstrate the need for the Restoration Engineer to keep an open mind when examining every situation.

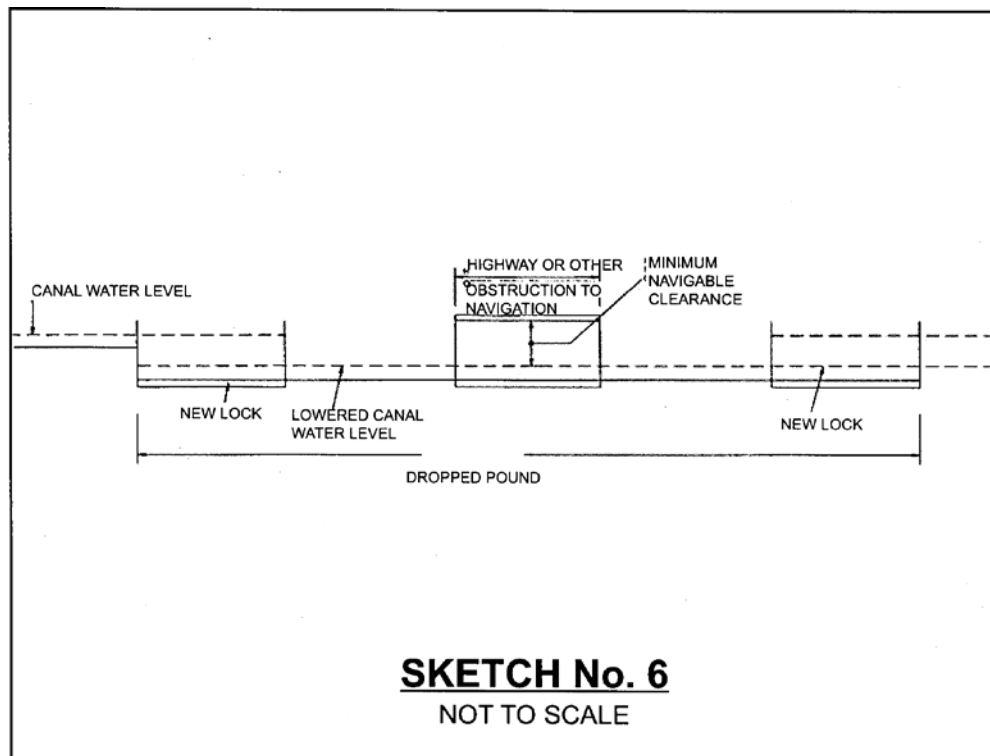
Option 7

35. The solution of a "Dropped Pound" has been proposed at various locations on many occasions. It is easy to see why. At a difficult crossing the canal can be dropped locally by the introduction of a lock, the lowered pound passes beneath the obstruction (usually a highway) and disruption to the canal is minimised by locking up again having cleared the obstruction, see Sketch No. 6.

36. This option requires deep consideration of its operation if it is to be made safe for the canal user, boater or towpath walkers. Even if the lockage water can be controlled by pumping, consider the result of either a lock-gate failure or misuse of operating paddles being left open through a lock. The situation could arise whereby a boat is jammed under a bridge by the sudden rise in water level. Even with an overflow weir to a discharge, a gate failure in a short, lowered pound could give rise to a surge that could be a safety hazard. Obviously, safety is a question of degree dependent upon the length of the proposed low pound, the overflow discharge, surrounding land levels and interlocked safety devices, etc.

37. A further factor is that pumping down the lowered pound is likely to be slow and expensive (unless in a location where there is a large water supply and a drainage sump).

38. The only present example of a drop-lock is at Dalmuir on the Forth & Clyde Canal.



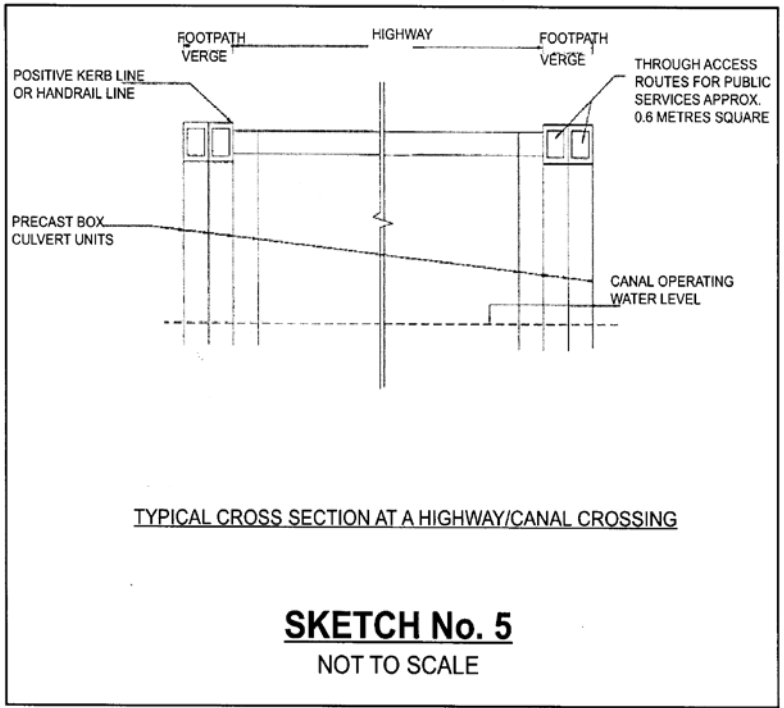
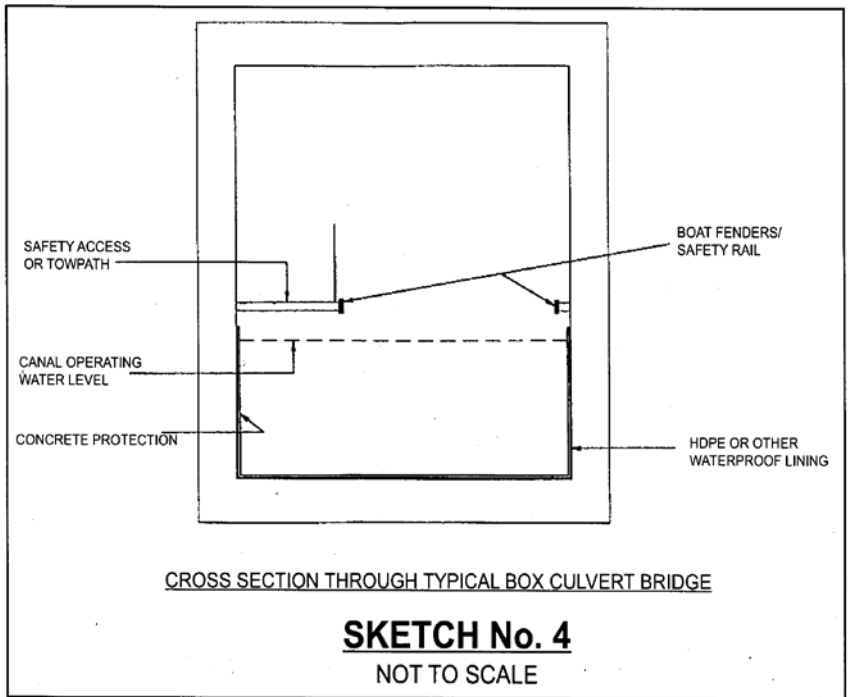
CONSTRUCTION METHODS

Methods of Creating a Bridge Opening Under a Highway for a Canal

39. Consider now the forming of the actual opening for navigation beneath the road. The vertical and horizontal alignments have been decided in terms of options 1 or 2, or 1 and 2, or 5 as discussed above. At this stage a decision on the type and form of structure to form the opening is required. Consideration is required of how to achieve its construction whilst maintaining or diverting traffic on the highway and how the public services are to be re-aligned and maintained.
40. In almost every case, at this stage, the Restoration Engineer must present proposals and liaise with various authorities to agree a scheme and method "in principle". This will enable a feasible scheme and a budget cost of works to be developed. As and when the full design and construction of these crossing structures proceeds, the works will be the responsibility of the appropriate authority. Generally, this will be the highway authority (County Council) which may do the work "in house" or sub-let to a Consulting Engineer. In the case of public services, the appropriate local area office for the service will be responsible for detailed planning and execution of any alteration works to their service.
41. It should be borne in mind that predominantly these structures are formed at locations where space is at a premium, traffic flows must be maintained and public services have to be temporarily suspended or diverted whilst structure construction is carried out. So, work should be completed as quickly as possible.
42. We require a rectangular opening having the minimum internal dimensions defined in 'Canal requirements for crossings' (above).
43. With these thoughts in mind an option often selected is a box culvert, which is economical and fast to build. The culvert is typically made up of one metre long, pre-cast box sections. The largest box culvert normally manufactured and transportable by road is 3.6m high by 6.0m wide (giving 2.4m headroom, 1.2m draught, 4.8m channel and 1.2m towpath). A wider

towpath (for a multi-user trail) could be provided with a separate box culvert. Many Highway Authorities view the pre-cast box section culvert with disfavor despite its advantage of speed of construction. Their reluctance stems from doubts that the joints between the box sections will remain watertight. It is worth remembering that a watertight HDPE lining can be carried through the pre-cast box culvert with the addition of concrete protection from boats, see Sketch No. 4.

44. Another possibility is the corrugated 'Armco' steel culvert type. This elliptical form however is not the ideal shape as it requires a higher clearance to achieve the minimum gauge at the shoulders. It has minimum required fill material thickness over the crown and therefore requires a greater height between water surface and road or rail surface than an in-situ or box culvert. This is also true (though to a lesser extent) of the 'Macrete' pre-fabricated 'FlexiArch'.
45. Most new road crossings over canals are of concrete construction. This generally comprises (i) bored-pile or pad foundations, (ii) in-situ abutments and flank walls and (iii) either precast beam or in-situ decks. Almost without exception they are designed by specialist consultant engineers.
46. Looking at methods of construction, the first method to be examined for maintaining the use of the highway for traffic during construction should be creating a road diversion around the works location. If the verge and/or footpath is of sufficient width this could be used for road traffic whilst the bridge/culvert is constructed. Once completed the traffic is placed on the now completed section whilst the remainder is constructed. One-way traffic working under traffic light controls may be necessary.
47. If there is insufficient width or property prevents the foregoing approach then another alternative would be to use temporary bridging (of the Bailey bridging or Mabey quick bridging type) to bridge the culvert location whilst construction is carried out. A temporary 24-hour road closure at a weekend would be sufficient to establish such a bridge and the approach ramps. Single way or double working is possible by these methods.
48. If there is sufficient headroom beneath the highway, then 'thrust-bore' methods could be used. The criteria for these are described below under "Crossing a Motorway".
49. Public Services. Generally, on highway crossings, the re-routed public services can be accommodated in special duct sections of the box culverts at the verges or footways. In addition to the depth/thickness of the roof slab there is an increased section due to the kerb and footpath at these locations, see Sketch No. 5. This, coupled with the lighter loading at the footpath, creates generous duct facilities for services.
50. The exception will be the foul sewers. These depend upon falls to outlet and they cannot be randomly raised. They must if necessary be stepped down at the canal and then re-laid to join in at a lower level preventing the chance of a back-fall. If the authority will permit a dual track siphon (i.e. dual pipe beneath the canal in a stepped down section to allow alternate use for maintenance and cleaning) then this may present a possible solution.



Methods of Crossing a Motorway

51. The crossing of a motorway presents problems of a different scale, due to traffic densities and speeds and the re-chargeable cost to the developer (i.e. those restoring the canal) of traffic delay costs. The authority for these is Highways England who may sublet to their agent Consulting Engineer. Obviously, the aim in an ideal world should be to phase the culvert construction with the periodic carriageway reconstruction/maintenance. This would perhaps allow the traffic delay costs to be mitigated by sharing with motorway maintenance.
52. Where the structure roof is at a minimum of 3 metres or more below the highway construction and the embankment is constructed of suitable materials compacted to 90-95% of optimum then it is likely that the structure can be achieved by thrust bore methods using strengthened one metre long pre-cast concrete box culvert sections. This work using modern tunneling methods need not impose restrictions on the traffic movements. Where cover to road construction is less than 3 metres it would be essential to close traffic lanes, bringing into use the hard shoulders and narrowed traffic lanes to maintain the traffic capacity with the least possible delay time.
53. A solution for structures with less than 3m cover is to close or divert one or two traffic lanes at a time. Then, in the available working width drive two rows of long 'secant' bored-piles (to form combined abutments and deep foundations). Then cast a concrete slab between them (to form a roof). Then replace the traffic lanes and move on to repeat the operation at an adjacent location. When the secant piles and roof cross the full width of the highway then the material beneath the roof can be excavated to form the required opening. This was done where the restored Droitwich Canal passes under the A449.

Crossing a Railway

54. The approach to achieving a structure crossing beneath rail tracks is different by the nature of the type of traffic, i.e. trains restricted to rail tracks. The safety aspects are of paramount importance due to high speeds and the greater number of passengers at any one time passing a works location. The authority will be Network Rail who will establish with the Restoration Engineer the basic requirements and they will then design and cost the scheme from feasibility to completion.
55. Usually Network Rail would wish to drive two narrow openings through the embankment in positions which will allow them to form the final abutments of the required bridge opening. This can be done by a series of small cross-section box thrust bores. With suitable bracing at track level by steel joists carrying the tracks during the work, this phase need have no effect upon rail traffic, or at worst a local speed restriction.
56. With the required abutments completed a whole section of deck complete with rails to span the gap between the abutments is constructed to one side. On completion and with a suitable track possession, the existing section of track between the abutments is removed and the new pre-fabricated section of bridge deck and track is moved into place. The excavation to complete the bridge opening can then be completed.
57. An alternative approach is to construct the whole bridge as a large box culvert on temporary foundations to one side of the railway embankment. A suitable "blockade" of the line is arranged, during which the whole embankment is excavated and the box culvert lifted or slid into position with the lines then reinstated on top. Clearly, this method of construction, whilst economic in certain circumstances, is a very specialist operation. The salient point here is to recognise that there may be more than one feasible solution and whilst the Network Rail personnel may prefer for one option it may pay to be persistent in ensuring that other options are not dismissed out of hand.

HOW TO START

58. How should the Restoration Engineer find solutions to these problems? The initial requirement is to gather as much information of the existing situation and proposed requirements as is available. A suggested list of essential information might be:
1. The existing pound levels and lock positions on the canal.
 2. Condition of canal. Infilled, silted up, overgrown, is it lined?
 3. Obstruction at crossing. In the usual case of a Highway: class of road, footways, traffic flow information including traffic speeds, longitudinal section with existing situation, type and levels of properties off the highway.
 4. Existing bridge at crossing. Span, headroom levels, foundation condition and level.
 5. Public services. Which services cross the location, size type and levels.
 6. Establish the criteria required for the canal and the highway.
 7. Environmental constraints such as local wildlife reserves.
 8. Likely noise and disturbance issues.
 9. Possible pollution and site remediation issues.
 10. Obtain ordnance survey mapping to cover the location: 1 to 25000 with contours for location: 1 to 10000, or larger scale, with contours to work from.
 11. Visit site to inspect location and photograph. Discuss with client and highway authority etc their preferred option solution.
59. Most of the information should be available from the Local Authority, the Highway Authority, the public services bodies, the Canal Trust/Society, Network Rail, The Canal & River Trust, The Environment Agency, adjacent landowners, the county wildlife trust, museum archivists, local historians, etc. Any gaps must be filled by inspections, possible survey and photography.
60. It is only at the completion of this exercise can the Restoration Engineer sit down and work up one or more schemes at outline feasibility level, for general agreement with all the parties involved. Subsequently these must be developed in greater detail for contract and construction. Early in this development is the need for trial pits and boreholes with associated tri-axial tests for physical properties and chemical tests for pollutants.