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Repair of Precast, Prestressed Bridge Beams Using External Prestressing

Poutres de ponts préfabriquées et précontraintes réhabilitées par précontrainte externe

Reparatur von vorfabrizierten, vorgespannten Brückenbalken durch externe Vorspannung

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SUMMARY

Precast, prestressed beam and slab bridges are common worldwide for short to medium span lengths, as used for overpass bridges. Major lateral impacts of the beams may cause severe damage impairing the function of such bridges. The paper presents experience gained in the repair and strengthening of severely damaged precast, prestressed concrete beams of two bridges. The beams were repaired in situ using proprietary high-strength, shrinkage compensating micro-concrete and external prestress techniques which fully re-established the functional life of the bridges.

RÉSUMÉ

Les poutres et dalles de ponts, préfabriquées et précontraintes, sont réalisées dans le monde entier, pour enjamber les portées de faible et moyenne importance. Les chocs transversaux importants agissant sur les poutres peuvent entraîner de graves dommages risquant ainsi d'altérer la fonction de ces ponts. Cette communication présente les expériences réalisées par la réhabilitation et le renforcement des poutres sérieusement endommagées sur deux ponts. Ces éléments porteurs ont été réparés sur le site, par mise en place de micro-béton à haute résistance et sans retrait, avec application d'une précontrainte externe. Il a été ainsi possible de rétablir complètement la fonction de ces ponts.

ZUSAMMENFASSUNG

Vorfabrizierte, vorgespannte Balkenbrücken werden weltweit für Überführungen eingesetzt in der kurzen bis mittleren Spannlänge. Grössere Querstösse am Balken können ernsthafte Schädigung zur Folge haben, wodurch die Funktion der Brücke beeinträchtigt wird. Dieses Referat beschreibt die Erfahrungen der Reparatur und Verstärkung ernsthaft geschädigter Betonbalken von zwei Brücken. Die Balken wurden am Ort mit hochfestem, schwindfreiem Mikrobeton und externer Vorspannung repariert, wodurch die Funktion der Brücke vollständig wiederhergestellt wurde.

1. INTRODUCTION

Unforseen circumstances and forces of nature often change or cripple the service life of well planned and constructed structures. Such problems, accidental damage and other causes may require the repair and/or strengthening of a structure to re-instate and extend the functional life, as in the case of two precast beam and slab bridges which were severely damaged by vehicular impact.

Most rehabilitation and repair problems fall into the surface repair category and are mainly concerned with aesthetic, durability and serviceability aspects which involve solutions based on materials technology. More serious problems of structural distress fall into the strength and stability category which involve solutions based on design and construction technology. Such structural distress may affect the strength, stability and function of the structure.

The assessment of, and solution to the problem is complicated by the fact that a structure exists with defined member types and dimensions, with material properties that cannot readily be determined accurately and experiencing a stress state that may differ substantially from the original design values.

The required functional life of the structure plays a major role in the decision whether to repair the existing structure or to demolish and reconstruct with a new structure. Such a decision is largely influenced by site conditions, operational requirements, possible technical solutions, and the cost vs benefit relationship. The structural system and member cross-section may influence the choice and detail of the repair procedure. Certain structural arrangements and types of distress may favour plate or reinforcement bonding solutions while others may be better suited to external prestress solutions.

2. STRENGTHENING WITH EXTERNAL PRESTRESS TENDONS

The FIP guide [1], provides some general guidelines to the strengthening of structures with additional post-tensioning. Further information is found in [3] [4] & [5]

The repair and strengthening of structures with external prestress tendons requires three main elements in the structural system, viz, the tendons, the anchorages and for deflected tendons, deviators. These three elements induce a self equilibrating force system into the structure which is resisted by internal member stresses.

The following aspects need to be taken into account when considering the use of external prestress tendons on an existing structure:

- access to the structural member to indtall the external tendon system,

- the feasibility and suitability of providing the necessary anchorages and, if necessary, deviators on the structure to be repaired or strengthened,

- the tendon layout and profile which determines the total effect of the additional prestress on the structural member. A straight tendon profile is preferred in most cases due to a simpler and more economic construction procedure.

3. BRIDGE DAMAGE AND REPAIR

3.1 General

Probably the most common bridge deck system used world wide is a composite precast, prestressed concrete beam with in situ slab type deck. The prestressed beams may be pre- or post-tensioned and are generally simply supported. Freeway overpass bridges commonly span 20m or greater.

Overpass bridges are planned for a 5,100 m vertical clearance. However, road rehabilitation may result in overlays to the underpass route reducing the effective clearance to between 5,000 and 5,100 m. Inspection of freeway overpass bridge soffits indicates that minor impact from vehicle payloads occurs frequently causing minor edge spalling and consequent loss of concrete cover to reinforcement bars.

Occasionally major impact accidents occur with beam and slab decks particularly at risk suffering sever damage.

3.2 Impact Damage, Inspection & Condition Survey

Recently two precast beam and slab bridges were damaged, one being a 2-beam pedestrian bridge, and the other a 4-beam overpass for single lane traffic. Although the beam damage was of a similar nature, the effect on the bridge decks was very different.

3.2.1 Seventh Avenue Pedestrian Bridge

The bridge consists of simply supported decks supported on single column piers with stairs at either end. Each deck comprises two precast, prestressed concrete I-beams with a composite in situ reinforced concrete top slab spanning 20,73 m over a carriageway. The precast beams are 1160 mm deep spaced at 2,35 m and the slab is up to 180 mm thick. The deck cross section is illustrated in Figure 1 which also shows the repair detail.

The beams of the western span were severely damaged betwêen the ¼ and ⅓ span position approximately halfway between transverse diaphragms by a transported excavator whose boom was too high to pass under the bridge. The boom struck the bottom flanges of both beams and the impact shattered the concrete exposing the reinforcement and the prestressing ducts and strands, and sections of the webs. The reinforcement was completely sheared and some strands of the lower prestress tendons of both beams were severed or damaged at the impact area, (Photo 1). The prestress effect on the concrete in the damaged area was lost, but the span was in no immediate danger of collapse. Since both beams were damaged to a similar extent, a simple longitudinal strut and tie system prevailed with no transverse redistribution of loads.

3.2.2 Candy Cornelia Vehicular Overpass

The bridge consists of simply supported decks supported on wall type piers. Each deck comprises four precast, prestressed concrete T-beams with a composite in situ reinforced concrete top link slab spanning 21,2 m over a carriageway. The precast beams are 1143 mm deep spaced at 1,524 m, and the slab is up to 165 mm thick. The deck cross-section is illustrated in Figure 2 which also shows the repair detail.

The western outer edge beam of the southern span was severely damaged between the ¼ and ½ span transverse diaphragms by a tipper truck whose tipper pan was raised during travel. The tipper pan struck the bottom flange of the edge beam and the lateral impact caused a block type shearing failure exposing the reinforcement and the prestress ducts at discrete locations and displacing sections of the bottom flange and the web, (Photo 2). The prestress effect on the concrete in the damaged area was lost, however the span was in no danger of collapse as redistribution of load could take place via the transverse diaphragms to the adjacent undamaged beams.

3.2.3 Beam Damage : General Observation

The nominal reinforcement in the beams for the two bridges was very different and the pattern of damage to the beams was different as can be seen on Photos 1 & 2. It is difficult to ascribe the form of the damage to the impact object or to the reinforcement containment. It is felt that the amount of reinforcement present and the bar spacing play a significant role in containing the damage. Nevertheless, the nature of the damage was very similar. The bottom flange was shattered between the transverse diaphragm beams. An elliptical shaped zone of the web was either shattered or displaced with heavy shear and torsion cracking extending to the underside of the top flange. Reflective impact spalling on the far face of the beam resulted in more extensive damage than on the impact face. The lateral resistance of the bottom compression flange is very low and it is clearly demonstrated that the transverse diaphragms play a very positive role of limiting the damage to the area between adjacent diaphragms.

3.4 Bridge Repair : Solution Development

The repair solution had to reinstate the function and operational life of the damaged bridge and had to incorporate the following operational requirements and procedures:

- The freeway traffic had to continue to flow without permanent lane restriction on each carriageway and a maximum speed restriction of 60 km/hr. Traffic deviation was allowed.

- The bridge had to remain open to overpass pedestrian or livestock traffic at all times to avoid the potentially dangerous situation of movements through the freeway traffic with the resultant risk of collisions and loss of life.

- Provision of an infill soffit slab between the soffit flanges of the beams to improve the lateral resistance against possible future impact damage. A minimum vertical clearance of 4,9 m had to be maintained at all times.

The rehabilitation of various bridge ancillary items and improvement to the general appearance of the bridge.

Various alternative solutions were investigated, ranging from repair of the existing beams to the demolition and reconstruction of the entire beam. The stringent operational requirements, the feasibility of repairing the beams by incorporating external prestress tendons and the lower construction period, cost and lesser traffic accommodation favoured the repair of the beams. The major work items are summarized in Table 1.

BEAM REPAIR		BEAM REPLACEMENT	
1.	Prop beam and remove damaged concrete between adjacent diaphragms up to underside of top flange only. (± 6 m length of beam)	1.	Remove infill top slab and diaphragms to expose splicing reinforcement.
		2.	Remove beam, kerb and tailing in sections and dispose rubble. (Demolishing a prestressed beam requires care, and fixity with diaphragms complicates the removal process)
	Concrete Removal: 2,0 m^3 vs 101,6 m^3		
2.	Shutter beam repair section and cast through access openings in top slab of deck.	3.	Shutter and cast complete beam on grade (cannot cast in situ due to required access to post-tension beam).
3.	Install external tendons and stress from top of deck @ ± 10 days age.	4.	Install bonded tendons and stress in casting bed prior to handling @ ± 28 days age.
4.	Epoxy injection of cracks in adjacent beam sections if necessary.	5.	Transport and lift beam into position on piers.
5.	Close access openings and remove props.	6.	Cast infill top slab and diaphragm splices.
6.	Clean outer beam face and surface treatment of exposed area of beam.	7.	Cast kerb & install balustrade/railing
	Estimated Cost R27 000 vs R92 000		

TABLE 1 : COMPARATIVE WORK REQUIRED FOR BEAM REPAIR AND BEAM REPLACEMENT (Candy Cornelia Overpass)

Each phase of the beam reconstruction procedure was modelled and analyzed using a grillage type finite element analysis. A normal design approach was adopted with the entire finite element modelling being based on linear elastic theory with the assumption that the principle of superposition is valid.

It is important to evaluate the probable construction and load history of the beams and composite deck as close as possible to that prior to the damage to determine the original design stress state. This is a matter of engineering judgement and an understanding of the construction sequence, the structural behaviour of the deck, the effect of the beam damage, and the repair procedure. The major uncertainties rest with concrete material properties and the shrinkage and creep effects that have taken place.

3.5 Repair of the Bridge Beams (Refer to Figures 1 & 2)

The repair of the beams to their original load carrying capacities centred around the use of high strength, shrinkage compensating micro-concrete and external unbonded prestress tendons. The accommodation of the anchors and the deviators, and the force transfer into the structure required careful evaluation of the load paths and details to ensure that the structural action could be accommodated.

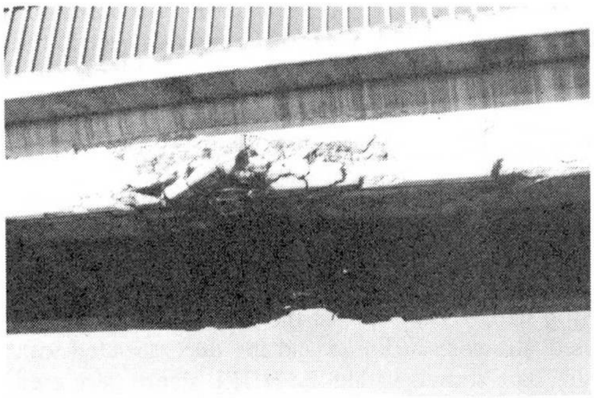

Photo 1 : Damage to Seventh Ave

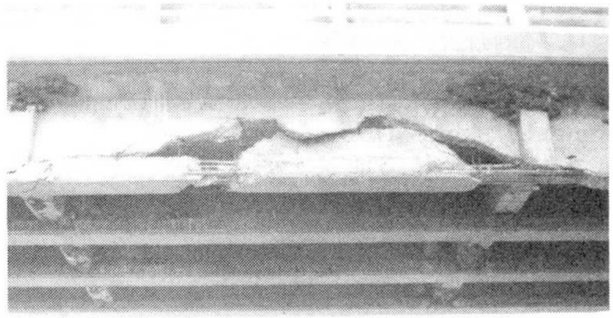

Photo 2 : Damage to Candy Cornelia

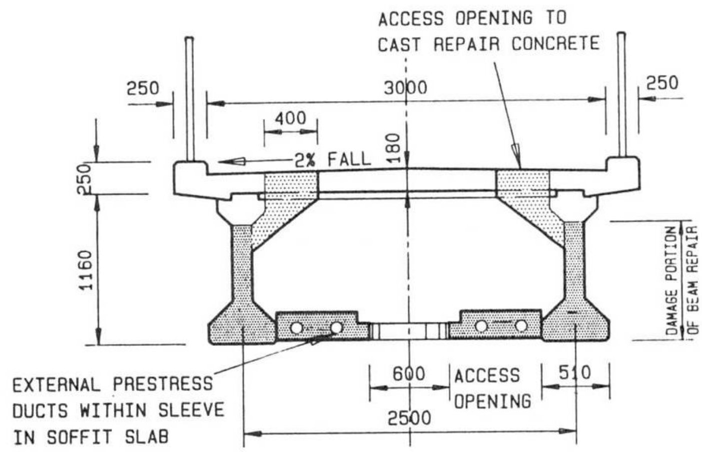

Figure 1 : Seventh Ave deck section indicating beam repair

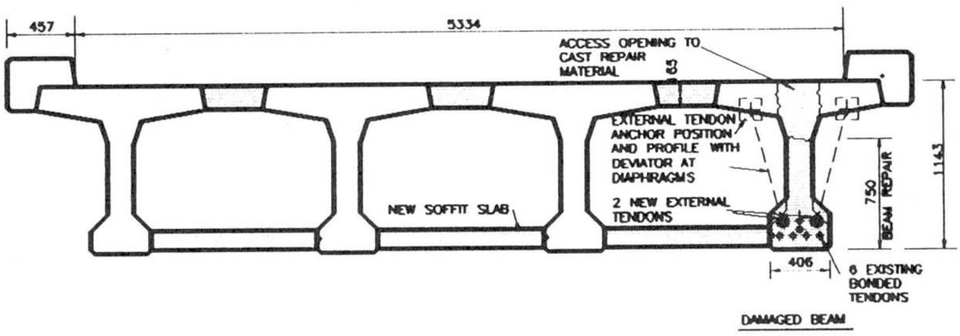

Figure 2 : Candy Cornelia deck section indicating beam repair

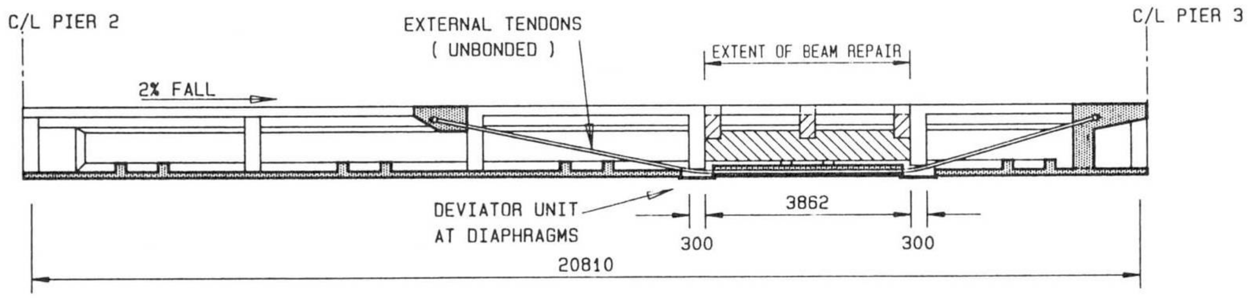

Figure 3 : Typical elevation of beam resonstruction (Seventh Ave)

The damaged beam sections between the diaphragms were removed to vertical faces at the ends and to a horizontal line following the web/top flange bulb junction. The concrete was carefully chipped away to prevent damage to the embedded reinforcement and prestressing ducts. New reinforcement was fixed and the beam formwork placed.

The flowable micro-concrete was batched and mixed on top of the deck and placed through carefully located access openings in the top slab to ensure complete filling of the voids. Light surface vibration on the outside of the formwork was applied to assist the flow and self-compaction of the micro-concrete, especially at the contact surfaces of existing concrete. The access openings were sealed with the last batch. The formwork was kept in place for 7 days for the initial curing of the micro-concrete.

The anchors were cast into a new anchor block just below the top slab, bearing against the exposed slab edge and the transverse diaphragm. The prestress tendons were installed, stressed, anchored and the ducts grouted with cementitious grout. External tendons comprising 7/12,9 mm dia. bare strands within the HDPE sleeve were used and no special provisions were made for monitoring or adjustments. The deviators were located at the diaphragm beams adjacent to the repaired beam sections. The tendon profile followed straightline segments between anchors and deviators.

Certain of the cracks in the bottom flange and webs of the beams extending past the area of reconstruction were were carefully injected with low viscosity epoxy resin to reinstate the material integrity.

Following the necessary surface finishing, the exposed surface of the beams were treated with a penetrating hydrophobic silane-siloxane system and then coated with a cementitious acrylic decorative coating to achieve a uniform texture and colour over the repaired and adjacent older concrete surfaces.

4. CONCLUSION

Where appropriate, the repair of structures with external unbonded prestress tendons provides a cost effective and technically efficient means to reinstate the function, structural integrity and durability of a structure following structural damage or increased load capacity and serviceability requirements. The severely damaged bridge beams described in this paper were repaired and the prestress effect reinstated albeit with a different tendon profile. The bridges can continue to fulfil their function with a new lease of service life.

5. ACKNOWLEDGEMENT

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