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The Influence of the Method of Construction on the Design of Urban Viaducts

Influence de la méthode de construction sur le projet de viaducs urbains

Einfluss der Konstruktionsmethode auf den Entwurf von Viadukten im Stadtbereich

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In the design of urban viaducts, particularly of prestressed concrete construction, it has been found of fundamental importance to consider the construction method to secure a harmonious and economic relationship between the form of the design and its translation into a practical structure.

1. Continuity and Sequential Construction

The provision of continuity in multispan viaducts can be accomplished by several methods of sequential construction involving both precast segments or longitudinal precast beams. The technique has been used on various urban viaducts in the United Kingdom designed by the authors' firm, such as Hammersmith Flyover (Ref 1), Mancunian Way (Ref 2) and Westway (Ref 3).

2. Span by Span Construction

Each stage of construction comprises a part span and a cantilever into the next span, the length of the cantilever being chosen by the designer. In practice the coupling point can vary from very close to the support up to about one third of the span length. A method of calculation of the self weight bending moments has been described (Ref 4) for prismatic and varying section beams. The self weight bending moment generated by span by span construction is modified from that developed by a fixed ended beam by a shift of the zero axis depending on the length of cantilever chosen. The modification in bending moments during erection assists the layout of prestressing cables.

The total difference between "span by span" and "instantaneous" erection is not marked and it has been found that the induced moments are such that final moments including creep redistribution may approach those that would have occurred if the structure had been erected and prestressed in one operation and not successively.

In the case of Westway Section 5 it may be of interest to consider the support moments of a typical 62 m span. The dead load moment at the supports assuming "span by span" erection is 49×10^3 tonf. ft. compared with a figure of 55×10^3 tonf. ft. assuming "instantaneous" erection. However, the parasitic moments in the first case are 22×10^3 and in the second case 30×10^3 so that summing the two moment diagrams represents a difference of only 2×10^3 tonf. ft., i.e. about 8%. These are sagging moments inducing tension at the soffit of the bridge. For this particular viaduct the concrete in the segmental units was about 8 weeks old before it was prestressed. The creep redistribution of the induced moment reduces the difference to 1.1×10^3 tonf.ft. A further reduction of 50% follows from the time lag of 6 to 8 weeks between the stressing of each span. The final induced moment was 0.5×10^3 tonf.ft. and responsible for a negligible component of bottom fibre tensile stress.

3. Serial Construction on Staging

A further technique employing serial construction on staging (Ref 4) utilises the fixity of spans supported on falsework. The moments and deflections arising in a beam on elastic supports depend on the values of a dimensionless parameter, a measure of the support stiffness. If the value of the formwork reaction modulus is such that the formwork is relieved of load then the conventional theory of elastic supports does not hold since the formwork is not capable of exerting downward as well as upward forces on the beam. This does not present a problem in practice as the bending moments derived by elastic support theory approach closely those obtained by assuming rigid supports. The moments developed at the interior supports under such a system of sequential construction therefore approach those for the encastré case.

In practical application it was found that the prestressing tendons in a span ready for striking the formwork could be arranged to contribute the necessary resisting moments for the sagging moment in the span and the hogging moment over the span supports. The moments developed in the adjacent span supported on falsework can be resisted by the nominal reinforcement provided in the beam for the control of cracking and secondary effects. Thus there is no restriction on the carrying out of stressing operations in continuous concrete beams cast in situ provided the temporary reinforced concrete condition in the adjacent span has sufficient strength to withstand the small moments and shears distributed to it.

This arrangement is of practical importance since it allows spans to be constructed so that the leading end as well as the trailing end can be joined to that which has already been constructed. An application of this method has been made for an elevated roundabout at Westway where serial construction was arranged to follow round the ring beam in stages of one span at a time, eventually closing the roundabout as one monolithic unit.

4. Sequential Beam Construction

Another form of span by span construction has been used at Westway where longitudinal precast beams were initially simply supported at column crossheads and completed as a continuous beam deck. Crossheads in this example were of steel box section and were designed to be composite with the concrete deck.

5. Segmental Construction

Segmental construction has been used on a number of projects. For some, such as Mancunian Way, the precast units weighing between 18 and 35 tons were designed specifically to be transported by a low loader. For Section 5 of Westway the units were concreted on site and weigh up to 135 tons; these required special lifting and erection methods and suggest that there is an optimum limit to the weight of units which can be moved with economy and speed in any particular project.

6. Handling Precast Units

For precast units, whether of the segmental or beam form, it has been found that handling stresses can be critical including the manner of temporary support during storage and erection. A small amount of extra reinforcement is usually necessary. The method of lifting units requires careful consideration and stresses arising from the lifting devices need to be carefully designed and supervised.

For instance, the manner of support of units prior to building into the completed structure has to be carefully considered at the design stage. An example arises when segmental units are supported on temporary steel beams. The initial deflection of steel beams may not fully recover during the longitudinal prestressing of the segmental units and hence there is an additional upward load on the concrete span before completion. Similarly transverse deflection of the cross section may induce built in stresses.

7. Location of Diaphragms

These considerations throw emphasis on the location of diaphragm units which induce rigidity and support. Although some redistribution of moments will occur in the cross section at the middle of the span, very little can occur near diaphragm positions. This is a good reason for locating the diaphragms at the pier supports and avoiding diaphragms wherever possible in the span itself.

8. Thermal Movement

Differential temperature movements and longitudinal and transverse thermal movements have to be carefully considered during erection of continuous viaducts built sequentially. This applies especially at leading cantilevers where vertical movements of the cantilevered tip can cause loads to be imposed on the supporting falsework. If freedom of movement is allowed, no connection should be made with the leading span being erected until the last possible moment. Sometimes this entails ensuring a favourable temperature condition. Alternatively propping restraints must be taken into account. It is generally concluded from the above remarks that it is essential for temporary works for continuous viaducts to be vetted by the designer before construction commences.

9. Quality and Economy

Repetition of continuous spans ensures economic use of plant. The employment of precast concrete units introduces factory conditions to the site and promotes better quality workmanship, continuity of work, rapid execution, and a higher standard of finish.

10. Conclusion

The use of precast segmental units and box beams of sophisticated type has enabled more efficient cross section designs to be achieved than would otherwise be possible. Hence the erection method has enabled improvements to be made in the theoretical design of structures.

Whilst the design and construction of any structure must inevitably be linked closely together, this contribution has attempted to deal with certain aspects of urban viaduct construction where a very clear influence on the theoretical design has been generated by logically following through the implications of the erection techniques.

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Summary

By laying down a proposed method of construction, important influences on the design of urban viaducts may be achieved. Several methods of sequential construction are discussed involving precast segments weighing up to 135 tons, longitudinal precast beams or in situ concrete. The manipulation of bending moments and stresses during sequential construction is related to those in the completed structure. Improvements in the theoretical design of structures are possible by the use of precast units. Construction requirements promote improvements in the design of structures including efficient shaping of torsion box beams, location of diaphragms and treatment of thermal movements.