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Docklands Light Railway and subsequent upgrading: general contract, design principles, and design and construction of bridges and viaducts

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Authors' Introduction

The Papers describe both the design and construction of the main elements of the Docklands Light Railway. The fundamental requirement of the upgrading contract was for the system to be able to carry longer and heavier trains (double or triple units) to accommodate an eight-fold increase in the passenger flow predictions for the initial railway, arising from the substantial increase in the investment and development plans for the area.

2. Now that the Docklands Light Railway has been operating for about four years, and given the considerable scope of upgrading works, extension of the railway to Beckton and proposed extensions south of the Thames to Greenwich and Lewisham, the very modest nature of the provision forming the original 1984 'design and construct' contract to which these new works are being attached should not be forgotten.

3. The performance specification for the original system stipulated a maximum one-directional passenger flow of 1500 passengers per hour at peak travelling time, with a total system-wide boarding of 4800 passengers in a one hour morning peak. In addition, the design of the system had to be such as not to preclude subsequent expansion of capacity, after construction of a Beckton extension, to a further 80% above the contracted level.

4. The latest passenger usage figures show that this capacity has already been significantly exceeded and that the original modest railway provision is already bursting at the seams.

5. The upgrading works were designed to enable construction to proceed with minimal disruption to the operation of the railway. At Canary Wharf, where Olympia & York's new retail and office complex accounts for a large portion of the increase in passenger numbers, the new station structure was designed to be supported on piles which could be installed only in areas beyond the extent of the initial railway viaduct. The central portion of the station was then effectively cantilevered from the outer pile caps. A new resilient track support system was also developed at Canary Wharf, consisting of concrete 'mini-slabs', each 1·5 m long and placed on soft rubber bearings to reduce noise and vibration in the adjacent retail areas.

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E. F. Humphries, *G. Maunsell & Partners*

The change in contractual arrangements caused heartache to contractors and also to the consultants. Kennedy & Konkin, Henderson & Busby, Maunsells, the Architects and many others were shocked to hear that, after working desperately to deliver documents and drawings to the project office of London Underground on Good Friday evening in 1984, to be ready to go out to tender on the following Tuesday, nothing happened for six weeks because of political decisions and then it went out as a turnkey contract. Henderson & Busby were commissioned by the London Underground project office to do a study on the junction; the delta junction was chosen from a number of alternatives.

7. London Underground also commissioned from both Maunsells and Henderson & Busby a detailed study of all possible track combinations throughout the length of the job, using existing track where possible, ballasted track and plinth track. They would have preferred to have had ballasted track throughout because of its being quieter. It was decided that ballasted track would be used on all existing viaducts, but on new structures plinth track would be developed and used with concrete guard plinths on the inside of the rails.

8. When the project was put into the hands of the contractor, the latter could not possibly do all the design work in a few weeks, and it was inevitable that the structures as built were substantially as the original concept drawings.

9. I understand that an order for a new computerized control system costing £2–3 million has been placed. The existing system has worked for three years or so and, apart from some breakdowns and teething troubles, has worked well. Why is a new system to be installed and will it be installed on top of the existing one?

C. J. Hancock, *Mowlem Civil Engineering*

I have worked on this project through all the tendering phases and through construction. The total responsibility rested with one contractor—for the supply of the vehicles, the electrical distribution, the signalling and all the civil engineering and structural work. It gave the employer one focal point for his attentions: the project manager for the joint venture. This gave a quick and clean decision-making process at minimum cost. The fees and the costs involved post-tender in the construction phase show that there were considerable cost savings.

11. As designers and constructors, my firm was able to take on the responsibility for clause 12 of the *ICE Conditions of Contract* and similar contract conditions because it was in command of the situation, and there were some contingency moneys within the contract. We were well experienced as a contractor in this area in Docklands from previous work over many decades, and we were therefore able to take on the particular risk involved. When there was a problem, the design team had full authority on the site and was able to make the decisions and proceed. The links with our consultants and their team and their liaison people on site were short, and problems were resolved quickly.

A. J. Powderham, *Mott MacDonald*

We need to make a stronger connection between design and construction, and this project presents excellent examples of how this may be achieved.

13. Two technical points: how was the load sharing, potential differential settlement and durability assessed for the old and new foundations; and why was on-site bending of the pile reinforcement adopted instead of using threaded couplers (including those appropriate for connecting ready-bent bars)?

R. N. Sainsbury, *Mowlem Civil Engineering*
What was the response time of the load transfer device and what are the dynamics of it? What is the difference between a quick load and a slow load? If a train does a long braking manoeuvre, does that constitute a quick load or does the device begin to freeze?

Dr M. S. Atkinson, *Soil Mechanics*
The point has been raised that clause 12 of the *ICE Conditions of Contract* was absent from the contract conditions. I note from the Papers that much of the piling was subcontracted. Bearing in mind that if piling is late it can be crucial to the rest of the works, how was the aspect of possible obstruction within the piling covered?

S. J. Matthews, *Frank Graham Consulting Engineers Ltd*
Could the Authors please describe how quality assurance in design was carried through to site? Although 'design and construct' contracts have significant overall advantages, conflict of interest can occur occasionally between theoretical requirements and construction practicalities. Were there any particular difficulties with this?

D. J. Sharpe, *Docklands Light Railway Ltd.*
Apart from the technical content of these Papers, the important aspects are: organization; co-operation; innovation. The project organization was established by a joint venture management, with a project strategy developed from clear objectives. Co-operation depends on well-defined and good relationships between people, and the DLR work which was constructed by the Joint Venture, with its various consultants, demonstrates the success of this. Innovation was necessary in view of the fixed price and fast track nature of the contract; this required and received application and considerable ingenuity.

18. Meeting the programme was a remarkable achievement: for example, the viaduct construction was completed in less than 18 months. The cost of all the works was remarkably low: this initial automatic railway system cost about £77 million, including all land and management costs. The aim of the contract was to provide 'a minimum viable railway'.

19. The DLR acted as a catalyst for the regeneration of Docklands. Even before the railway was opened for public service, it was recognized that there was a need for a massive expansion in passenger capacity to respond to the undoubted high demand in a fast-changing environment. Hence there has been the need to upgrade and expand the capacity.

20. The conditions of contract did not include clause 12 of the *ICE Conditions of Contract*. Furthermore, the contract eliminated the use of the word 'reasonable'. No guarantee was given by the employer in respect of the feasibility of the conceptual designs. The management team is therefore to be congratulated for overcoming any intrinsic objection or financial nervousness.

21. The quality assurance with its systematic methodology and application of a quality plan was impressive. The early preparation of a design manual must have been of enormous assistance in creating fluid communication and co-operation between groups and individuals.

22. The manner of treating service diversions, particularly the brave step of adjusting span arrangements, was a challenge to the modern penchant for strict standardization.

23. The initial rail was basically a greenfield site, using some existing BR infrastructure but with no constraints on electrical and mechanical installation. Upgrading of the DLR under the second contract has had to be approached differently by the joint venture and the DLR, insofar as the DLR has an obligation to maintain a passenger service during a period of considerable change and potential interference from added construction and modification, while catering for an ever-increasing passenger demand. The implementation of civil engineering and building works in an operating railway scenario has been achieved. However, the implementation of major additions and changes to the electrical equipment has not been without problems, and not as successful, in the DLR's experience, as devoted proponents of design and construct contracts claim they can be.

24. New design concepts involved the following: water-repellent silane impregnation of concrete decks; separately supported falsework for concrete slabs to ensure full composite action with steel girders; controlled heating of reinforcement to allow site bending, with the use of temperature indicators; glass-reinforced polyester sheeting for soffit protection of pile caps; 'cotton reels' for fabricated junctions; special prestressed concrete cross-heads; spiral pins for shear connections; and shock transmission units for impact loads.

25. The innovation shows management's task to keep within a fixed price and rigid programme, which necessitated close co-operation between the designer and the constructor. An integrated design process was used to allow fast-track construction with positive ideas throughout, as well as, as Pilgrim and Pritchard write, 'close harmony'.

C. F. Bonnett, *London Transport International*

About midway through the contract period, I was appointed managing director of the newly formed Docklands Light Railway Ltd, which was the subsidiary company set up by London Regional Transport to oversee the completion of the works and to bring the railway into operation for public service in the early autumn of 1987. The railway was completed within budget and on time, as set down by the Government.

27. As is often the case with transportation projects, more time was spent in the early political debate before a decision in principle was reached than in the period of actual design, construction and commissioning. Both the Docklands Development Corporation and LRT were convinced that there must be a transport centrepiece to the Docklands if they were to be redeveloped and revitalized. Early studies in the 1970s recommended the extension of the Jubilee Line into Docklands, but at that stage there seemed little likelihood that the considerable expenditure involved could be found from the public sector, and so low-cost alternatives had to be considered. After years of investigation and public debate, the Government agreed in late 1982 that LRT should proceed with a light railway.

28. Originally, it was LRT's intention that separate contracts would be placed for civil engineering works and for mechanical and electrical equipment and systems, and consultants were appointed in the various disciplines. The client appointed Nichols Associates as project management consultants to co-ordinate and control the work.

29. Invitations for the mechanical and electrical works, including the systems, were issued in January 1984, with the intention of seeking the civils tenders in April of the same year. However, during March, the Secretary of State for Transport indicated a strong preference for the adoption of a single turnkey contract for

the whole initial railway project. At first, there was considerable apprehension, both within the project team and also expressed by several of the contractors who had been preselected, relating to the fundamental change that this would bring about. This approach had never before been adopted in the UK for a complex railway project. In fact, it proved to be most successful, although it might not always be desirable or applicable. In the subsequent contracts on DLR extensions there has been considerable modification to the original concept.

30. This particular contract had the following key elements: first, there was a single package for design and construction, for equipping and commissioning of the entire railway; second, it was to be completed within a fixed period for an agreed lump sum; third, there was to be a performance specification defining broad functional and performance requirements; fourth, as far as was feasible, all the risks were going to be passed on to the contractor; fifth, stage payments were to be made by achieving 'milestones' without remeasurement of quantities or valuations; sixth, the employer had very restricted powers of intervention; seventh, no engineer was appointed by the client because most of the former's responsibilities were passed on to the contractor; eighth, the contractor was responsible for the independent checking of both the design and the completed works.

31. The initial railway was opened in less than five years from the time that the Government gave the go-ahead, and only three years after the turnkey contract was placed. In taking a turnkey approach, it is essential that adequate time and resources are made available to ensure that the client establishes his real needs for the project and then translates them into the tender documentation. In particular, it is vital that the performance specification truly reflects the essential needs of the project without unduly limiting the contractor and thus losing much of the benefit of the turnkey approach. A serious change of mind on the part of the client during the contract stage can at best be expensive and at worst be disastrous.

32. In this case, the extremely short time-scale and the requirement to keep within budget for the initial railway were achieved only because of the turnkey approach and the co-operation of all concerned. The DLR has shown that, in certain circumstances, the turnkey approach is both valid and useful.

N. L. Sadler, *Cass Hayward & Partners*

My remarks relate to the upgrading contract and the additional strength that was required in the steel viaducts on Docks crossing and on the South Quay viaducts.

34. The design of the upgrading works was more technically demanding than the original design which was comparatively conventional. One might expect that in order to upgrade structural steel beams, one has to increase the capacity of the steel sections by the addition of more plated material. This was indeed the case in the South Dock crossing, which is the third span of the Docks crossing, and on the South Quay viaduct.

35. The main problem in these Southern spans, where the loading upgrading was low, was to reduce live load stresses in order to increase the fatigue life of the structure. The increase in static loads could reasonably be accommodated in the existing structures. So the problem was to increase the strength of the steel girders and the capacity of shear connectors by increasing inertia on the main girders and at the same time paying due regard to the fatigue sensitivity of the structure. Steel plates were attached to the bottom flange and to the web near the top flange at the strategic locations indicated by the reanalysis of the structures under new loading.

Wherever possible, connections were bolted to avoid site welding and more fatigue-sensitive details.

36. At South Bridge, additional steel plates could be added relatively conventionally, as access from the ground was available over most parts of the structure. However, in the northern part of the Docks crossing, it was necessary to increase strength and fatigue life and also to provide additional girders to support sidings into an increased number of platforms through Canary Wharf. Access there was more difficult and the actual increase in load intensity was greater over the middle and north bridges.

37. The means of achieving the increased load capacity was decided on at a relatively late stage in the upgrading contract. It was agreed to provide additional girders on the outside of the existing deck of these two crossings. The structural steelwork and the concrete slab were widened with the intention that the additional girders should absorb some of the extra loading, such that four girders would share the loading as opposed to the original two girders. When new girders are erected, they have to be set at an appropriate level so that they can absorb the dead weight of the new concrete, and thus absorb the deflexion caused by the dead weight of concrete, rather than impose more load to the existing girders.

38. A bracing system was therefore devised which at the initial stage of loading the outer girder had merely top and bottom horizontal members which served to stabilize that girder during construction, but did not transmit any load to the existing structure nor cause any bending in the extension of the slab.

39. After the outer part of the slab was cast (precast units were used in that area to save on the cantilever formwork), the edge girder was loaded by most of the extra concrete but there was no transference of the load to the existing structure.

40. When the concrete slab was completed, it was possible to introduce the main cross-bracing members and to complete a small stitch between to ensure that the extra girder would take its share of the increased live loading from the new requirements of the upgrading. It was deemed to be more cost-effective to add an additional girder than to do strengthening works over the water.

P. F. Mead, *formerly Mowlem, now retired*

When asked if Mowlem's could deliver a railway to do a certain thing in a certain time for a certain sum of money, I realized that certain aspects were essential if one was going to control both money and time. We had six weeks, including Christmas, in which to prepare the design and construct bid. We had handfuls of drawings from different consultants available and made complete use of them without any shame.

42. The many years of working on design and construct had taught me that with this system, once all the facts are known and provided that there is no interference, decision-making is rapid. One is the only one making the decisions, but is also the one who is taking all the risk—for planning approval, for statutory authorities and for all obstruction. Design and construct also gives one direct access to the client, so one can use one's wit and intelligence to find out exactly what is required.

43. Five tomes of a bid were produced by mid-January, but it took two more tenders before we won the contract. We felt proud to be able to say that we devised a performance specification: 'You tell us what you want and we will provide it and tell you how much and when', and we stuck to it.

S. Evans, *Colebrand Instrumentation*

My company, based in Lancashire, is the only manufacturer of the shock transmission unit used on this project. One of the main attractions of this unit is that it is easy to install and is virtually maintenance-free once it has been installed.

E. Hollamby, OBE, *Chartered Architect and Town Planner*

I was chief architect and planner to the London Docklands Development Corporation and later chairman of the design group for the DLR. I was one who was initially very unhappy at the prospect of a turnkey contract. I thought disaster loomed, and that all our aesthetic ideas would disappear in minimum costs. The DTp were cynical and sceptical, and many people said, 'You have got to prove Docklands is worth it before you can get the money for it'.

46. Excellent co-operation was achieved on the West India Dock bridge. I wanted to retain the great granite monoliths in the new bridge although they had not been included in the design and construction. It was thought at first that to include them would delay the bridge by two years and increase the cost by £3 million. However, two or three weeks later, the contractor thought it would be possible, and it was in fact done. That was a great tribute to the spirit of co-operation, not just the everyday expected co-operation between the professions, but the spirit that wanted to produce the best they could for the money.

47. I envisaged the bridge over the Docklands relief road as an open trellis-like bridge—a bow-string structure, on the skew. Sadly that idea would apparently have delayed the railway by several months and was not accepted by the Board.

48. A job I had when I was consultant to the LDC after retiring was to introduce the arts into Docklands. I envisaged setting up markers to the great engineers who had built the Docks whose names were unknown to many people. Busts of John Rennie and James Walker have now been erected. Perhaps in the future, busts of the engineers who built the Docklands Railway in the 1980s will be added.

D. Jobling, *formerly London Underground, now retired*

Once the glamour of building a railway is over, it is maintenance which is of paramount importance. Over many years I have repeatedly seen corroded steelwork which cannot be maintained, spalling concrete, crumbling brickwork, unmaintainable drains and so on. Frequently, a small difference in design could have avoided the problems.

50. On a turnkey contract, it is not easy to specify maintainability. How much effort went into this design in respect of subsequent maintenance? How easily can the system be maintained, and over what life?

Major C. B. Holden, *Health and Safety Executive, Railway Inspectorate*

I wish to sound a note of caution with design and construct turnkey contracts. In the slightly special circumstances of the construction of a new railway or of significant alterations to an existing one, there is a danger that a design and construct contract does not adequately cover the regulatory circumstances: e.g. a bland statement that the contractor shall satisfy the requirements of the Railway Inspectorate can lead to difficulties.

52. There are no statutory regulations, British standards, or formal codes of practice which fully cover the construction of a railway. The Department of Transport's *Railway construction and operation requirements*[1–3] can, at best, be

described as a guide to good practice; they are not mandatory. The present edition is out of date, and never envisaged the construction of a railway such as the DLR. This was recognized some years ago but the production of a new edition as opposed to a revision of the old edition is proving to be an exacting and time-consuming task. It is reasonable for the design and construct contractor to seek guidance from the Railway Inspectorate but the latter must always have the right not to approve the final product, however much its design might have been influenced by such guidance.

53. The dialogue between the contractor and the Inspectorate provides another stumbling block. Statutorily, it is the client, not the contractor, who has to seek approval for the opening of the railway. It is he, therefore, who has to be satisfied that the contractor has provided him with a railway which will gain that approval. The vicious circle is complete. There is also a danger that the client, in trying to cover a gap in the performance specification, will seek to have it closed by declaring it a 'requirement of the Railway Inspectorate'. Similarly, a contractor may seek to provide a solution to a problem which the Inspectorate considers may be unsatisfactory, but the latter has no means, until the railway is submitted for approval by the client, of enforcing a change. Hence the Inspectorate becomes embroiled in a dispute over whether or not a change which could be made in the interest of increased safety, or ought or must be made to achieve that same object, is a variation to the performance specification (and therefore paid for by the client) or one on which the contractor has fallen short of his contract (in meeting the requirements of the Inspectorate) and for which he pays. Some way to avoid this impasse must be found.

54. The spirit of co-operation between the contractor, the designer and the client was extended to the Railway Inspectorate and was instrumental in overcoming any problems which might have arisen (and in some minor instances did arise) in the way described. The contractors put in much hard work to make it easy to carry out the formal inspections. There were very few outstanding matters to be put right at the final inspection, which was evidence of the determination to have a railway which was safe not only for HM the Queen to open but also for the public to use. Whatever the legal niceties of whose railway it was at the time of those inspections, the value of carrying them out as soon as practicable after the completion of a stage of the work was amply demonstrated.

Mr Gonsalves

With reference to *Mr Bonnett's* point about the conditions of contract: when we look back on the final nature of the actual conditions of contract we worked with, they were different from the conditions we bid under, and they were introduced during the process of the horse-trading deal after the tenders had gone in, so we did not have a great deal of time to consider them. When we looked back at them at leisure, we were rather horrified to find what we had accepted.

56. If I can take a little further *Mr Joblin's* point about maintenance, the contract required us to carry out the design and construction in a manner which would produce minimum maintenance for the 120 year life of the railway. Now that is a very vague statement with which lawyers would have a field day. At the end of the day, we were contractors and we employed a very responsible and reputable consulting engineer as our designer. We did not in any way interfere with him in how he developed the design, and that applies to the design principles as well as to the requirements of the maintenance obligations which were part of

his contract with us. We were required to produce a minimum maintenance railway for our client; our consultant was required to provide for us a minimum maintenance design; and we were relying on his undoubted expertise in producing that through the design drawings. That is how we believe it should work, because we, as contractors, are not in the business of designing things ourselves.

57. If I can come to *Mr Sharpe's* points, I should like to begin by thanking him for his comments about the project management team, and I should like to echo Mr Pilgrim's thanks to the DLR project management team for the help and assistance that we had from them and the operators as well. Basically, a contract of this kind, being carried out at this speed, can be carried out only with the complete co-operation and commonality of aims of all the parties involved. Perhaps I can put it on record on this particular contract that the co-operation we had from the client through his project management was indeed excellent, and that was one of the features which helped to make the railway a success.

58. I should like to take issue with him on one point that he makes about the electrical and mechanical equipment, which he said was not without its faults. That is indeed true. I think that what needs to be recognized is, first of all, the minimum cost nature of the contract in the first instance. In the course of $2\frac{1}{2}$ years, the railway has doubled the number of passengers it carries daily. The railway contract, as I have said, was required to carry a maximum at peak hours of 1500 passengers per hour, which represented something like 16 000–18 000 passengers a day. The railway is now carrying an equivalent peak load of something like 2500 passengers an hour, which is well up to what it was required to carry in its original post-Beckton phase. The railway cannot, of course, carry such a large number of passengers because the single cars are not big enough. The result is that the railway is well overcrowded and the peak stretches either end of the true peak. Certain sensitive parts of the railway, such as the doors, do take a fearful hammering, and in an automatic system everything interreacts. Consequently, there have been problems.

59. Another factor to bear in mind is that we are sometimes compared with the Lisle automatic system. Lisle had a six months' honeymoon period with the passengers. After Lisle had been tested and commissioned, passengers were allowed on the railway for six months without paying, so that the operators were able to de-bug the whole of the system under actual operational use. We had no such luxury. The day we finished testing and commissioning, we had to hand the railway over to Mr Bonnett to start earning revenue, and that had its own problems.

60. It also has to be borne in mind that almost as soon as we had handed the railway over to Mr Bonnett to start a revenue service, we had to start taking it back from him actually to cut into the service to start upgrading it, and that does not make for good short-term reliability.

61. I think at the end of the day—and in this I am defending our joint venture partner, GEC—the automatic railway that they produced, given all the strains an contingencies, is a tribute to their ability.

62. On the question of the new signalling system, I think we will need to get some advice from our client because it was his decision to change to the new signalling system.

63. I have to take slight issue with *Mr Hollamby* in his statement about my response to his request about the granite columns. The idea of using them seemed a good preservation suggestion, but we could not appear too enthusiastic at first as

it might have proved a very expensive solution for which no money was available. However, what Mr Hollamby says is, of course, quite right. The six columns, which were about $4\frac{1}{2}$ m high and were all turned from a single piece of granite, were pieces of Victoriana, and therefore almost unique I would think. It is quite right that we acknowledge his desire to maintain that sort of legacy and heritage, which could be done at no extra cost.

Mr Pilgrim

If I could take first *Dr Atkinson's* query on the obstructions below ground level, and the piling. When the contract was let, we had to get Atkins to do the initial design, and that took a lead-in period of about four to five months before we could actually let the piling to a variety of contractors specializing in different types of piling. In that time, we decided to set up various teams to either probe or excavate every base position on the contract down to a depth of at least 4 m. Any obstructions found were removed and replaced with soft material. If the obstructions went below 4 m, then we carried on down until we had removed them all. So, by the time the piling contractors were appointed, they came on to the site with only one way to make money, and that was to put their piles into the ground as fast as possible. It worked extremely well. Every piling contractor did a very good job, very quickly, and we had a minimum of claims, and I would commend this approach to any employer in the future.

65. *Mr Matthews'* question concerns the QA system, and I will deal principally with the QA system on site as opposed to quality assurance and quality control within the design office.

66. When the design reached us on site, each document was recorded to make sure that everybody was working to the up-to-date design and drawings, and not working to out-of-date drawings. Quality assurance, in my view, is merely a management tool to introduce some commonsense into the process of construction and to make sure that work is constructed correctly and to specification at the first attempt. We introduced a quality programme which was a fairly simple programme and which, in essence, meant that before any particular element of work was carried out, a method statement was drawn up. We employed Atkins Laboratories (Atlabs)—now called Atkins Quality Management—on site, and each of the method statements was checked with them and altered if necessary before the work was carried out. Check-lists were then drawn up for checking that reinforcement was clean, that it was in the right place, that it was properly tied, and so on; and each and every engineer played a part in checking and signing off the work before the next stage took place. Auditing and spot checks of our procedures were carried out regularly by Atlabs throughout the construction period.

Mr Deacon

Responding to the point raised by *Mr Humphries*, the preliminary design work undertaken by other consultants, before the award of the design and construct contract, was treated as a conceptual design for the railway project. This was of great assistance to the design and construct team, and the level of detail provided was no doubt a contributory factor in enabling a very compressed overall programme to be adopted. Paper 9552 acknowledges this point, but also draws attention to the fact that neither the validity nor the feasibility of the conceptual design was guaranteed. Indeed, in some areas, the conceptual design was found not to be acceptable—for example, to the Railway Inspectorate or to British

Rail—and in such cases, W. S. Atkins had to develop the design in an alternative manner. In other areas, the conceptual design was not perceived as the right or best solution to achieve the programme, to meet construction needs, or, indeed, sometimes to satisfy the performance specification.

68. Track plinth rather than ballast was generally adopted on new elevated structures in order to keep the overall loads down. The concrete track plinth which was developed by W. S. Atkins, Mowlem and GEC was considered to have a number of advantages over the conceptual outline: it was straightforward to form; it was quick to construct; support for the third rail was available from either side on one or other of the derailment guard concrete upstands; the location of the 'wiggly wire' train control cable was at the required level in the centre of the track.

69. *Mr Powderham* raises a question regarding the load sharing between old and new structural elements. The example of Cable Street viaduct, which is described in the Papers, best demonstrates this point where one side of the new superstructure is supported off the old brick arch viaduct and the other side is supported on new piled columns. Until relatively recently, the brick arches had been carrying full railway loading from British Rail track. Comparison of the loads the brickwork would have been taking under the previous situation, with the new loads from the stub columns on the brick piers, showed a satisfactory situation in terms of stresses. Small differential settlement between the new column and the brickwork arch has little structural implication and an insignificant effect on track levels. In addition, cores were taken from the brick arches at the pier positions in order to verify both the integrity of the brickwork and its capacity to carry the loads the new system imposed on it.

70. The shock transmission unit (STU) contains a silicone compound in a form of valve. The compound will move through the 'valve' under a long-term load and thus enable temperature movements to take place. However, the compound will not move under short-term load application such as braking, even prolonged braking, and hence in this situation the load is transferred across the 'valve' from one side of the unit to the other.

Mr Pritchard

I should like to carry on with *Mr Powderham's* point about ensuring the load transfer between the old and new structures. Of course, there were actually two sets of old and new. There was the transfer of load from new structures alongside the 150 year old arches in the initial contract and, in the strengthening contract, we also had to transfer load from new girders built alongside the three-year old girders of the Docks crossing, which we had just finished. It was unusual to complete a very fast-track design and construct job and then immediately to start on its strengthening.

72. The actual load transfers were carried out in several ways. Load transfer to the underloaded arches in the original contract was made in a simply supported form, as shown in Fig. 7 of Paper 9552, so that there were no problems of differential settlement.

73. In the upgrading contract, the load transfer from the new outer girders to the inner Docks crossing girders was interestingly innovative. The new cross bracing between new and old acted as a flexible pantograph during construction. After the new girders had picked up all self-weight loading, the bracing diagonals were fixed to transmit the fairly small live load and the remaining differential settlement load transfers.

74. Another interesting load transfer problem lay in the introduction of the new shear connectors, because initially they would not pick up any dead load, only live load. Stud shear connectors do slip with repetitive live load, and dead and live load is gradually transferred from the old stud connectors to the new connectors, which suffer much less live load slip, such that the new connectors eventually take some original dead load.

75. The other interesting point is that regarding future maintenance. As a firm, we were extremely conscious of maintenance because we have worked for the last 12 years on one of the biggest maintenance jobs in the country, namely the 12 miles of overhead structure carrying the M5/M6 motorways around Birmingham: the Midlands Links. Many of the things we learned from the Midlands Links were applicable to Docklands, including the silane treatment; we were, it should be recalled, very cautious about the piles coming out of the Dock water. Other than that, a great deal of research went into the use of the best possible steel protection treatment, and, indeed, the latest technology high-build painting system used has an expected life of 14 years.

76. *Mr Sainsbury* asks about the shock transmission units. Shock transmission units are not new; they have been used in the oil-filled version for many years. In fact, Glasgow's Kingston Bridge, recently in the news, used shock transmission units to relieve pier and foundation loading in the approach viaducts.

77. In the 1970s, the DTp engineers, John Chafe and the late Reg Mander, realized that silicone putty rather than oil could be used to give a simpler and less thixotropic maintenance prone unit. Silicone putty has some very peculiar properties: it can be left on a desk for a time and it will spread slowly like a liquid; it can be squeezed and then bounced like a tennis ball; but if it is thrown hard enough against the wall, it will shatter like glass. The new shock transmission unit (STU) itself is of extremely simple and robust construction, consisting of a steel cylinder containing a loose-fitting piston fixed to a transmission rod, the void around the piston being filled with the silicone putty. Under slow movement, this putty is squeezed slowly around the piston and displaced from one end of the cylinder to the other. The transmission rod passes through the entire length of the cylinder so that the volume of the cylinder remains constant at all positions of the piston. The new STU has been designed to function primarily in a horizontal position but can be adapted for vertical movement by incorporating an internal spring to return the piston to the neutral position.

78. Bridge units are made to resist impacts ranging between 10 t and 120 t; larger impact requirements are satisfied by increasing the number of units employed. Movement rates are controlled by the clearance around the piston, the usual 50 t unit giving a very low 'drag' resistance to the slow movements of bridge decks arising from temperature, shrinkage and creep.

79. Typical impact resistance/time behaviour for such a unit requires that the extension or compression shall not exceed 2 mm in the first 10 seconds, or 4 mm in the first 20 seconds after the impact application, providing a virtually rigid force transmission link during short duration impacts.

80. In short, this is a device which allows the bridge structure to move slowly with the normal diurnal variations of the environment, while at the same time enabling it to transmit large shock or impact forces applied over a few seconds' duration. These bridge STUs have found a very good application in resisting earthquake effects on the substructures of bridges located in such zones.

References

1. Ministry of Transport. *Railway construction and operation requirements for passenger lines and recommendations for goods lines of the Minister of Transport.* HMSO, London, 1950; reprinted 1967.
2. Department of Transport. *Railway construction and operation requirements, structural and electrical clearances.* HMSO, London, 1977.
3. Department of Transport. *Railway construction and operation requirements, level crossings.* HMSO, London, 1981. *Ibid. Supplement.* Section 16: protection of pedestrians. HMSO, London, 1985.